AO Publishing

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AO Principles of Equine Osteosynthesis

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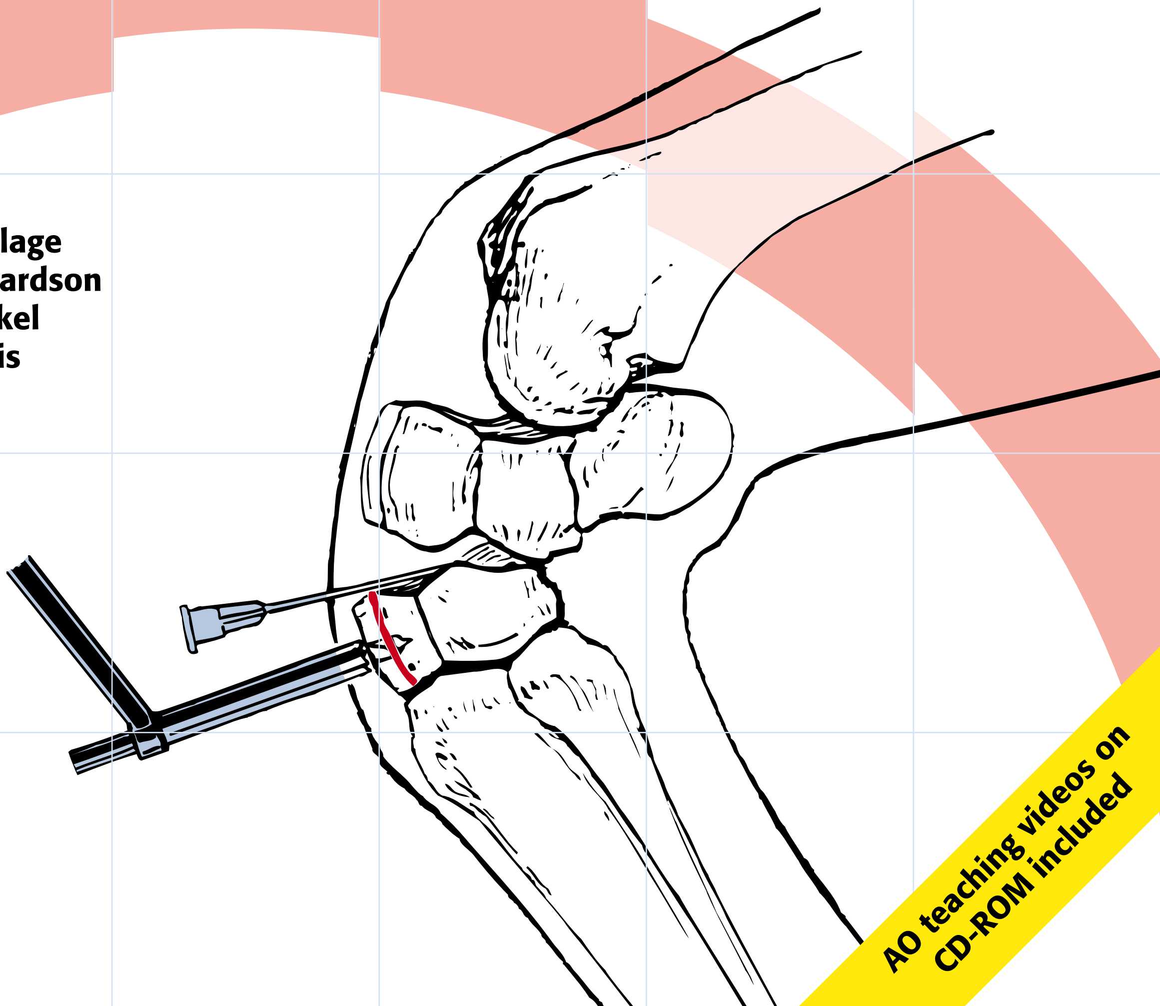

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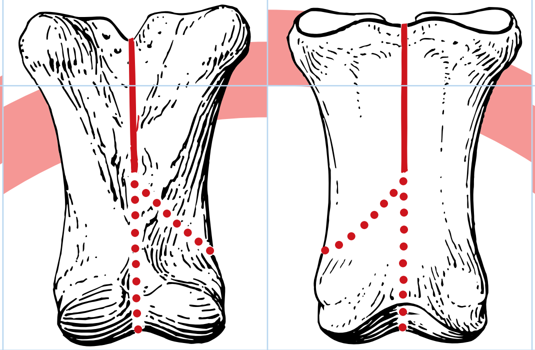

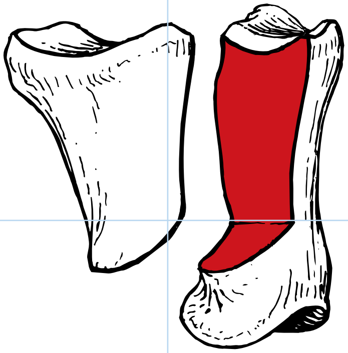

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L. R. Bramlage
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Foreword

Howard Rosen

It is indeed a pleasure and an honor to be asked again to write the Foreword to the book, The Principles of Equine Osteosynthesis **(PEOS)**. The authors are to be congratulated on their exciting innovations in this piece. With your forbearance, I have repeated portions of the foreword of its predecessor, the Electronic Manual of Equine Osteosynthesis **(EBEQOS)** for historical background and have added a summary of the newer techniques, principles, and ideas included in this new work.

Before the Swiss Association for the Study of Internal Fixation, **AO**, **was established in 1958**, the treatment of animal fractures, and indeed human fractures, was mostly by closed reduction, splint, and cast immobilization. Less than adequate simple internal and external fixation appliances were used when the occasional open reduction was performed, and usually required casting as well. Thus disability followed fracture treatment in a high percentage of cases, as functional aftertreatment was prevented by the long periods of cast immobilization. This resulted in stiffness, swelling, disuse atrophy, and, frequently, deformity.

With the advent of the AO principles of open reduction—anatomic reduction, rigid (stable) internal fixation, careful soft tissue handling, and early functional mobilization with protected weight bearing as tolerated—invalidity after fracture treatment decreased tremendously. This, of course, was accompanied by better instruments and appliances, better metallurgy, aseptic techniques and antibiotics to decrease infection, and better diagnostic modalities. The principles and techniques for successful internal and external fixation of fractures, non-unions, osteotomies, and fusions were annotated in the first editions of the human, canine, and equine AO manuals. These were based on an extensive documentation of thousands of successful results using these techniques, as well as careful analysis of problems and poorer results. As a result of the need for documentation, an extensive classification system of the vast numbers of fracture patterns was created in both humans and animals.

At the AO Research Institute in Davos and in other research centers, through animal experimentation and fundamental cellular and biomechanical research, as well as human and animal clinical trials, the AO concepts have been continually tested and refined. The basis for these concepts have thus been scientifically established, and newer methods and ideas have constantly evolved.

PEOS = Principles of Equine OsteoSynthesis

EBEQOS = Electronic Book of Equine OsteoSynthesis

AO = Arbeitsgemeinschaft für Osteosynthesefragen/ Association for the Study of Internal Fixation was founded in 1958

These trends and advances in recent years in human osteosynthesis, and in animals applicable as well, have been:

1. More extensive preoperative planning utilizing better diagnostic radiographic, CT, and MRI imaging and bone scans of the injured and normal side.
2. More emphasis on biology and less on mechanics to attain more rapid fracture healing, e.g., opening a diaphyseal fracture for its reduction utilizing smaller incisions and less invasive and traumatic indirect reduction techniques (as if closed treatment of these fractures were being utilized).
3. Less hardware to achieve stable fixation, e.g., fewer screws in plates, and transcutaneously inserted cannulated lag screws for both diaphyseal and metaphyseal articular fractures, as well as the use of arthroscopy to monitor accurate joint reduction.
4. Better appliances that cause less avascularity, e.g., limited contact dynamic compression plates (LC-DCP); PC-Fix plates; closed IM nails with locking screws (both unreamed and reamed); dynamic hip screws (DHS), dynamic compression screws (DCS), and other special plates for metaphyseal-diaphyseal fractures where accurate reduction and stable fixation are essential.
5. Temporary external fixation of the adjacent diaphyseal fracture fragments in conjunction with screw fixation of metaphyseal articular fractures to minimize the need for long and multiple plates.
6. Better tolerated, more elastic metallic fixation through titanium.
7. More advanced external fixation techniques utilizing Ilizarov principles for lengthening, segment transport, and deformity correction in fresh fractures and non-unions.
8. New techniques, instruments, and implants for the treatment of human pelvis, acetabulum, hand, feet, and spine fractures. In addition, computer and robotic-assisted surgery as well as special implants to fit the varied sizes and shapes of animal bones.
9. Better bone-grafting techniques including allografts and bone substitutes.
10. Extensive classification of fractures and soft tissue injuries; and newer techniques for computer documentation.
11. More careful postoperative management to ensure return of function and prevent loss of the race between implant failure and fracture healing.

A great many of these newer advances and techniques are applicable to large animals and are incorporated in PEOS. The work encompasses the more extensive large animal osteosynthesis applications and techniques that were developed in the 5 years since the publication of EBEQOS. Finally, the most innovative and exciting change in PEOS is its refinement of the electronic format utilizing CD-ROM for a true multimedia approach to teaching equine fracture treatment. With simple commands the reader can switch from text to figures, to animation, to videos. Indeed this pioneering computerization is to be a template for the upcoming human manual—another first for veterinary orthopedics and the authors!

PEOS has two additional chapters: on humeral fractures encompassing better compression technology, and on documentation including the AO Vet Equine Documentation System itself. There have also been added full length videos on the use of the dynamic condylar screw plate (DCS/DHS) systems in the treatment of short oblique distal fractures of the adult radius.

The bibliography style has been changed to the one adopted by AO Publishing to be utilized in the books to be published in the future.

This edition also encompasses newer concepts, advances, and techniques, seeking the true etiologies of conditions we deal with—such as biomechanics and tissue growth factors. Newer implants and instruments are shown, but biologic fixation will be stressed where applicable in large animals. Local antibiotics via loaded polymethylmethacrylate (PMMA) beads, more constructive use of allografts, and expanded use of nuclear scintigraphy, MRI, and CT scanning for better and earlier diagnosis and more effective intervention have also been incorporated.

Finally, the greater use of electronic technologies in everyday practice and teaching, utilizing documentation and computer-aided learning methods, have been given an impetus by this book, propelling these advances well into the new millennium.

It is still strongly suggested that the user complement the book's informative guidance through equine osteosynthesis by obtaining specialized practical training at an AO course or at a school where these exacting techniques can be practiced on plastic bones and/or cadavers. To insure the best possible clinical results, however, careful soft tissue handling, aseptic operating room conditions and good preoperative and postoperative management should be practiced, in addition to the proposed osteosynthesis.

In conclusion, I wish all the practitioners and students who utilize the AO techniques promulgated in this exciting new work the best of luck in obtaining excellent functional results following their repair of equine fractures. I also congratulate the authors, editors, and publishers once again on a job well done.

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1 Basic principles of fracture treatment

David M. Nunamaker

1.1 Introduction

A full fifteen years after the publication of the Manual of Internal Fixation in the Horse by Springer Verlag, the principles of internal fixation using AO techniques remain intact. New techniques have expanded the capabilities of the surgeon, and experience with established techniques has added a perspective that was not present a decade ago. Immediate full weight bearing following fracture fixation remains a goal that cannot always be achieved in the horse. **Functional fracture treatment with early joint mobility and gradually increasing weight bearing** as tissue healing progresses are admirable goals. In the horse, early or immediate full weight bearing is a necessity difficult or impossible to side-step. The use of casts and splints to protect internal fixation devices from failure, and techniques such as plate luting that increase the fatigue life of those implants can combine to significantly improve results [1, 2].

Successful internal fixation starts with the anatomic reconstruction of bone and joint surfaces that **allows the sharing of loads between the reconstructed bone and the implants**. Anatomic reconstruction can be accomplished by screws alone or screws combined with a plate. Interfragmentary compression is absolutely essential for maintaining bone contact between fragments to protect the relatively weak implants. Orthopedic implants by themselves are not able to withstand the full force of weight-bearing without failure.

1.2 Surgical approaches

The **accurate alignment** of fracture fragments and the **perfect reconstruction of joint surfaces** is made possible by surgical approaches that **allow adequate visualization**. Perfect reduction cannot be ensured if the joint surfaces are reduced without direct vision, and inadequate exposure of shaft fractures may not allow reduction of overriding fracture fragments or proper placement of plates or screws. Surgical approaches should also be designed to maintain vascular integrity and to avoid areas of compromised soft tissues. Evaluation of compromised skin may be difficult, and decisions need to be modified based upon the amount of time which has elapsed since the injury. In general, **incisions into badly bruised skin with subcutaneous hemorrhage** carry a **high risk of subsequent infection**. Devitalized skin may mean delaying open reduction and internal fixation. External skeletal fixation alone may be considered or in combination with minimal internal fixation using screws placed through stab incisions [3, 4]. Casts or splints are not usually helpful in preserving unstable fractures with compromised skin, but bulky bandages such as the

Accurate alignment of fracture fragments is made possible by surgical approaches that allow adequate visualization.

Goal of AO fracture treatment: Functional fracture treatment with early joint mobility and gradually increasing weight bearing.

Incisions into badly bruised skin with subcutaneous hemorrhage carry a high risk of infection.

Successful internal fixation allows sharing of loads between bone and implants.

Keep skin incisions away from the intended location(s) of plate(s).

Robert Jones Dressing can be useful. When planning an open reduction and internal fixation of equine fractures, the **skin incision** must always be **far enough away from the proposed placement of the plate(s)** to ensure soft tissue coverage. In general, the incision line should not be directly over the implants.

1.3 Precise anatomic reconstruction

Interfragmentary compression creates large "normal" (rectangular) forces.

Axial and rotational alignment must be preserved at the time of fracture reduction.

Interfragmentary compression occurs whenever two fracture surfaces are pressed tightly together.

Use bone grafts as a replacement for early bridging callus.

Normal function in the horse depends upon anatomic reconstruction of fractures and joint surfaces. Slight malalignments in the reconstruction of a fractured bone can lead to significant deviations in foot position and leg conformation in this long-legged species. It is important that **axial and rotational alignment are preserved at the time of fracture reduction**.

Comminuted fractures may make anatomic reconstruction more difficult since many small fragments may no longer be salvageable. Length, axial, and rotational alignment can be maintained using interfragmentary screws. Voids in the bony cortex are filled with a cancellous bone graft. The grafts are used wherever possible because they cause formation of an early structural bridge. This can be important in preserving the integrity of the internal fixation. **Cancellous bone grafts can be used as a kind of callus replacement** over potentially weak areas of the reconstruction; stable internal fixation may limit natural callus formation.

Nowhere is anatomic reconstruction more important than in the case of a fractured joint. Here, even a small step or incongruity in the surface may lead to degenerative joint disease and associated loss of function. When dealing with displaced fractures, direct visualization is essential for adequate reduction. Intraoperative image intensification or radiographic monitoring can help ensure reduction but the images obtained can be misleading.

1.4 Stable fixation

Interfragmentary compression is at the heart of internal fixation using screws and plates. **Interfragmentary compression creates large normal forces** (forces perpendicular to the fracture planes) that prevent movement of the individual bone fragments (**Fig. F1A**). These large normal forces in turn create large frictional forces that prevent sliding of the fracture fragments over each other. Although usually thought of as being achieved only with the use of lag screws, **interfragmentary compression** occurs whenever **two fracture surfaces** are pressed tightly together. For instance, it occurs when

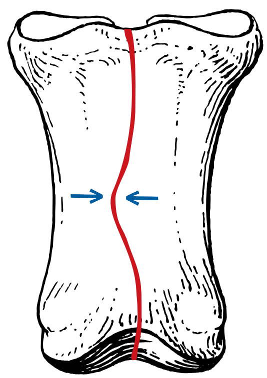

Fig. F1A: Creating large "normal forces" upon the fracture plane is the main objective of interfragmentary compression.

plates are used to compress the surfaces of a transverse fracture or osteotomy (**Fig. F1B**). This **axial compression** is often **combined with interfragmentary compression produced by individual lag screws** in fractures that have transverse and oblique components (**Fig. F1C**).

When fractures are treated with casts or splints, healing occurs with motion and callus formation. Relative motion between individual fragments fixed with screws or with screws and a plate may be detrimental to fracture healing.

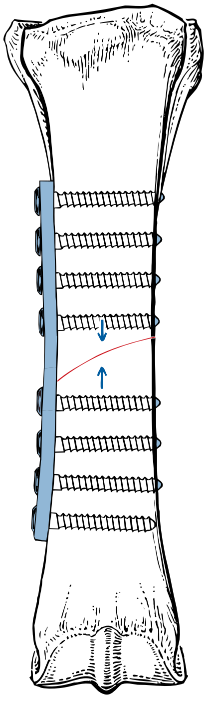

Fig. F1B: A plate applied to the reduced fracture provides axial compression.

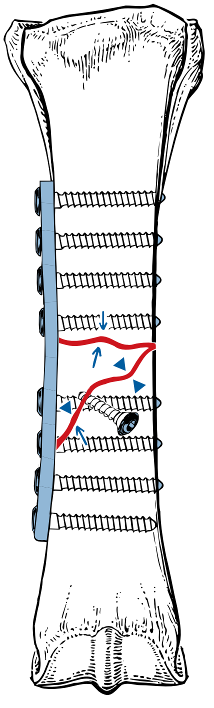

Fig. F1C: A combination of plate axial compression and interfragmentary screw compression in a comminuted fracture.

Large gaps seem less sensitive to small amounts of motion than small gaps. This observation can be explained by the fact that equal amounts of motion in small gaps and large gaps represent a different percentage of that gap. Healing tissues can only stretch so far before they rupture. As healing progresses and motion decreases the tissue's ability to stretch diminishes as well, i.e. from granulation tissue to cartilage to bone. Theoretical and experimental studies have explored this phenomenon which has been termed interfragmentary strain [5, 6].

Since **interfragmentary strain may influence fracture healing**, relative motion should be controlled by the internal fixation and special attention must be given to small gaps that may be subject to delayed healing or non union due to micromotion. These **small gaps may also increase the risk of implant failure through the cyclic loading** that occurs during weight bearing.

1.5 Soft tissue considerations

Adequate vascularity of soft tissues and bone is important if fracture healing is to occur. Most equine fractures are high energy events with bone literally exploding into the surrounding soft tissues. This initial trauma may devitalize the soft tissues as well as the bone. **Bone receives its blood supply** by way of its **nutrient vessel and periosteal soft tissue** attachments. Much of this blood supply may be interrupted at the time of the fracture. While the nutrient vessel is almost always compromised, the integrity of the periosteal blood

Combine axial compression produced by a plate with interfragmentary compression produced by a lag screw.

Interfragmentary strain may influence fracture healing.

Small gaps may also increase the risk of implant failure through cyclic loading.

Adequate vascularity of soft tissues and bone is very important.

Nutrient vessels and periosteal soft tissues provide a blood supply to the bone.

> Avascular tissue will be at a higher risk for necrosis and infection.

> Anesthetic recovery can be a critical time.

> The need for open reduction and internal fixation must be balanced by its risks.

> Success in fracture treatment is measured against preoperative expectations.

supply can be difficult to assess prior to surgical intervention. This makes open reduction and internal fixation a risky technique since **avascular tissue will be at a higher risk for necrosis and infection**. Further loss of blood supply to the bone may occur due to the exposure necessary for open reduction and implant placement. Proper evaluation of soft tissue viability will influence the outcome of postoperative complications, such as infection and wound dehiscence. Adequate first aid and preoperative care are essential for the preservation of the remaining blood supply following injury.

Whenever possible, internal fixation using lag screws should be accomplished under radiographic control through stab incisions to minimize additional soft tissue compromise. This is usually performed for nondisplaced fractures. Sometimes additional stab incisions can be used for the insertion of screws even when open approaches are used for visualization and reduction. As an alternative to expansion of the primary incision, this technique serves to limit the necessary exposure. Soft tissues should always be protected during drilling and tapping by the use of drill guides and tap sleeves.

The need for open reduction and internal fixation must be balanced by its risks. Experience with this paradox in the horse will help define each surgeon's abilities and limitations.

1.6 Functional rehabilitation

As stressed in this chapter, anatomic reconstruction, stable internal fixation with good soft tissue evaluation, and careful surgical handling should permit early weight bearing with preservation of joint function. To accomplish these goals, external casts or splints must sometimes be used in the postoperative period or at least during recovery from anesthesia. **Anesthetic recovery can be a critical time** in the early treatment of a horse with a fracture, and protection of the animal and the reconstructed fracture is of paramount importance. Casts are often used to help ensure a safe recovery. Concern for preservation of the animal and its operated extremity has resulted in specialized recovery techniques such as the raft/pool recovery system.

- Healing of bone itself does not ensure full functional rehabilitation. Failure of bone healing, however, does ensure failure of functional rehabilitation. Therefore, healing of bone is the first criterion for the rehabilitation of an afflicted animal.

Success in fracture treatment is measured according to expectations. Some injuries are so severe that they are lifethreatening. In such cases, just saving an animal's life to allow it to be pasture sound may be a success. In other cases, the animal will be expected to perform at levels equal to or surpassing those of its former status. Here, fracture fixation and bone healing constitute only a small part of the total rehabilitation process. Further efforts will be required to bring the horse back to its former athletic prowess. Truly **successful fracture treatment** must involve the whole animal and reach beyond the gains made in the operating theatre.

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2 General techniques and biomechanics

David M. Nunamaker

2.1 Screw fixation

Screw fixation is a technique that is at the heart of internal fixation using AO techniques. Screws can be used in a variety of ways to stabilize bone fragments and to secure plates to bone.

2.1.1 Drilling and tapping holes in bone

Screws are inserted into bone through drill holes. Drilling is an important process since it helps determine the nature of the bone-screw interface. Use of a hand brace or drill may cause the operator to drill oval holes due to drill bit wobble. **Power drilling is recommended and combined with the use of appropriately sized drill guides, will help prevent the drilling of oval holes.**

Drill hole quality is also dependent on the drill bit itself. **A good sharp drill bit that is designed for use in bone should drill at a rate of 1 mm/s**. Sharp drill bits are necessary for drilling in bone. Drilling rates slower than 1 mm/s may be related to a dull bit or the accumulation of swath material in the drill bit's flutes that prevent further penetration and increase heat production. Drill bits may become dull instantly when they strike a metal surface as can occur when drilling into a previously placed screw. A sharp bit can drill through more than 1 meter of bone before it becomes dull. Dull bits should be discarded. Resharpening is not recommended for large animal surgeries because **the drill bit accumulates cyclic fatigue in rotational bending as it is being used. Older drill bits are therefore more easily broken than new ones.**

> Older drill bits break more easily due to fatigue accumulated in rotational bending.

When a drill bit is used to drill a hole in bone the tip of the bit creates heat due to friction. High temperatures in bone (>54°C) may occur causing protein coagulation and bone necrosis. Temperature generation is inversely related to drilling rate when sharp drill bits are used. **Increased pressure on the drill bit will increase the cutting rate and reduce bone heat generation** but the introduction of bending to the drill bit by a surgeon pressing on the drilling machine may lead to drill bit breakage. Cooling of the drill bit is impractical since it has been shown that more than 500 ml/min of saline are necessary to adequately cool the bone [1]. Temperature control is possible however by using saline as a lubricant in the drill hole to decrease friction at the point of drilling. Much of the frictional heat generated during the drilling process is incorporated into the swath material. **Periodic removal of this bony material from the flutes of the drill bit during the drilling cycle will decrease heat buildup** and allow for further swath material accumulation. Impaction of swath material in the drill bit's flutes will decrease cutting rates of the drill bit since there

> Increased pressure on the drill bit improves efficiency, but can cause bending.

> Power drilling results in a round, symmetric hole.

> Use a sharp drill bit, and drill at a rate of 1mm/s.

> Periodically cleaning the drill bit is important in preventing heat generation.

will be nowhere for the cut bone to go. Saline should be supplied as a lubricant to the drill point at the time of drilling and can be placed into the drill hole when the bit is removed periodically for cleaning. Drill bits are designed to circulate fluid for lubrication. The fluid descends via the lands and ascends with the swath material (**Fig. F2A**).

Pretapping insures a good interface between bone and screw.

Pretapping of drill holes prior to screw insertion insures a good interface between the bone and screw. It also permits the screw to be inserted with less torque. Using saline for lubrication increases the ease of hole tapping and screw insertion as well. Screws without tapping flutes on their tip can easily be removed and reinserted during surgery without danger of cross threading the hole in the bone. Special care must be taken when using self-tapping screws in this regard. **In equine bone self-tapping screws may not work well because the flutes of the tap may fill up before the entire cortex is penetrated, leading to imperfectly threaded holes and heat generation**.

Avoid the use of self-tapping screws in thick cortices.

2.2 Screw types

There are two basic types of screws. The cortex screw is fully threaded, has relatively fine threads and is used in cortical bone and dense cancellous bone. It is the screw that is used most commonly in equine orthopedics. The cancellous bone screw is partially threaded and has a larger coarser thread. It is used in soft cancellous bone and may be used as a substitute for a cortex screw if the cortex screw has stripped the threads in the bone during insertion. Both screws are available in a wide variety of sizes and special large 5.5 mm cortex screws have been developed with the horse in mind.

2.2.1 Cortex screws

A cortex screw is fully threaded and can be used as a fixation position screw with threads holding in both cortices to attach a plate to a bone. It

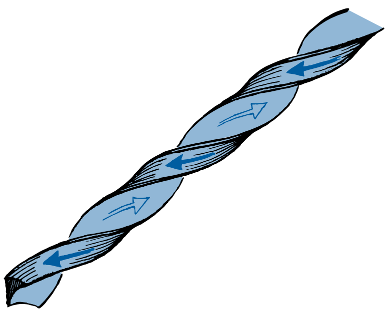


Fig. F2A: Lubricating fluid circulates along a drill bit by descending behind the lands and ascending with the swath material.

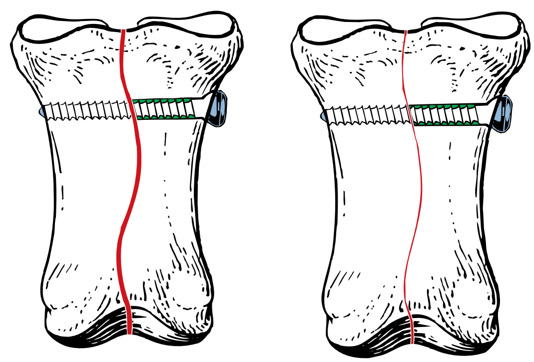


Fig. F2B: A fully threaded cortex screw is made to act in lag fashion by overdrilling the cis cortex and cutting threads only in the trans cortex.

can also serve as an interfragmentary screw that compresses two fragments together by drilling a glide hole in the near cortex (cis cortex) while providing a threaded hole in the far cortex (trans cortex) (Fig. F2B). Cortex screws are available in a large range of sizes with the 3.5 mm, 4.5 mm, and 5.5 mm diameters used most commonly in the horse. Testing of the various screw sizes has been carried out and the results show that in general screw strength is related to its core diameter [2]. Therefore, increased strength comes with larger screw diameters. **When soft bone is encountered, the large-diameter screw threads hold better**. In general, equine bone is so dense that cancellous bone screws are rarely needed. Therefore when dealing with a stripped screw hole it would be better to replace the stripped screw with a cortex screw of a larger diameter rather than substituting it with a cancellous bone screw.

To use a cortex screw as a lag screw it is necessary to use a large drill bit, equivalent to the outside diameter of the screw thread, to drill the glide hole through the cis cortex while a smaller drill bit, equivalent to the approximate core diameter of the screw, is needed to drill the smaller threaded hole into the trans cortex. For each cortex screw size, drill bits of the proper diameter are available to drill both the glide and threaded holes; see table (Fig. T2A).

Cortex screws used as lag screws require a glide hole.

Larger-diameter screws provide better holding power in soft bone.

Veterinary - Large Animal Screw - Drill bit - Tap - Chart

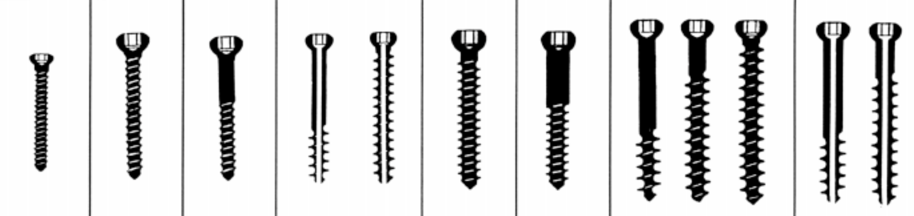
Screw name	3.5 mm Cortex	4.5 mm Cortex	4.5 mm Shaft	4.5 mm Cannulated		5.5 mm Cortex	5.5 mm Shaft	6.5 mm Cancellous			7.3 mm Cannulated	
Screw ø	3.5	4.5	4.5	4.5		5.5	5.5	6.5			7.3	
Gliding hole ø	3.5	4.5	4.5	4.5	none	5.5	5.5	(4.5)			none	
Thread hole ø	2.5	3.2	3.2	3.2		4.0	4.0	3.2			selftapping	
Screw tap ø	3.5	4.5	4.5	4.5		5.5	5.5	6.5			selfdrilling	
Screw shape												
Cannulation / Guide pin	–	–	–	1.75 mm / 1.6 mm		–	–	–			2.1 mm / 2.0 mm	
Type thread	cortical	cortical	cortical	cancellous		cortical	cortical	cancellous			cancellous	
Pitch	1.25	1.75	1.75	1.75		2.0	2.0	1.75			2.75	
Screw head ø	6.0	8.0	8.0	6.5		8.0	8.0	8.0			8.0	
Thread length	entire length	entire length	variable	16.0	entire length	entire length	variable	16.0	32.0	entire length	16.0	32.0
Shaft ø	–	–	4.5	3.1	–	–	5.5	4.5	4.5	–	4.5	
Core ø	2.4	3.1	3.1	2.7		4.0	4.0	3.0			4.5	
Self tapping	planned	yes	yes	yes		planned	planned	–			yes	

Fig. T2A

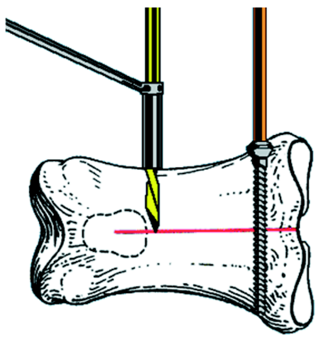
The glide hole should extend just beyond the fracture plane.

Rotate the countersink through a full 360°.

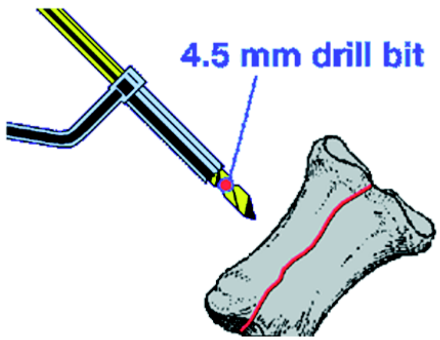
Power tapping is convenient, but can quickly lead to breakage or stripping.

The techniques for insertion of lag screws are shown in **Video P1LAGSCR** and in the animation **Video DBASICS**. After reduction of the fragments using bone clamps, K-wires, or some other device, a large glide hole is drilled through the cis cortex using a drill guide to prevent drill bit wobble and to protect the overlying soft tissues. **This hole must be drilled across the fracture plane which may include cancellous bone as well as cortical bone**, especially near the metaphyses. A drill insert is then placed into the glide hole and pushed across the fracture plane. This guide will center the thread hole precisely. The thread hole is drilled through the trans cortex using this drill guide along with the appropriate diameter drill bit. The drill bit and drill guide are then removed and the hole is countersunk to provide a seat for the head of the screw. It is important to **turn the countersink tool a full 360° in a clockwise direction to avoid any ridges that would be created by simply oscillating the instrument back and forth**. The countersink depression should only be deep enough to support the head of the screw and prevent its bending during tightening. Next the hole is measured with the depth gauge to determine the proper screw length; then it is tapped. Tapping of the thread hole is accomplished by inserting the tap through the tap sleeve into the glide hole and cutting threads in the trans cortex. The tap should be advanced into the bone by using two half turns forward and then one quarter turn back to keep the bone cuttings clear of the cutting edges. If the tap starts to bind, cutting should stop so that the tap can be removed and cleaned before continuing. The tap must be maintained free of all swath material in its longitudinal grooves in order to cut satisfactorily. Finally, a screw of the proper diameter and length is chosen and inserted using the screwdriver. As mentioned above, saline used as a lubricant will decrease the torque occasioned by tapping and screw insertion.

Although power drilling is recommended for drilling holes in bone, power tapping is reserved for applications where many screws are to be used in an internal fixation, as with a long plate or a double plating procedure. Special attention should be paid to directing the tap in the same plane as the drill hole. **If the tap misses the hole in the trans cortex it may jam or break or the cis cortex threads may be stripped.** When inexperienced operators begin to use



Video P1LAGSCR: Techniques for insertion of lag screws.



Video DBASICS: Introduction to drill basics.

power equipment for tapping bone, the torque of the machine may be lowered by decreasing the air pressure. This will help preserve instruments as well as the newly cut threads in the cis cortex. Power tapping should not be used when only a few screws are to be used since each hole is so important for fixation that stripping one cortex may be a reason for fixation failure. Insertion of screws using power equipment will decrease the time of a surgical procedure as well as the fatigue of the operator. All screws should be tightened by hand following power insertion.

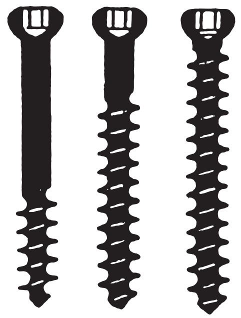


Fig. F2D: Cancellous bone screws are available as fully threaded or in two different thread lengths: 16 mm & 32 mm.

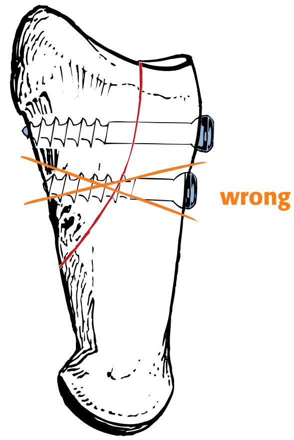


Fig. F2E: When inserting a cancellous bone screw, the threads must only engage the trans cortex if it is to act as a lag screw.

2.2.2 Cancellous bone screws

Cancellous bone screws are available in 6.5 mm and 4.0 mm diameters. The 6.5 mm screw has three different thread lengths—16 mm, 32 mm and fully threaded (**Fig. F2D**).

Only the partially threaded cancellous bone screws will produce interfragmentary compression at the fracture site using a single-sized drill bit. If interfragmentary compression is desired then it is important to choose the proper length thread combination so that the threads are located only within the trans cortex/cancellous fragment (**Fig. F2E**). **Cancellous bone screws should only be used in soft cancellous bone** since it may be impossible to remove them from hard cortical bone without breaking them.

To insert a large cancellous bone screw a 3.2 mm or 3.6 mm hole (hard cancellous bone) is drilled across the entire bone. A 6.5 mm tap is then used to tap the thread into the bone and measure the length of the screw to be used. The tap does not cut the entire 6.5 mm thread, leaving some uncut bone to be cut by the screw itself at the time of insertion; therefore, the

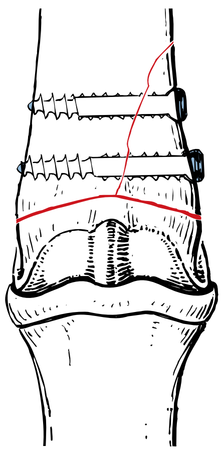


Fig. F2F: In this figure, two cancellous bone screws inserted in lag fashion are illustrated.

Only the partially threaded cancellous bone screws will produce interfragmentary compression at the fracture site using a single-sized drill bit.

Cancellous bone screws should only be used in soft cancellous bone .

Screws should be placed perpendicular to the long axis of the bone if weight bearing loads are to be expected.

Normal forces on the fragment surfaces create the greatest compression.

torque necessary to insert a cancellous bone screw will be greater than that of a cortex screw and much greater in hard bone than in soft bone (**Fig. F2F**).

2.3 Screw position

Screws are designed to provide purchase in bone that will be advantageous in fracture fixation. They are designed to be loaded in tension and not in bending or shear. **Interfragmentary compression is greatest when the forces on the surfaces of the fragments are normal** (perpendicular to the fracture plane). To accomplish this, the screw must be placed perpendicular to the fracture planes in all directions (**Fig. F2G**). This means that when a fracture spirals, the screws used to fix this fracture must spiral as well. The loads experienced by the reduced and stabilized fracture will be those imposed by the screws and by the loads associated with use (i.e., postoperative weight bearing). Vector analyses will show that the loads of weight bearing change the resultant forces (loads) through the bone so that simple fixations become far more complex systems when subjected to weight bearing (**Fig. F2H**). **As a rule of thumb, screw placement should be perpendicular to the long axis of the bone if weight bearing loads are to be expected.** Screws placed perpendicular to the fracture plane will be subjected to shear forces during weight bearing. A decision on screw placement may represent a compromise if the screw itself will induce large shear forces independent of weight bearing forces. In these cases, the screw should be placed at an angle between perpendiculars drawn to the fracture plane and to the along axis of the bone. In all instances, the screw placement should spiral in the longitudinal plane in concert with the fracture (**Fig. F2G**).

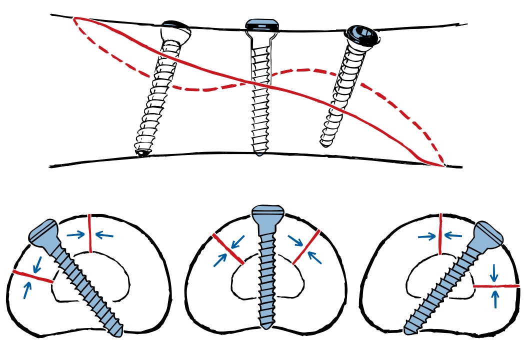


Fig. F2G: To efficiently create interfragmentary compression, the screws must be placed perpendicular to the fracture plane in all three dimensions.

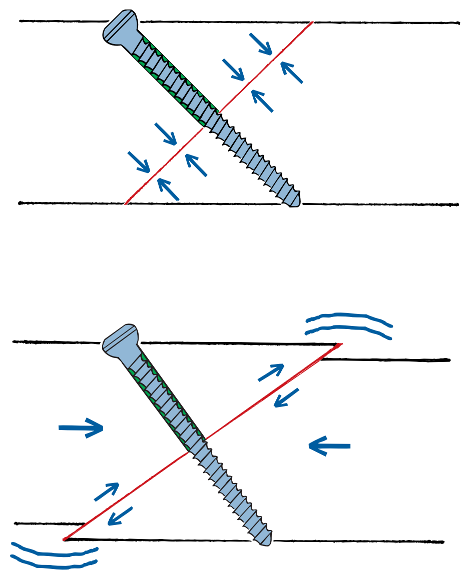


Fig. F2H: Weight bearing loads can result in shear forces at the fracture site and displacement of the fragments if the screws are inserted perpendicular to the fracture plane.

2.4 Plate fixation

A variety of plates are available for use in internal fixation. Recent introductions of new plate designs with new materials have been utilized in many animal species including humans; the most commonly used plate in equine orthopedics, however, continues to be the **dynamic compression plate (DCP)** fabricated in stainless steel. This is available in two cross-sectional dimensions, the narrow and broad configuration. The narrow DCP has the screws placed in a straight line while the broad plate has the screws placed in a staggered configuration. The sectional properties of the plates, especially around the screw holes, determine their strength and fatigue resistance. The larger cross-sectional dimensions of the broad plate make it the choice for most applications. The **dynamic condylar screw (DCS)-** and corresponding **dynamic hip screw (DHS) plates** have correspondingly larger cross-sectional dimensions and would therefore be stronger than the broad DCP. They are only manufactured, however, with the large sliding screw at one end which limits their application in the horse. Choosing the proper length plate for use in any specific situation may represent a dilemma based on soft tissue viability, surgical approach, and configuration of the fracture. While four cortex screws are recommended as a minimum on each side of the fracture with each screw threaded into both cortices (eight cortices) it is best to plate most equine long bone fractures from end to end. **Two or more plates are often used in the repair of fractures in the horse. These plates should be placed at right angles to each other to optimize the inertial properties of the fixation.** Specific recommendations regarding plate size and number are addressed with individual fractures and arthrodeses as they are presented in later chapters.

DCP = Dynamic compression plate
DCS = Dynamic condylar screw plate
DHS = Dynamic hip screw plate

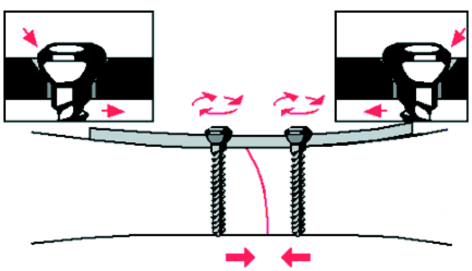
2.4.1 Plate application

The technique for application of a plate will be described for the dynamic compression plate (DCP) as a self-compressing plate and with the tension device as used in certain circumstances, such as with a dorsal plate arthrodesis of the metacarpal phalangeal joint.

2.4.2 Self-compressing DCP

Video SCDCP

Following contouring of the plate to the bone surface, a 3.2 mm hole is drilled through the bone approximately 1 cm from the fracture surface. The plate is placed over this hole, and the depth gauge is used to determine the




Video SCDCP:
Animation about self-compressing DCP.

Self-compressing DCP:
1. Drill 3.2 mm hole 1 cm from fracture site
2. Measure depth
3. Tapping with 4.5 mm
4. Insert first screw loosely, displace plate toward fracture
5. Drill 3.2 mm hole on opposite side using yellow load guide
6. Measure depth
7. Tapping with 4.5 mm
8. Insert second screw
9. Tighten first screw
10. Apply other screws

Drill the first hole approximately 1 cm from the fracture plane.

Two or more plates are often used. They should be placed at right angles to each other to optimize the inertial properties of the fixation.

Slide the plate *toward* the fracture.

Reduction should be almost perfect *before* plate application.

length of the screw taking into account the thickness of the plate and the diameter of the bone. The hole is then tapped with the 4.5 mm tap and the correct length 4.5 mm screw is chosen and inserted. This screw is not tightened at this time but only inserted until the screw makes contact with the slotted hole in the plate. The fracture is reduced and stabilized with a bone-holding forceps or other means (lag screw, K-wires, etc.) and the plate is aligned with the long axis of the bone. **The plate is slid toward the fracture line, from the side stabilized with the screw, until the screw engages the end of the oval hole**. A second hole is drilled through the plate hole nearest the fracture in the other fragment using the yellow load guide in its proper position. the load guide has its hole placed off center, and the arrow on this guide should point toward the fracture line which positions the screw 1.0 mm up the inclined plane of the oval DCP screw hole. The position of this guide is very important since the insertion of the screw in this second hole will, upon screw tightening, move the plate over the bone surface and pull together the fractured ends of the bone in compression. Following drilling of this hole, it is measured, and tapped and the proper length screw is inserted. As this screw starts to engage the oval hole it should be tightened, alternating with the first. In this way both screw heads are drawn down equally. Any screw left with its head high on the inclined plane will be subjected to bending loads and may fail. The remaining holes on both sides of the plate should be drilled using the green neutral drill guide. This guide has the hole centered in the guide and its use will result in a hole that is 0.1 mm up the inclined plane of the oval hole. Therefore the neutral drill guide will still position the screw so as to exert a slight compressive effect. Overuse of the load guide can place all screws on the inclined plane of the DCP hole and expose them to destructive bending forces. Once the fracture fragments are in contact the neutral guide should be used for all other screws. The load guide can theoretically be used three times on each side of the fractures so the total distance that the fractured ends of the bone can be moved is 6.0 mm before the screw heads come to lie at the end of the oval holes. In this case it is necessary to loosen the screws previously placed prior to tightening any subsequent ones, since the tightened screw will make further movement of the bone fragments impossible. **Obviously, it is preferable to achieve better reduction before plating, and not to use the definitive implant(s) for this purpose**. Once the fixation is complete the screws should be checked for tightness from the center outward, since any change in tightness in one screw may shift the plate slightly and leave other screws loose. This tightening procedure should be repeated several times until all the screws are tight.

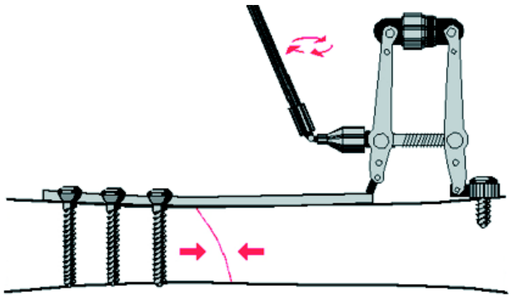
If great force was necessary to bring the fracture fragments together the central two screws may be exchanged for new ones since the heads of these screws may have been weakened by bending during insertion.

2.4.3 Tension device with DCP

Video TDDCP

There are times when it is necessary or desirable to move the fragment ends more than the 6.0 mm allowed by the use of the DCP when used as a self-compressing plate. In these circumstances the tension device should be used.

Following contouring of the plate a 3.2 mm hole is drilled approximately 1 cm from the fracture. The plate is applied over this hole and the measuring device is used to select a screw of the proper length. The hole is tapped and the screw is inserted but not completely tightened. The fracture is reduced and held with a bone-holding forceps, and the plate is aligned with the long axis of the bone. The guide for the tension device is placed in the last screw hole and a 3.2 mm hole is drilled in just one cortex. The hole is tapped and a short screw is placed through the tension device after it has been extended and hooked into the last hole in the plate. The tension device is tightened slightly to align the plate, and the first screw that was placed into the plate is tightened. At this time all the screws (at least four) should be added in the fracture fragment containing the first screw. This is accomplished by drilling with the neutral drill guide, measuring, and tapping as previously described. All the screws in this fragment are inserted and tightened. The tension device is now tightened using the socket wrench. A pin wrench is also available and may provide additional load on the fracture fragments. The holes on this side of the fracture are now drilled using the neutral drill guide. They are measured, and tapped and their screws are inserted and tightened. The tension device is then loosened,



Video TDDCP:
Animation about tension device DCP.

and removed, and the final screws are inserted into the plate after proper drilling, measuring, and tapping.

Use of the tension device was the standard method of plate application when round hole plates were used. These plates are rarely used today but may be applied as described above.

Use the tension device to move the fragment ends more than 6 mm.

2.5 Mechanics of plate fixation

Success with internal fixation using plates and screws comes with good technical ability and an understanding of the mechanics of plate fixation. Plates used for internal fixation are strongest in tension and compression. They are weakest in bending. They are also weak in torsion, but this is a result of the screws that fasten the plate to the bone. Therefore, plates should be applied to bones so that tensile forces are applied and bending forces minimized. To accomplish this, the plates should be applied to the so called “tension side” of the bone. This is

A plate should be contoured to the exact shape of the bone to which it is to be affixed.

Bones bend and the bending force can be converted to a tensile force in the plate.

Avoid cycling a plate during contouring.

There is a 1.5–2 mm gap beneath a properly prebent plate.

the surface that *in vivo* weight bearing and theoretical studies have shown to be subject to mainly tensile forces. When the plate is applied to compress the bone ends together the plate is already placed under tension. The loads of weight bearing will increase the tension in the plate and therefore the compression in the bone. Since bones have a tension surface they must also have a compression surface. This means that **bones bend and the bending force can be converted to a tensile force in the plate** if the cortex opposite the plate is intact. If a gap is present due to comminution of bone then an unstable situation may occur. If the comminution is bridged by the plate then it may be stable but if the comminution is at the cortex opposite the plate (trans cortex), then the implant may be subjected to cyclic bending rather than tension, and fatigue failure may result (**Fig. F2J**). Some situations dictate that the plate be applied in a less than optimal location. This may occur based on soft tissue coverage, vascularity of the skin, and the shape and extent of the fracture or loss of bone stock. Even when implants are applied under the best of conditions, failures may occur. Certain techniques can be used to optimize internal fixations. These are enumerated in the following sections of this chapter and demonstrated on the videotapes corresponding to the individual fractures.

2.5.1 Contouring and prebending

A plate should be contoured to the exact shape of the bone to which it is to be affixed. The importance and difficulty of this step cannot be overstated. Some of the shortcomings of inadequate plate contouring can be overcome by so-called luting (see below). Bending and twisting the plate may be necessary to make it conform. **In general, plates should be bent in one direction and not back and forth since such cycling weakens them**. A single bend may actually work-harden the material and does not affect the overall strength of the implant. A bending press, pliers, and bending irons are available to accomplish this task.

The work of Askew and others has shown that when a straight plate is applied to a straight bone and placed under tension (compression in the bone) a gap will form on the side opposite the plate (trans cortex) [**3**]. Thus, only a small area (1/5) of the bone will be in contact with resulting large stresses in the bone and implants. This phenomenon has been known for years, and the histology of Schenk showed the result of contact and gap healing using this model [**4**]. If bending is superimposed on the gap, stress concentrations develop that could induce fatigue failure of the implant. This problem can be addressed by using a technique known as "prebending." Prebending involves making a small kink in the plate over the area of the fracture (**Fig. F2K**). This is accomplished after the plate has already been contoured to the bone. **The prebending is done in the bending press to form a gap between the bone and the plate of 1.5–2.0 mm**. When the plate is then attached to the bone the kink will be elastically straightened to allow contact between the plate and the bone, but the plate will be applying

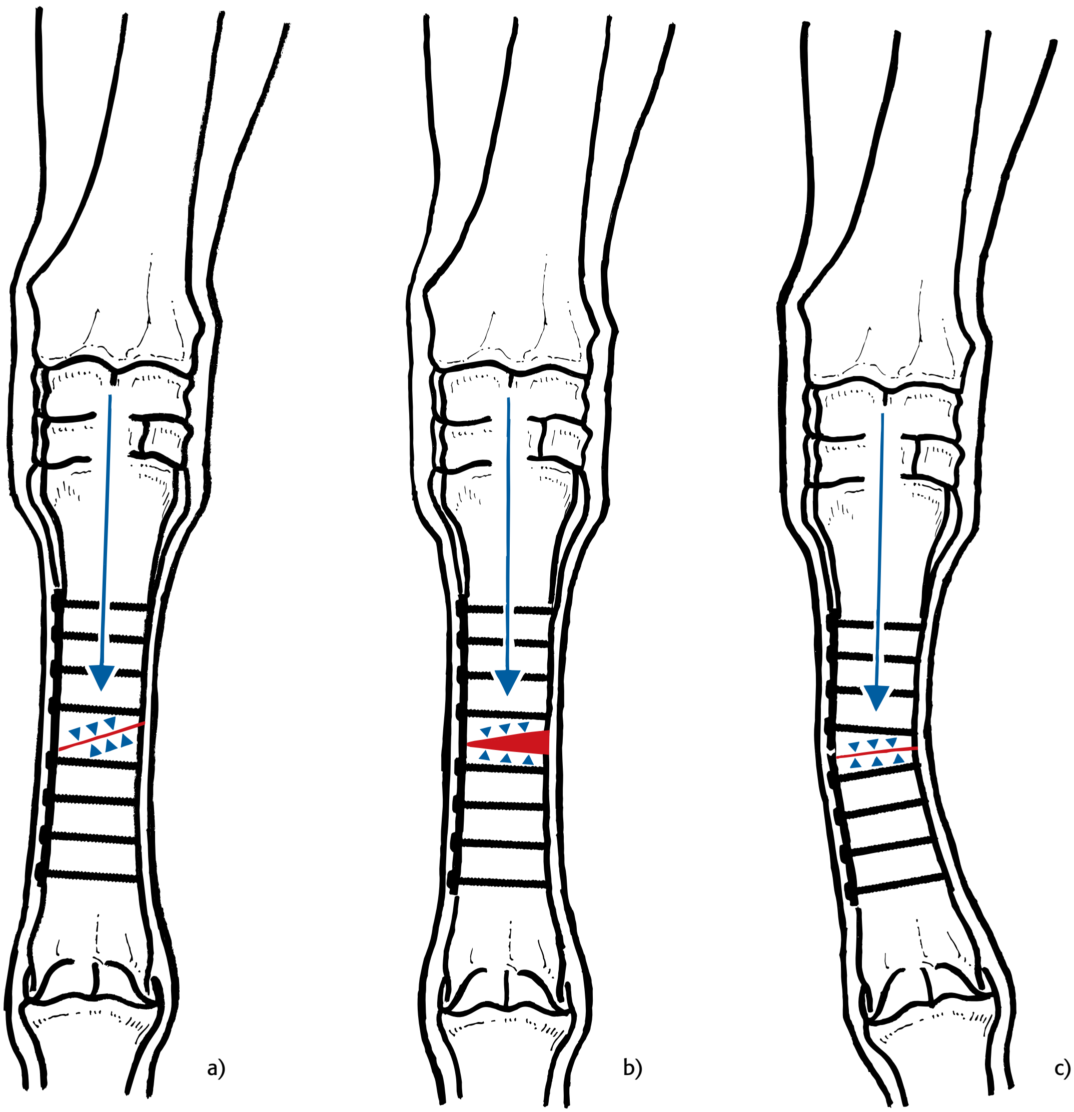


Fig. F2J: a) Load transmission across the fracture line after anatomic reduction with resultant stability. b) Any inability to transmit loads across the fracture site will result in implant deformation. c) Persistent cyclic deformation will result in implant failure.

Do not prebend the plate if there is a defect in the opposite cortex.

compression to the cortex opposite the plate (**Fig. F2L**). This technique can only be used when cortex contact is made between the fragment ends on the side opposite the plate. Insertion of all plate screws results in compression of the entire bone circumference (**Fig. F2M**). **If a defect were present, plate prebending would cause malalignment.** A lag screw can be applied across the fracture to augment the prebending technique (**Fig. F2N**). This is even possible in the fractures of very large bones as seen in the horse. Combining prebending the plate with lag screw compression will provide the best conditions for stability at the fracture site, regardless of subsequent loading characteristics.

2.5.2 Plate luting

The concept of placing a plate on the bone is similar to that of using a lag screw to attach two bone fragments. The plate is lagged to the bone just as two bone fragments are lagged to each other. Friction prevents the bone and plate from moving in relation to each other [5]. The screws are used to create a frictional force which amounts to 37% of the axial force generated by the screw/plate combination. It follows that a greater number of screws will provide a greater bone/plate frictional force. This in turn will allow larger weight bearing loads before shifting

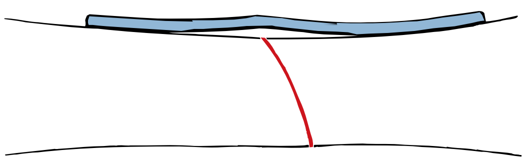


Fig. F2K: After contouring, a small "kink" or "tent" is put in the plate at the fracture site. It should separate the plate from the bone surface by ± 2 mm.

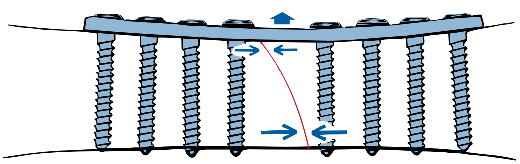


Fig. F2M: Insertion of all plate screws results in compression of the entire bone circumference.

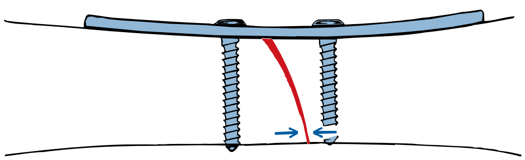


Fig. F2L: As the screws are tightened the plate is elastically straightened. As it tries to return to its prebent shape, it exerts compressive forces upon the fracture in the trans cortex.

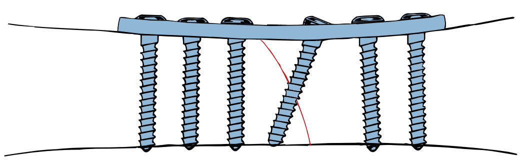


Fig. F2N: A lag screw can be combined with prebending the plate to maximize compression and stability.

between the bone and the plate occurs. Since **screws are strongest in tension and weak in bending and shear** it is important to optimize bone/plate friction to minimize these damaging loading patterns. Contouring of the plate is a key factor in increasing bone/plate contact but the radius of curvature of the plate may still differ considerably from that of the bone to which it is to be secured.

This mismatch may result in a single line of contact between the bone and plate in the longitudinal plane or point contact in the transverse plane. The inappropriate contouring of the plate in the longitudinal plane may be further complicated by the spiraling and uneven nature of the bone.

Plate luting describes a technique that serves to optimize contact between bone and plate [6]. Polymethylmethacrylate (PMMA) is used as the interface between the bone and plate and between the screw heads and plate. The material acts to improve the contact area between bone and plate as well as between the screw head and the plate. This decreases the bending and shearing effects of weight bearing on the screw heads that occupy the oval holes of the DCP. *In vitro* mechanical tests showed that the cyclic fatigue life of bone-plate composites exposed to bending forces increased three to twelve-fold when plate luting was used. *In vivo* experiments and clinical experience have confirmed this advantage.

Plate luting begins with the completion of a normal internal fixation (see above). The screws are loosened to produce a ± 2 mm gap under the plate. When two plates are used, each is luted separately while the other provides stability. Surgical grade PMMA is mixed into a dough-like consistency and the material is pressed under the plate with the fingers. The screws are retightened and excess PMMA is removed as it is extruded from under the plate and around the screw holes. It is important that no PMMA penetrates between the fragment ends since this would inhibit healing.

Screws are strongest in tension and weak in bending and shear.

2.6 Cancellous bone grafting

The use of a bone graft will be discussed here only in its relation to the mechanics of plate fixation. The use of axial compression in fracture fixation is only helpful if there is intact bone stock that will result in a stable situation under pressure. Many equine fractures are comminuted with oblique cracks and unstable segments. Where possible, interfragmentary compression using screws incorporated into the plate fixation will be helpful. There are times, however, when the fragments are too small to be stabilized and may have lost their blood supply. In these cases a gap is produced that can lead to stress concentration in the plate. Paradoxically, small gaps are potentially more devastating than large ones since they will cause greater concentrations of stress in the plate. Most surgeons will not hesitate to use a bone graft if there is a large defect, but many will neglect its use for ostensibly insignificant cracks or gaps. **A bone graft will act as a portable callus or bridge, and the structural strength of the graft can be expected to increase rapidly after the first 10 days**. Often the mechanical advantage contributed by a bone graft makes the difference between healing the fracture and premature breakage of the implants. If the need for a bone graft is ever questioned, the answer is… …use one!

Plate luting optimizes the contact between the bone and the elements of the fixation.

Bone grafts contribute to structural strength after 10 days.

2.7 Cerclage wire

Wire fixation is used in both cerclage and tension band modes. Tension band wiring is perhaps best illustrated by the repair of olecranon fractures in young animals (**chapter 16**, Ulna (olecranon): tension band wiring). It can be accomplished with wire alone or with wires and pins to limit rotation. When pins are used they should be placed in pairs to prevent rotation. The wire should encircle both pins and should be tightened on both sides of the fixation. Single pins or screws should not be used. Screws may prevent the wire from compressing the fractured fragments and will often bend or break at the thread junction nearest the fracture site. Cerclage wires can be combined with tension band wires, or be used by themselves as in sesamoid fractures (**chapter 9**, Proximal sesamoids: tension band wiring). Wires and screws can be used successfully to retard growth across a physis and are often used in this way to correct angular limb deformities (**chapter 25**, Carpal and tarsal deviations).

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3 Pre- and postoperative considerations

Gustave E. Fackelman

3.1 The day before surgery

The patient should arrive safely at your facility having been given appropriate first aid and having been carefully transported, the details of which are described elsewhere [1]. The following discussion is intended as a checklist of activities to promote ideal operative conditions and enhance the probability of a satisfactory outcome.

Completeness of biographical data should be carefully checked. The patient's name, age, breed, previous surgical/anesthetic history, known drug sensitivities, the dates of injury and of arrival, along with the owners name, address and telephone number would be the minimum. Gathering this data, as well as recording much of which is described below can be facilitated by the use of an appropriate computerized format such as the **AO Equine Fracture Documentation System** [2].

The **owner should be made aware of the alternatives to surgery**, the risks involved in any operative procedure, and any dangers that are specific to the intended surgery in this particular horse. A clear description of these risks should be part of a written document that details the operation and the recommended aftercare. This document is **countersigned by the owner** as having been read and understood. On the same page, the owner is provided with an enumeration of the costs involved and an estimated value of the animal concerned. (This latter value may be left to the owner to fill in.) This information is important to patient care and client relations and also touches upon the medicolegal aspects of patient care, described at length in a recent text [3].

A complete physical examination and hemogram are performed. While focused on the musculoskeletal system, including potentially predisposing conformational defects, care is taken to evaluate the animal as a whole. **Assessment of lameness and any associated lesions should follow a systematic approach** [4] with which the clinician has become comfortable. In the so-called exercise induced fractures [5], particular attention is paid to the possibility of the lesions being bilateral. The pain on one side is usually greater than on the other, and masks the existence of the second fracture. The findings of the examination are carefully documented, and communicated to the owner and any interested colleagues in practice. The initial (referral) set of radiographs is reviewed and augmented when necessary with additional views. From these films, a preoperative plan is diagrammed indicating the location and size of the implants to be used in the surgical repair

Perform a complete physical examination including a hemogram.

Assess lameness and associated lesions. (See Movie: Evaluation of the Equine Musculoskeletal System).

Start gathering data by using the AO Equine Fracture Documentation System.

Make the owner aware of the alternatives to surgery and have your description countersigned.

(**Fig. S3A**). This plan is initially used to serve as a check on the availability of implants in the size(s) indicated, and the appropriate instrumentation for their insertion, and later to guide the surgeon during the actual operation. Recently a Large Animal Preoperative Planner has been introduced.

Withhold food for 12 hours prior to anesthesia.

The area surrounding the surgical site is clipped with a fine blade (#40). For fractures of the limbs distal to the carpus or the hock, this is carried out circumferentially to facilitate draping in a subsequent step. The entire animal is bathed to remove dirt, sweat, and detritus from its body and limbs (**Fig. S3B**), and the operative site is scrubbed with a soap containing tamed iodine. A sterile dressing is used to cover the site, and this is held in place with a light bandage (**Fig. S3C**).

Use antibiotics from the day before through the day after surgery.

Perioperative **antibiosis** is warranted even in elective surgeries [6]. When truly prophylactic, it is brief in duration, extending roughly **from the day before surgery to the day after** [7]. The nature of this therapy will be dictated by the condition of the surgical site [8], concerns about anesthetic interactions [9], the presence of infection at a distant locus [10], the identification of nosocomial organisms, or certain details of the procedure itself [11]. As a rule, the treatment is timed so that an effective level of drug is present at the time of surgery. Broad-spectrum antibiosis consisting, for instance, of a penicillin and an aminoglycoside is applied.

In consultation with other members of the staff, the time of surgery is decided upon, assuring the presence of all necessary equipment and personnel throughout induction, surgery, and recovery phases. **Food is withheld for 12 hours prior to the induction of anesthesia**.

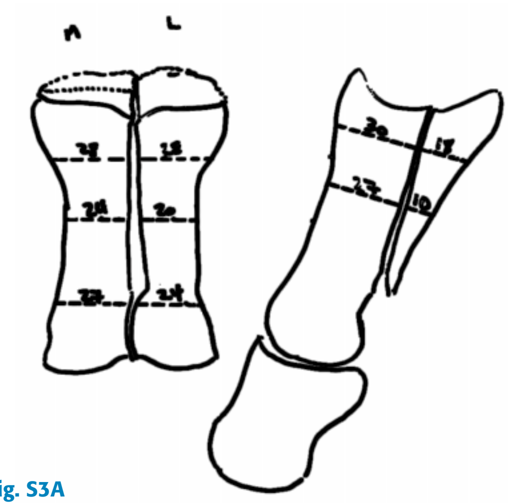

Fig. S3A

Fig. S3B

Fig. S3C

3.2 The day of surgery

A final check is carried out on the readiness of the surgical suite, the instrumentation, the personnel, and the anesthesia/recovery equipment. The patient is examined, and its vital signs are measured and recorded. Any significant changes since the initial evaluation are documented and communicated to the owners and/or their representative(s). **The horse is positioned to allow easy access of the surgical team to the fracture site and to facilitate intraoperative radiographs** (**Fig. S3D**). Final preparation of the patient, the surgical site (**Fig. S3E**), and the surgeon are described in detail elsewhere [**12**], and the salient points are covered below. Any points on preparation related to specific procedures are detailed in the chapters devoted to them.

Ideally the correctly positioned, adjusted, and carefully draped x-ray machine (**Fig. S3F**) will need only to be wheeled up to the table to make the exposures required (**Fig. S3G**). The films in their holders are also covered with

Fig. S3E

Position the horse for 360º access to the surgical site.

Fig. S3F

Fig. S3D

Fig. S3G

Fig. S3H

Fig. S3I

sterile drapes prior to their being extended into the field. If facilities permit, image intensification offers the advantage of being much quicker, but similar precautions must be taken against contamination. Many ready-made sterile plastic covers are obtainable in sizes that fit most of the common pieces of equipment. Any staff that remain in the room during the radiographic examination (e.g., surgeon, anesthetist) are suitably attired in lead aprons (**Fig. S3H**) worn throughout the procedure underneath their gowns (**Fig. S3I**).

Fig. S3J

Suction drains are inserted immediately postoperatively.

At the conclusion of surgery, a suction drain is usually inserted in those cases having a significant amount of soft tissue trauma and "dead space" that could potentially develop into a seroma. Bandaging, splinting, and casting will vary depending on the surgeon's preferences and the lesion(s) in question (**Fig. S3J**). This topic will be treated in detail in the chapters dealing with specific fractures.

3.3 The day after surgery

Typically, perioperative prophylactic antibiotics are administered throughout the 24-hour post-surgical period, then discontinued. The horse's vital signs are monitored twice daily and recorded in the case record.

A report of the surgical procedure is generated and sent to the client, the referring veterinarian, and any other interested parties. The report should deal with any changes in diagnosis or prognosis made at the operating table and should detail the responsibilities of the animal's caretakers in the long and short terms postoperatively. In a practice or clinic with a heavy orthopedic load, it is probably best to develop certain standard aftercare programs that can be tailored to fit individual circumstances.

Physical therapy [13] **and controlled exercise** should begin **as early as possible** during the recovery phase and continue at home. This commitment to the animal's final well-being is extremely important to the successful outcome of any given surgical procedure. Many surgeries of the distal limb such as those considered later in this manual require little or no protection by external fixation in the post-operative period. This allows for early joint and tendon mobilization, and prevents the capsular fibrosis and stiffness that are otherwise almost inevitable. The use of non-steroidal anti-inflammatory agents in the early postoperative phase permits passive joint manipulation by limiting the development of capsular and subcutaneous edema. Movement reduces the formation of adhesions, improves the nutrition of articular tissues, and aborts progression of degenerative changes [14].

Plans for follow-up radiography are made and the dates calculated based upon the date of surgery. Computer programs with "datebook alarms" can be helpful in reminding the surgeon of these dates. The follow-up information is essential to an adequate documentation of results, and to developing improvements and modifications of technique for the future.

Generate the surgical report immediately postoperatively.

3.4 Summary—Checklist

Day before...

- Completeness of medical record concerning biographical data and medical history checked.
- Owner made aware of alternatives and risks.
- Complete physical examination performed.
- Preoperative plan developed, indicating needs for implants and instrumentation.
- Patient bathed; operative site clipped, scrubbed, and protected with a sterile wrap.
- Antibiotic therapy instituted.
- Food withheld 12 hours preoperatively.

Begin physical therapy and controlled exercise as early as possible.

Day of...

- Final check of patient, personnel, and equipment.
- Positioning of patient determined based upon accessibility and ease of intra-operative radiographic monitoring.
- Appropriate drainage of the surgical site provided (if necessary).

Day after...

- Surgical report generated and distributed.
- Physical therapy instituted, its continuance described in writing, and discussed with owner/trainer.
- Dates set for follow-up radiographs and examinations.

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4 Mandible, maxilla and skull

Jörg A. Auer

4.1 Mandible and maxilla fractures

Mandible fractures occur more frequently than maxilla fractures. More often only one ramus of the mandible is affected. In foals, the incisors are commonly involved. **If the germinal buds were not badly damaged, maturation will be normal.**

4.1.1 Etiology

In most cases, fracture follows catching of the teeth in a mesh wire (**Fig. F4A**) [1]. Occasionally, kicking injuries occur (**Fig. F4B**) or the animal may injure that part of the face falling or running into an immovable obstacle (**Fig. F4C**). Pathologic fractures may be seen in progressive severe dental disease with chronic infection and osteolysis. On other occasions, tumors render the mandible fragile, predisposing it to fracture.

Maturation of incisors will be normal if the germinal buds have not been damaged.

Fig. F4B: Kicking injuries of the jaw may lead to mandible and maxilla fractures.

Fig. F4A: Fractures of the incisor region most frequently occur when the teeth are caught in a mesh wire fence during playing. Sudden pulling back results in a fracture.

Fig. F4C: Jaw fractures may also occur when a horse runs into an object.

4.1.2 Diagnosis

In many cases, inanition is the first hint of fracture (**Fig. S4A**). Excessive salivation is common, possibly associated with asymmetry of the face, and open wounds [2]. Radiographs provide a definitive diagnosis (**Fig. X4A**). Multiple projections are recommended [3]. For rostral fractures of the mandible V-D intraoral radiographs are indicated. These are best carried out under anesthesia or heavy sedation. **Mandibular and maxillary fractures have always to be looked upon as open fractures, since gingival bacteria quickly invade the bone.**

Mandibular and maxiallary fractures are open fractures.

Fig. S4A: Fracture of the incisor region in a 7-year-old Arabian stallion. The rostral fragment could easily be displaced through finger pressure.

4.1.3 Preoperative management

Carry out a detailed examination of the entire animal, with special emphasis on the injured region, prior to surgery. Pay special attention to metabolic disorders such as dehydration, acid base derangements, and nutritional status. The animal may not have eaten for a considerable time. Plan the surgical procedure carefully, and cleanse the mouth thoroughly before intubation. Do not remove any loose teeth prior to fracture repair because the teeth brace each other and can thereby confer stability. If necessary, the loose teeth can be removed at a later stage or at the time of implant removal. Often, such removal proves unnecessary.

Fig. X4A: Intraoral radiographic view of a rostral mandible fracture. Several incisor tooth roots are fractured. Some displacement is visible.

4.1.4 Management options

Selected fractures of a single mandibular ramus may sometimes be treated conservatively. Surgical options will vary with the configuration of the fracture. Following repair, the incisors can be rasped down to prevent contact with the opposing arcade, protecting the repair from strain for several weeks.

Fig. S4B: With the help of a 2 mm drill bit a hole is drilled between the incisor teeth to facilitate placement of the wires.

4.1.5 Surgical procedures

A distinction is made between intraoral and extraoral fixation techniques. In some instances, combined modalities are used.

4.1.5.1 Intraoral fixation techniques

Cerclage wires

Cerclage wires are the most frequently applied fixation devices for dental fractures in the rostral mandible and maxilla [2]. They are very versatile and may also be used in conjunction with other implants. Furthermore, they are quite economic.

These devices are mainly used to fix fractures in the rostral half of the mandible. Several wiring techniques are described in the literature and their selection depends on the preferences of the surgeon [1, 2].

Pass the wire between the teeth from inside to outside. If this proves difficult or impossible, drill holes of 2 mm diameter between the teeth at strategic locations facilitate passage (**Fig. S4B**). A large needle may be sufficient in younger foals [2] (**Fig. F4D**).

The following techniques are available: wiring of the teeth in a figure-8 fashion from left to right, or including at least two teeth on either

Fig. F4D: Cerclage wiring of a fracture of J2 and J3. A 14-gauge needle is inserted between the teeth and a 1.25 mm stainless steel wire threaded into the needle cannula as it is withdrawn.

Cerclage wiring is the most frequently employed technique in the repair of rostral fractures.

Wire loops may be applied in a variety of ways.

side of the fracture [1]. **Application of overlapping wire loops [2] allows individual tightening of the loops** (Fig. F4E) and results in greater stability than with the sinsuoid wire loop technique mentioned above. The Obgeweser technique [1] involves extruding wire loops from the inside to the outside between each of the teeth (Fig. F4F, Fig. S4C). The wire loops may be prepared with special bending pliers. Feed one end of the wire through each wire loop in front of the teeth and unite it with the other end (Fig. S4D). Then tighten each loop by twisting it with a pair of pliers (Fig. S4E). This type of fixation is extremely stable and may be left in place for several months (Fig. X4B).

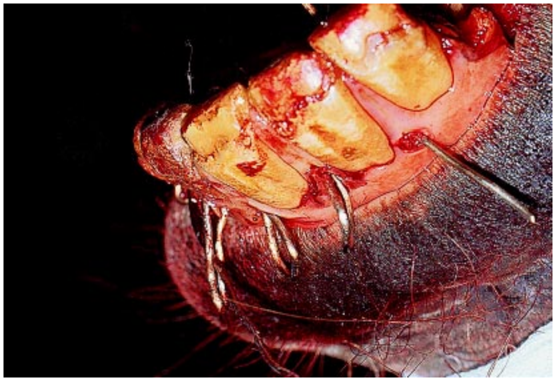


Fig. S4C: Wire loops are exited from the lingual side between the incisor teeth.

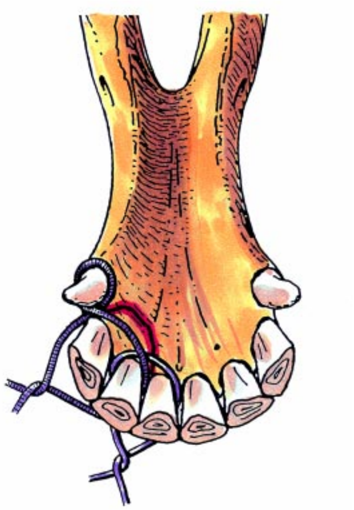


Fig. F4E: The fracture is treated with two cerclage wire loops; one around J1 and J2 and the other in figure-8 fashion around J2 and the adjacent healthy canine tooth.

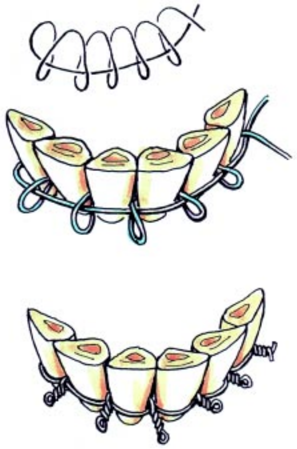


Fig. F4F: An alternative method involves exiting wire loops from the lingual side to the labial side, followed by feeding of one end of the wire through each loop. After uniting and tightening the two wire ends, each wire loop is tightened as well, resulting in the most stable of all wire fixations. The twisted ends are directed toward the gingivae.

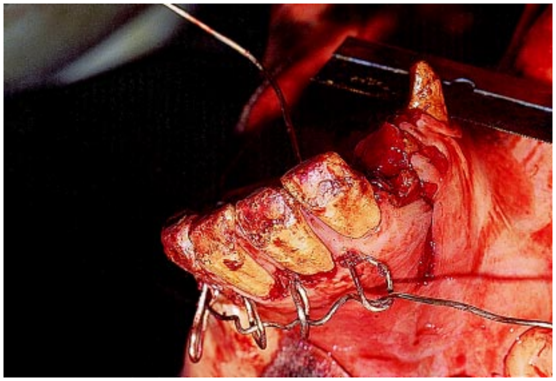


Fig. S4D: One end of the wire is fed through each of the loops in front of the incisor teeth.

Fig. S4E: The wire ends are united and tightened securely. Then each of the wire loops is tightened individually, resulting in superior stability of the fixation.

When the rostral part of the incisors or the diastema is fractured, some type of fixation placed further caudally is indicated. Include the canine teeth in male horses (**Fig. F4G**) or one or two of the premolar teeth. In the latter case, feed the wire around P2 after prior drilling of a 2.5 mm hole between P2 and P3 (**Fig. F4H**) and unite the ends of the wire further rostrally [**1**, **2**].

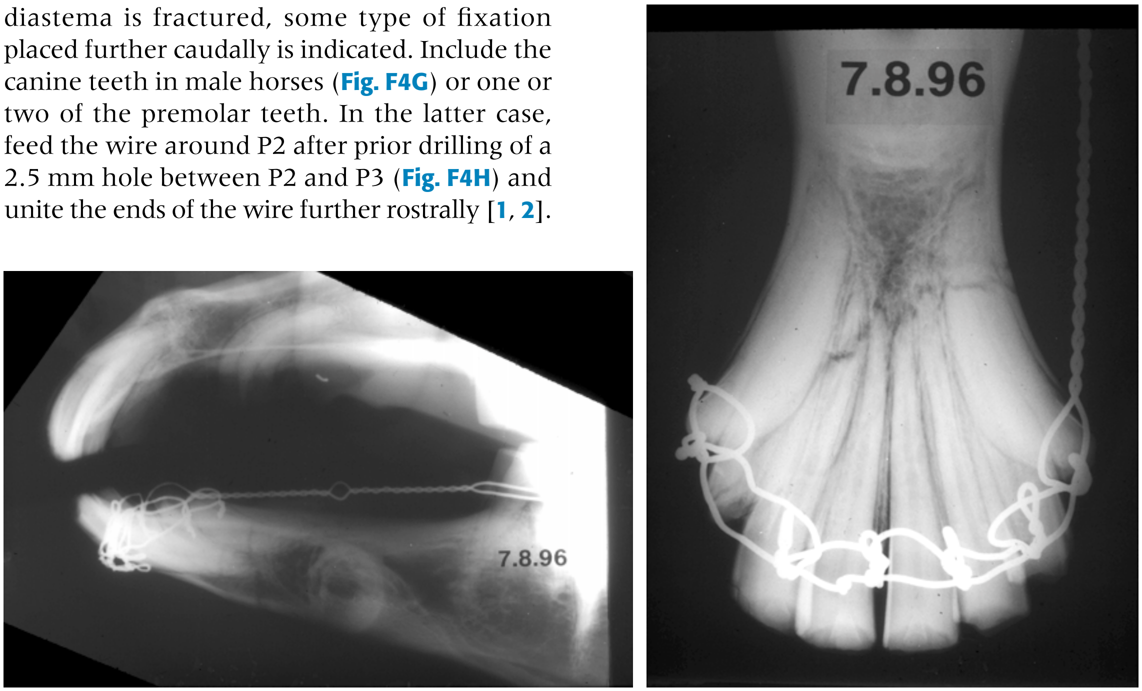


Fig. X4B: The fracture shown in **Fig. S4A** and **Fig. X4A** was reduced and repaired with the Obwegeser technique. Note, a wire loop was placed around each tooth and tightened. The fixation remained in place for 6 months. No teeth had to be removed.

Drill holes in the bone of the diastema to allow cerclage fixation of fractures without encircling the teeth.

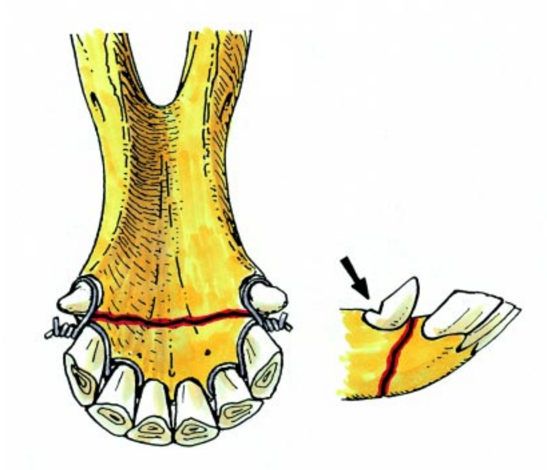


Fig. F4G: Tension band wiring of a fracture to the canine teeth. Note, an indentation (arrow) was created with a rasp in the nuchal aspect of the canine teeth to anchor the wire.

Tighten the fixation by twisting the long wire loop at the diastema with one end of a Steinmann pin (**Fig. X4B**).

Drilling small holes into the diastema on either side of the fracture allows application of wire in a figure-8 fashion through the holes [2] (**Fig. F4I**). In selected cases, cerclage wires may be applied around the ramus and an oblique fracture (**Fig. X4C**, **Fig. X4D**). Apply a tension band involving the incisor and premolar teeth to increase stability.

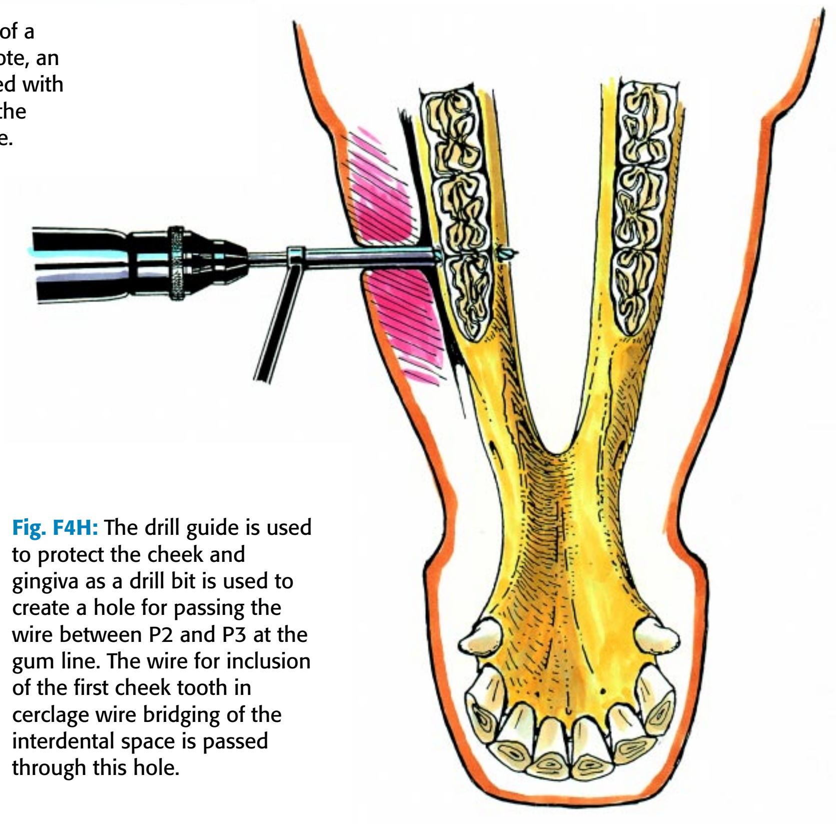


Fig. F4H: The drill guide is used to protect the cheek and gingiva as a drill bit is used to create a hole for passing the wire between P2 and P3 at the gum line. The wire for inclusion of the first cheek tooth in cerclage wire bridging of the interdental space is passed through this hole.

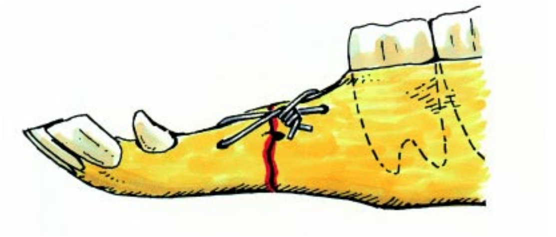


Fig. F4I: Figure-8 wiring of a transverse fracture of the interdental space. The holes are created with a 2.5 mm drill bit or a Steinmann pin.

Fig. X4C: Long oblique fracture through the diastema of one ramus of a Shetland pony.

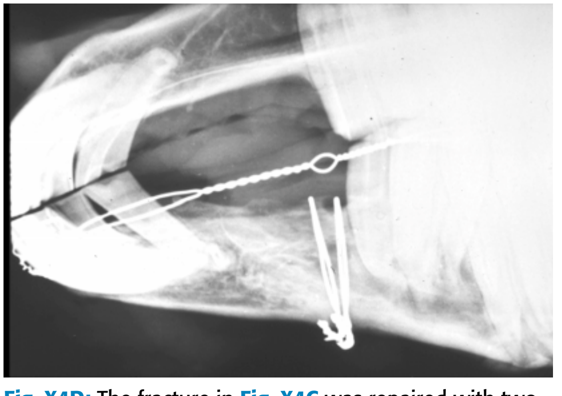


Fig. X4D: The fracture in **Fig. X4C** was repaired with two cerclage wires supported by a tension band wire fixation between the incisor and premolar teeth. The picture was taken 4 months after the surgery at the time of implant removal, which was necessary because of a persistent draining tract.

The advantages of wire are that it is easy to use, versatile, and inexpensive, and it confers a secure fixation. Disadvantages include loosening of the fixation and, in certain instances of molar fractures, exposure. **Application may involve several stab incisions through the cheek, with its abundant neurovascular network.**

Application of cerclage wires to the molar arcades is facilitated by stab incisions through the cheek.

Steinmann pins

Steinmann pins are rarely employed as a sole mode of fixation, except possibly in young foals [1]. They can be used in fractures of the diastema (**Fig. X4E**), but trauma to the tooth buds may present a problem. In most cases, this fixation is not stable. In suckling foals, the fixation may be adequate but may traumatize the udder of the dam.

Fig. X4E: A bilateral mandible fracture in a 3-week-old foal was repaired with a Steinmann pin along each horizontal ramus.

Place a screw transversly into the diastema to provide anchorage for wire fixation.

Screws

Screws may be used in fractures of the symphysis or in oblique fractures where good interfragmentary compression may be achieved through cortex screws applied in lag fashion [4, 5] (Fig. F4J). **Screws may also be used to anchor cerclage wires in the region of the diastema** [1] (Fig. X4F).

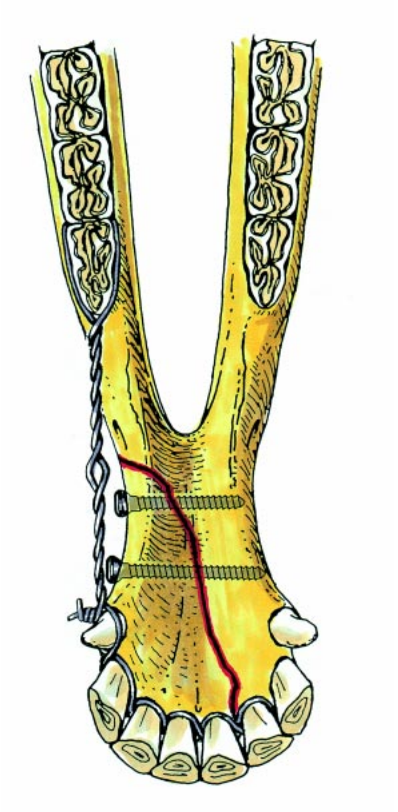


Fig. F4J: Lag screw repair of a unilateral fracture of the mandible containing a large osseous fragment. The fixation is protected with tension band wiring of the incisors to P2.

Fig. X4F: A rostral mandible fracture was repaired with cerclage wires anchored to two cortex screws placed into the diastema.

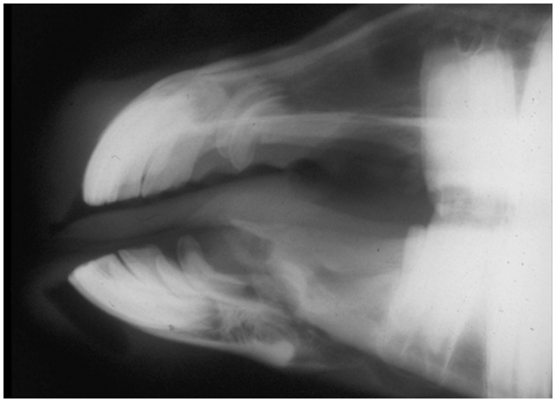


Fig. X4G: Laterolateral radiographic view of an unstable mandible fracture in a 1-month-old foal.

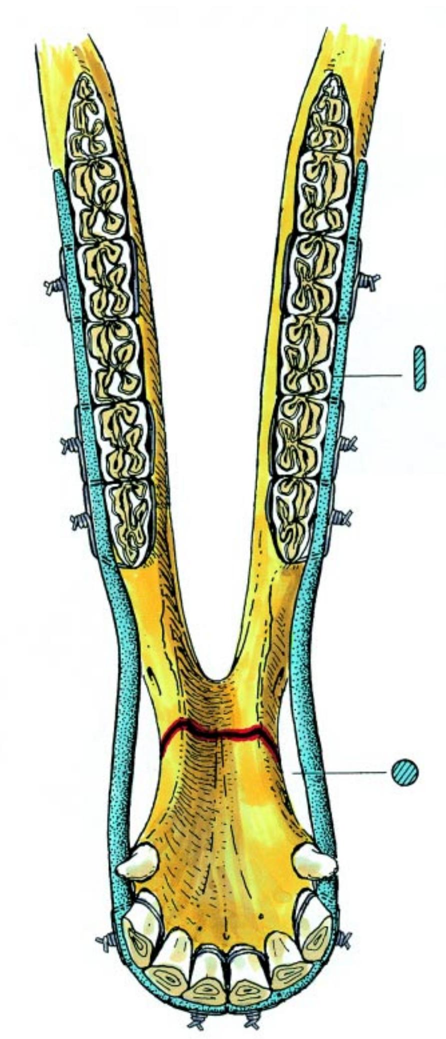


Fig. F4K: Intraoral splint made from aluminum bar and molded around the contours of the mandible. The bar has a round cross-section in front and a flattened cross-section on either side. The aluminum bar is attached to selected teeth with cerclage wires.

The U-bar

An aluminum U-bar, rounded rostrally, and flattened toward the premolars and molars can be used in very unstable fractures of both rami of the mandible [6] (**Fig. X4G**). It should be fixed with wire loops around the incisors and, further caudally, around the premolar and/or molar teeth on both sides of the cheek (**Fig. F4K**). Position the animal in dorsal recumbency to allow simultaneous access to both sides of the jaw. U-bars can be cumbersome, requiring several incisions to secure them to the molar arcades [6] (**Fig. S4F**). To add stability, dental acrylic may be applied as described below.

Fig. S4F: An aluminum bar was applied to a very unstable bilateral fracture of the mandible shown in **Fig. X4G**. The U-bar is attached to the mandible with wires. (Photo courtesy JP Watkins, Texas A&M University.)

Enhance stability by the application of dental acrylic.

Typically, plates must be placed in a less than ideal location, in terms of biomechanics.

Dental acrylic

Dental acrylic may be applied intraorally to serve as a buttress and enhance stability [7, 8]. In its softened state, the acrylic is molded to the contours of the mandible or maxilla. It is important to select an acrylic that does not produce an exothermic reaction during the hardening process. Such a reaction can be harmful to the gingival tissues. In selected cases, wires may be incorporated into the acrylic while it is still soft. When the acrylic hardens, these wires are firmly anchored to the neighboring teeth. This type of fixation has the function of a stent [1, 2, 7, 8] (Fig. F4L).

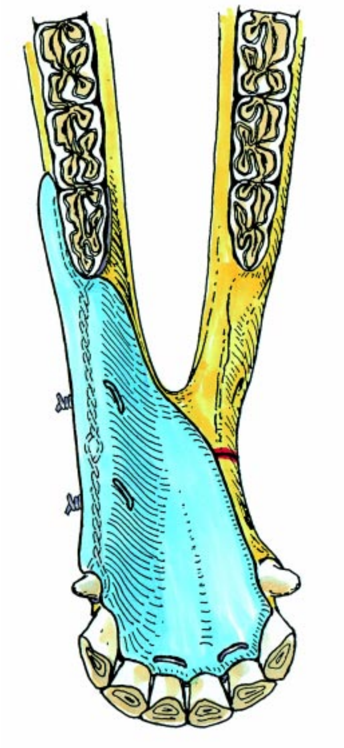


Fig. F4L: Intraoral splinting with dental acrylic (cold curing type) formed around a tension band wire between the incisors and first cheek tooth. Several additional wires are used to unite the splint with the mandible.

Plates

Plates may be applied directly to the bone, or attached to the teeth. It may be difficult to identify the ideal location for the plate [9, 10] (Fig. F4M). Underlying teeth may cause a problem and may be traumatized. It is also difficult to apply a plate to the tension side because this tension side is, in fact, the occlusal surface. **Therefore, the plate is typically applied in a less than ideal location, in terms of biomechanics**, with resultant reduction in stability (Fig. X4H). Care has to be taken to avoid insertion of screws through tooth roots. Plates can be applied in the rostral mandible and possibly on the caudal rim of the ramus if it is large enough to accept the screws [11] (Fig. F4N).

Only one report exists of plates being applied to the teeth [12]. With a specially hardened drill bit holes are prepared in the teeth, and short screws are employed to attach the plate. About four to five screws are necessary (Fig. F4O).

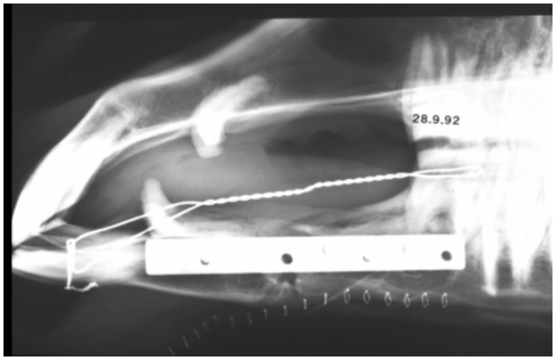


Fig. X4H: A rostral mandible fracture was repaired with special plate (PC-Fix) and short screws. The repair was supported with a tension band wire between the incisor and premolar teeth.

Avoid insertion of a screw through a root canal whenever possible. The benefit of this technique is that the plate is applied in a more rostral position of the mandible and closer to the tension side of the bone. After the fracture has healed, remove the screws and fill the holes in the teeth with dental acrylic.

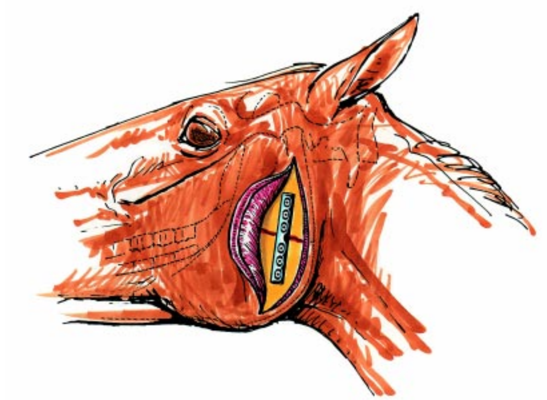


Fig. F4N: Surgical approach for plate application to the vertical ramus of the mandible via a subperiosteal elevation of the masseter muscle.

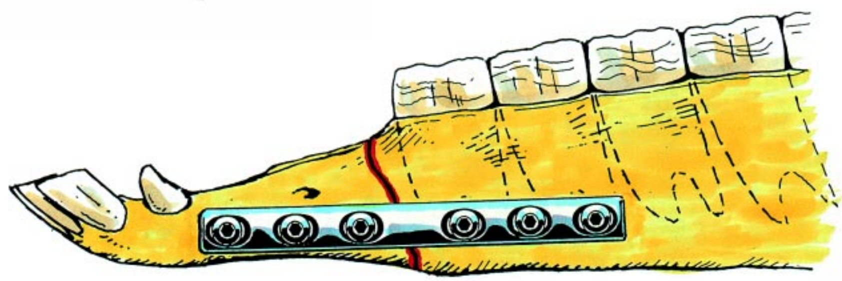


Fig. F4M: A 6-hole 4.5 mm narrow DCP is applied to the horizontal ramus of the mandible. The screws are inserted between the tooth roots.

Use a type II external fixator for mandibular fractures.

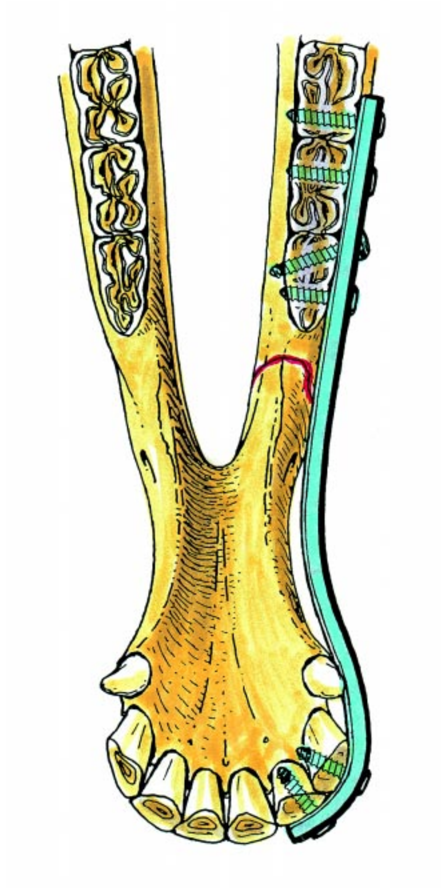


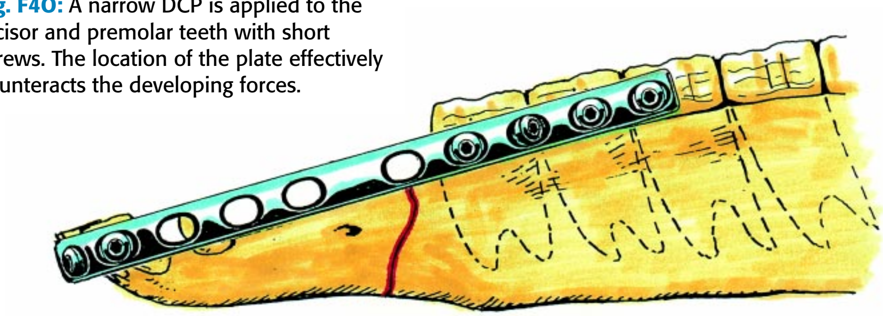
Fig. F4O: A narrow DCP is applied to the incisor and premolar teeth with short screws. The location of the plate effectively counteracts the developing forces.

4.1.5.2 Extraoral fixation techniques

Among these techniques external fixators are distinguished from the pinless external fixator.

External fixator

An external fixator type I consists of one longitudinal bar and four to five Schanz screws or intramedullary screws, being inserted into one ramus of the mandible or maxilla [1, 2, 4] (Fig. S4G). **A type II configuration consists of Steinmann pins through and through, involving both rami of the mandible or maxilla and bilateral longitudinal fixation bars**. In external fixators mainly Steinmann pins and occasionally Schanz screws are inserted on either side of the fracture and connected to clamps and tubes, cerclage wires, and dental acrylic [1, 2, 4]. Plastic tubes filled with acrylic represent another option (Fig. F4P). With the external fixator, interfragmentary compression of the fracture can be achieved. The integrity of the tooth roots should be preserved. Place the Steinmann pins in such a way as to prevent excessive trauma to the tongue. In the rostral aspect of the mandible, use Steinmann pins with positive threads [2]. Prevent untimely removal of the fixation device by the animal by housing it in a hazard-free environment. If



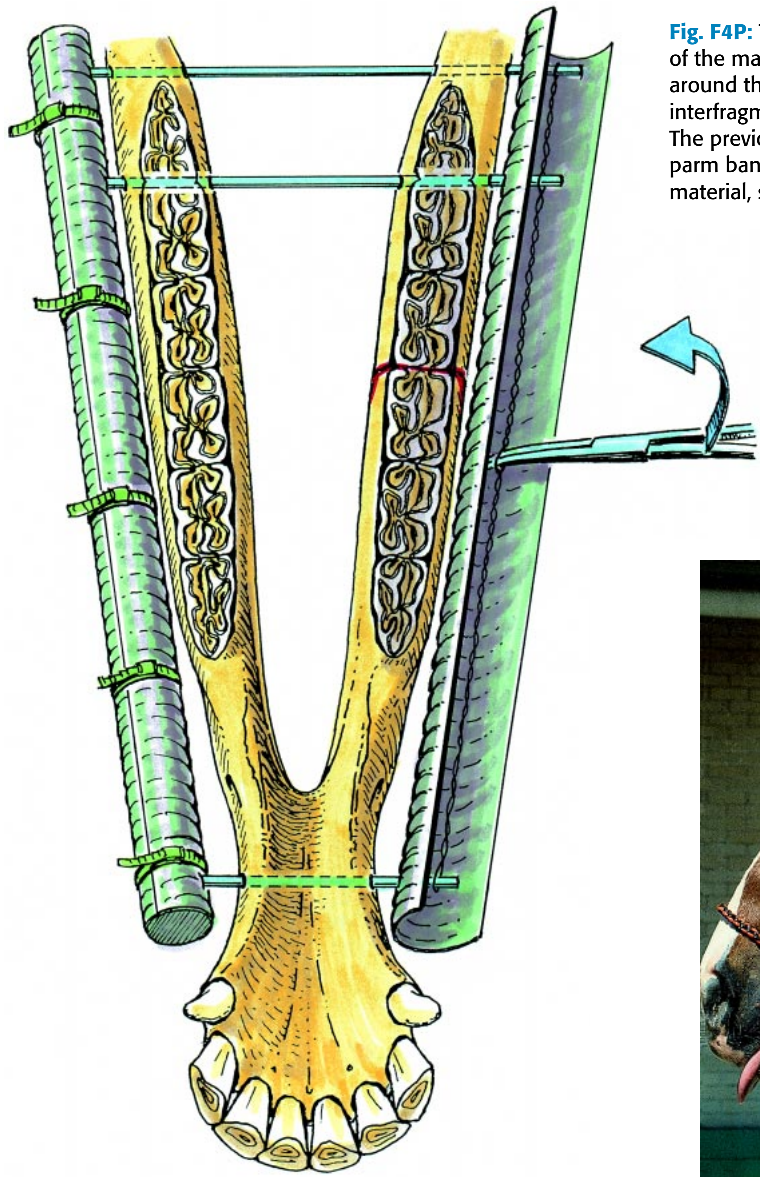


Fig. F4P: Type II external fixator across both rami of the mandible. A tension band wire is applied around the pins and tightened to achieve interfragmentary compression of the fracture. The previously open soft tubes are closed with parm bands and the lumen filled with epoxy material, such as PMMA, hoof acrylic, etc.

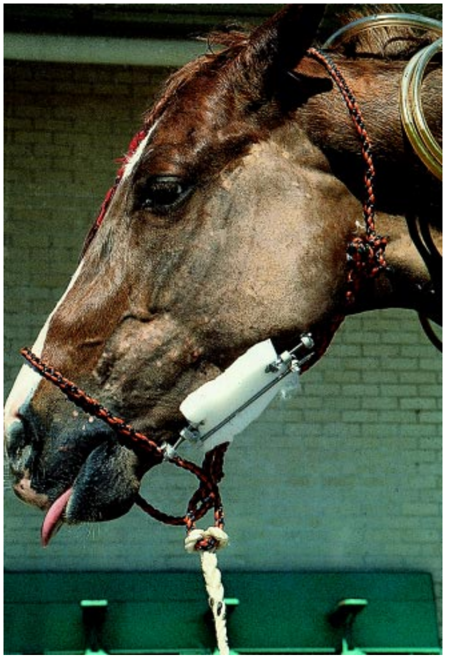


Fig. S4G: A type I external fixator is applied to a mandible fracture in a 2-year-old Quarter Horse stallion.

applied properly, good stability may be achieved across the fracture site. It may be necessary to use an alternative feeding technique, such as liquid diet or nasogastric tube feeding. Esophagostomy is also an option, but it is associated with a high complication rate.

Pinless external fixator

The pinless external fixator presents an alternative technique [13]. Several sizes of titanium clamps are currently available. An asymmetric clamp (Fig. S4H) complements the large and small symmetric clamps. The symmetric clamps are applied across the rostral mandible in the region of the diastema, while the asymmetric clamps are applied to a ramus on both sides of the fracture. **A minimum of four clamps should be applied and connected to the longitudinal rod** (Fig. F4Q). Application involves only minimal trauma, since only small incisions are needed and no transosseous pins

Use at least four clamps—two on either side of the fracture.

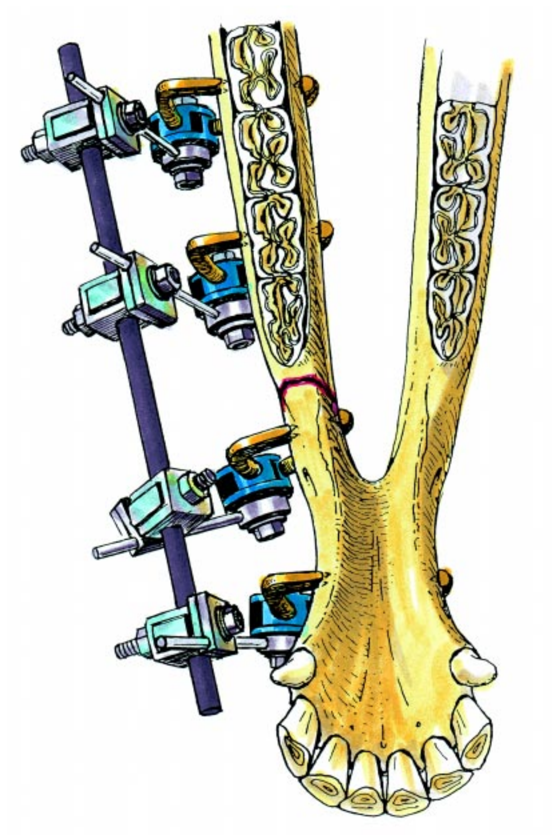


Fig. S4H: Configuration of the three clamp types of the pinless external fixator. The large and small symmetric clamps are complemented by the asymmetric small clamp. The latter fits ideally around the ramus with the straight arm placed medial of the ramus.

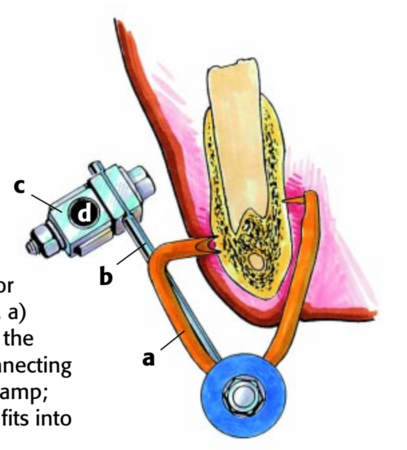


Fig. F4Q: Pinless external fixator applied to a mandible fracture. a) Asymmetric clamp attached to the ramus; b) small adjustable connecting bar; c) single external fixator clamp; d) tubular connecting rod that fits into the clamp (c).

are inserted. The clamping force of the fixators persists over a long period, making the devices an attractive alternative. The device can be reused several times. Results so far are excellent, especially in bovine patients [13]. The fact that these animals ruminate should be taken into account. The associated masticatory action causes frequent and powerful cyclic loading. This fixation device must also be protected against inadvertent removal. Good stability can be achieved, leading to good healing. Sequestra may form and require subsequent removal.

4.1.6 Postoperative management

Monitor the animal and the fixation at least daily during the first 3 postoperative weeks. Delegate the care to the owners as soon as possible, but make them aware of the "danger signs". Clean the mouth daily with water from a hose and take follow-up radiographs at 6 and 12 weeks. Depending on the fixation technique, it may be advisable to maintain the animal in a box stall until the implants can be removed.

4.1.7 Complications

Infection is the major complication encountered. This becomes especially problematic if instability is present. This instability is occasioned by use, or by trauma to the device. Bone sequestra are not infrequent because these are open fractures. Some teeth may have to be removed in a second operation. Breakdown of the fixation may be an additional complication.

Infection is especially problematic in the presence of instability.

4.1.8 Prognosis

The prognosis is, in most cases, favorable for healing, mainly because of an abundant blood supply. Fractures rostral to the premolars have an especially good chance of healing. If only one ramus is involved, the chances are even better. Generally speaking, foals have a better prognosis than adults do.

4.2 Skull fractures

The prognosis for skull fractures is dependent upon their location. A fissure fracture of the skull may simply cause minor trauma compared with a displaced depression fracture of the skull into the brain, which may be fatal [14]. Most facial and cranial bones are very flat and are readily rendered bereft of a blood supply, predisposing them to sequestration. In many locations the bones are subtended by a hollow cavity, such as a sinus. The brain is also located beneath portions of the bony shell. Rigid internal fixation may not be a prerequisite to healing. The main task involves the reduction of disfiguring fractures and their maintenance in that location until they have healed.

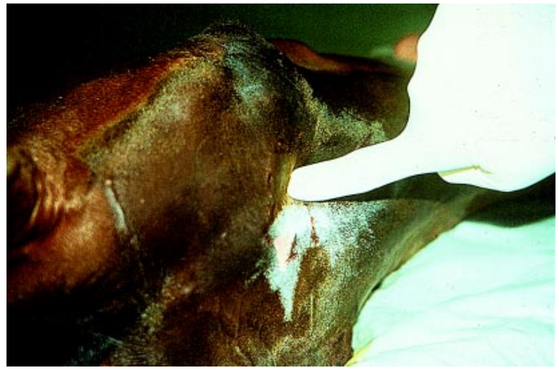


Fig. S4I: Palpation of skull fracture. The index finger demonstrates the instability created by the fracture.

4.2.1 Etiology

Kicks and collisions are the main causes of skull and facial fractures.

4.2.2 Diagnosis

The diagnosis devolves from the anamnesis and observation [14] (Fig. S4I). Assess the extent of the injury by palpation. Some animals may resent this, causing additional, sometimes dangerous, instability. Radiography is indicated but it may be difficult to pinpoint the exact number of injuries and their extent because overlying structures obscure many details [3]. **Computed tomography may be the technique of choice, allowing precise identification of the various fragments.** Ultrasonography may also be helpful.

Employ computed tomography to precisely define the extent of the pathology.

4.2.3 Preoperative management

Assess the injury in detail, and issue a prognosis, giving due consideration to quality of life. This is important in skull fractures with brain injury or permanent disfigurement. Address the metabolic state of the patient. Some animals will require fluids and correction of acid-base imbalance. If the animal is unconscious or ataxic, tranquilizers and agents such as intravenous DMSO are indicated to help prevent additional damage due to edema. Prepare a surgical plan and check the availability of any devices needed for the surgical intervention [1]. Decide on the approach through which correction of the problem will be attempted well ahead of time to allow expedient correction. Evaluate the animal for gait abnormalities and determine whether the problem is improving or worsening or if there is no change.

4.2.4 Surgical procedures

The following surgical procedures are carried out dependent upon the characteristics of the injury. Either an open or a closed reconstruction, possibly with the aid of a Richards bone hook, can be performed [15] (**Fig. F4R**). Depression fractures may have to be elevated. This can be achieved with periosteal elevators and hooks or by preparing a hole in an adjacent bone and then inserting an instrument or bent large-gauge wire through the hole and elevating the depressed fragment from the inside [2, 15] (**Fig. F4S**). Take care to preserve the tenuous blood supply in an effort to avoid sequestration.

In selected cases, closed reduction is performed and the fragment kept in place by interdigitation of its serrated edges. This would seem to be the ideal situation but it is only applicable to fractures around the zygomatic arch [16]. Insert cerclage wires through small holes prepared in the fragments and in adjacent bones to act as wire sutures (**Fig. S4J**, **Fig. S4K**). In cases with large areas of unstable depressed fractures, contour a bone plate and place it over the depressed bones; then apply wire sutures through the plate holes to hold the plate in position. These wire sutures, which are connected to the

Fig. F4R: Use of a bone hook to reduce a depressed zygomatic arch fracture.

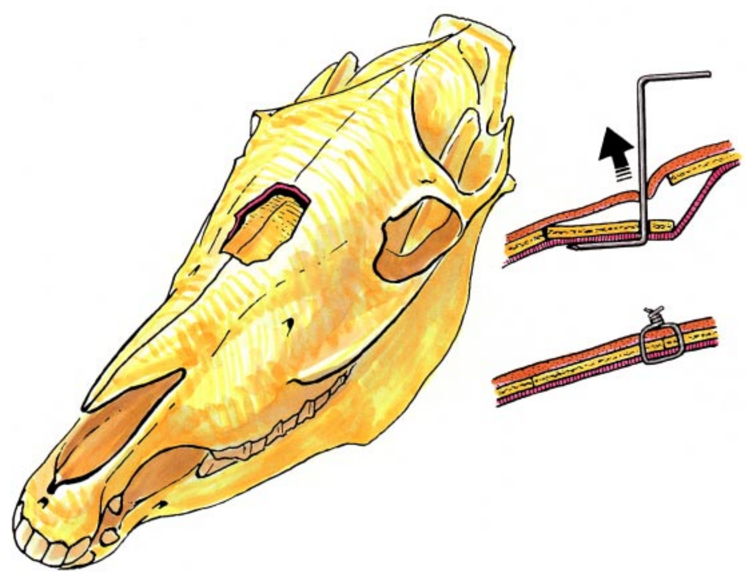


Fig. F4S: Insertion of a Steinmann pin through a small drill hole for elevation of a depressed bone fragment. If necessary the fragment is fixed with cerclage wire.

Use a bone plate as a buttress or bridge, from which fragments may be suspended.

adjacent bones as well as to the fragments (**Fig. F4T**), maintain the normal shape of the skull until healing occurs [1, 17]. The fragments are lifted into their normal positions. **The bone plate serves as a buttress and bridge, allowing suspension of the bone fragments.** If deemed necessary, place a bone graft over the repositioned fragments.

If the defect cannot be corrected by reduction, it can be filled with silicone [18] or fluorocarbon implants [19]. These materials appear to be well tolerated.

Reconstructive procedures are indicated in cases of bone defects. With time, some of the bone may slough and leave wide areas of exposed sinuses. Merely closing the skin over these defects proves inadequate because beneath them lies an air-filled cavity. Typically, the skin becomes desiccated and necrotic (**Fig. S4L**).

Fig. F4T: A reconstruction plate is contoured to the shape of the head over a comminuted fracture of the skull. Through strategically placed wire sutures the underlying bone fragments are stabilized. It is important that the plate is anchored on the healthy bone on either side of the fractures. Once the fractures are healed the implants are removed.

Fig. S4J: A comminuted fracture of the rostral sinus region was approached surgically. Several small fragments were removed because they were totally devoid of blood supply. The larger pieces were reduced and fixed in place with a wire suture.

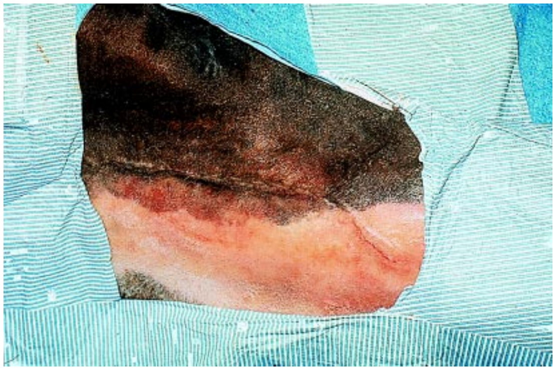


Fig. S4K: Closure was uncomplicated after repair of the fracture.

Two types of reconstructive procedures can be effective: periosteal flaps and muscle flaps. Periosteal flaps are prepared in the area adjacent to the bone defect with their bases at the edge of the bone defect [20]. The flaps are then inverted, drawn over the bone defect, and sutured either to each other or to the periosteum of the opposite side (**Fig. S4M**). Apply a cancellous bone graft over the latter, and suture the skin (**Fig. S4N**). It may be necessary to perform relief incisions and/or transportation flaps to allow adequate coverage of the bone graft [20] (**Fig. S4O**, **Fig. S4P**). The other technique involves selection of a special muscle. It is dissected free from the surrounding tissues and transected at its tendon of insertion [21]. Maintain the base of the muscle, then rotate the muscle flap over the defect and fix it in this position. Then close the skin over the area, possibly with the help of relief incisions.

Repair large defects with inverted periosteal or muscle flaps combined with a cancellous bone graft.

Fig. S4L: A foal with a frontocutaneous fistula adjacent to the right eye.

Fig. S4N: A cancellous bone graft was subsequently applied over the periosteal flap.

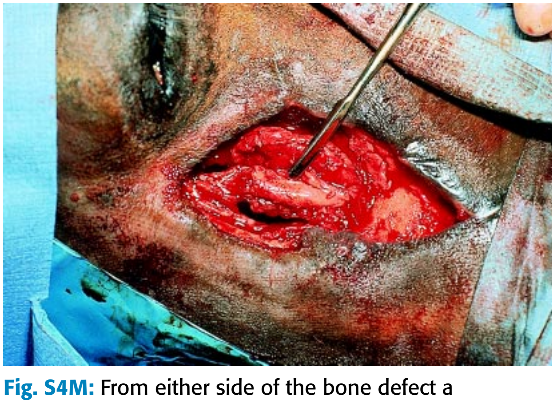


Fig. S4M: From either side of the bone defect a periosteal flap was dissected free and sutured closed over the bone defect.

Fig. S4O: For tensionless closure of the skin defect, a relief incision was necessary.

Prevent trauma to the surgical site during the postoperative period.

4.2.5 Postoperative management

Take every precaution to prevent trauma during the recovery period. The surgical site should be protected by bandaging and/or a padded hood. Prevent subcutaneous accumulation of fluids by the insertion of drains. Anti-inflammatory drugs and antibiotics are mandatory to control inflammation and prevent post-operative infection. Sutures and any tension reduction devices should be removed 2–3 weeks postoperatively.

4.2.6 Complications

Complications include breakdown of the fixation through external trauma or selfmutilation. This may lead to disfigurement; possibly to sloughing of vital tissue. Postoperative infection is the only other important complication and should be prevented if at all possible. Both these complications may dictate further revision. Revision may also be indicated in cases in which per primam fixation was not possible.

Fig. S4P: A good cosmetic result was achieved with this reconstructed approach. An ultrasonographically bony union could be verified 3 months later.

4.3 References

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5 Carpus

Dean W. Richardson

5.1 Description

Slab fractures of the cuboidal bones of the carpus are fairly common injuries in racehorses [1, 2] but very unusual in horses used for other activities. The third carpal bone (C3) is the affected bone in more than 90% of carpal slab fractures, although the radial, intermediate, ulnar, and fourth carpal bones can also be affected. The clinical signs are typically dramatic with obvious joint effusion, pain on carpal flexion, and moderate to severe lameness.

Although it is possible for C3 slab fractures to heal with rest alone, it is advisable to **repair any lesion** that is **radiographically evident on a lateral or DLPMO projection** [3]. Radiolucent lines that are seen solely on the tangential view may involve only the subchondral bone of the proximal joint surface [4] and therefore not require internal fixation. Prognostic considerations include comminution at the joint surface, marginal osteophytes, loose fragments in the palmar-lateral joint space (an indication of comminution), size of the fragment, and degree of displacement.

5.2 Surgical procedure

Arthroscopy during screw fixation enables a more thorough evaluation of the entire articulation [5]. It allows a visual check of accuracy of reduction/fixation while minimizing soft tissue trauma [6]. Arthroscopic technique follows basic principles [7]. The scope is positioned between the extensor carpi radialis and common digital extensor tendons when the fracture is in its typical location in the radial facet (Fig. F5A). If the fracture is in a more frontal plane and

Use the arthroscope to more thoroughly evaluate the joint.

Rule: repair any lesion that is clearly visible radiographically on a lateral or DPLMO projection.

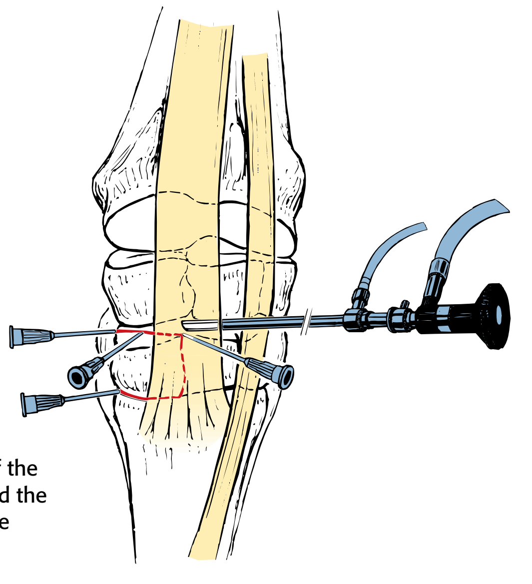


Fig. F5A: An overview of the relationships of the arthroscope to the extensor carpi radialis and the common digital extensor tendons, and of the needles used to mark the C3 fragment.

Do not position the scope too close to the distal row of carpal bones.

Displaced slab fractures: instrument portal on the opposite side of the joint.

Use needles for orientation during drilling.

extends into the intermediate facet, it is important **not to position the scope too close to the distal row of carpal bones**. Otherwise, it may be difficult to see the intermediate facet clearly. If the fracture affects the dorsolateral corner of the intermediate facet, the scope is inserted medial to the extensor carpi redialis.

In **displaced slab fractures**, an **instrument portal** is made on the **opposite side of the joint**. If possible, the instrument portal is made exactly at the margin of the fracture so that a curette can be inserted deeply into the fracture plane for debridement. It is essential to remove all loose fragments to allow accurate reduction.

After debridement (with a displaced fracture) or after examining the joint (with a non-displaced fracture), a 3" (7.5 cm)18 g spinal needle is placed in the joint just above the proximal edge of the center of the slab fragment. If the position is not central, a second needle is inserted in the correct position. **Additional 1" (2.5 cm) 22 g needles are inserted at the medial and lateral margins of the fracture to verify the central positioning of the spinal needle**. After the central needle is positioned correctly, a 22 g needle is inserted into the carpometacarpal joint immediately distal to the first needle (Fig. F5B, Fig. F5C). A #10 scalpel blade is used to make a deep incision reaching the face of C3 after measuring proximally from the carpometacarpal needle. It is usually possible to feel the dorsal ridge in the center of the face of C3 as the overlying soft tissue is incised.

The alignment of the spinal needle is checked arthroscopically. A 3.5 mm hole is drilled through the slab fragment using the spinal needle to

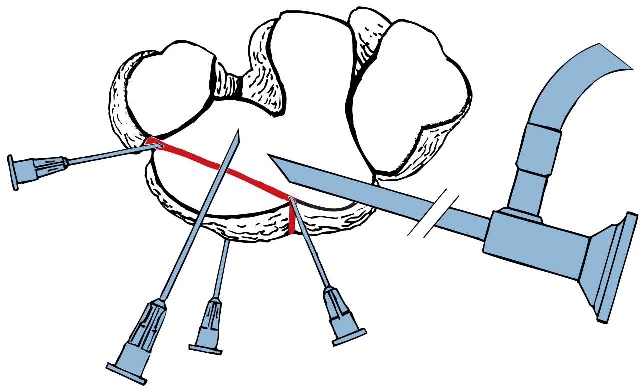


Fig. F5B: The arthroscope is inserted into the midcarpal joint between the extensor carpi radialis and common digital extensor tendons, and directed medially. A spinal needle marks the intended screw direction, while 20 g needles mark the fracture site and the carpometacarpal joint.

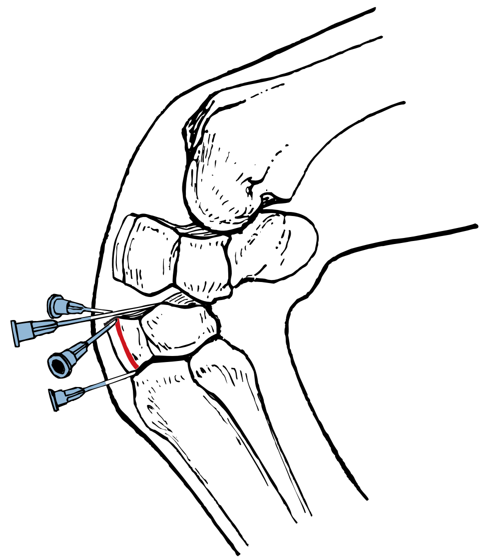


Fig F5C: In the lateral view, the position of the needle in the carpometacarpal joint may be better appreciated.

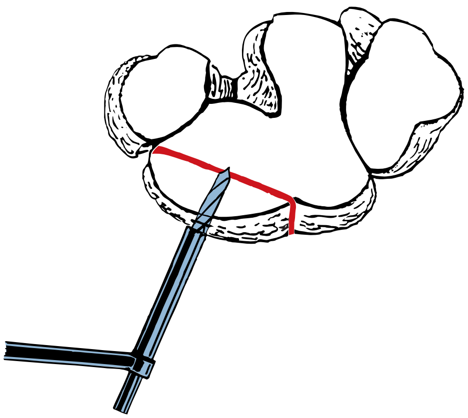


Fig. F5D: The glide hole is prepared in the fracture fragment by drilling parallel to the previously placed spinal needle.

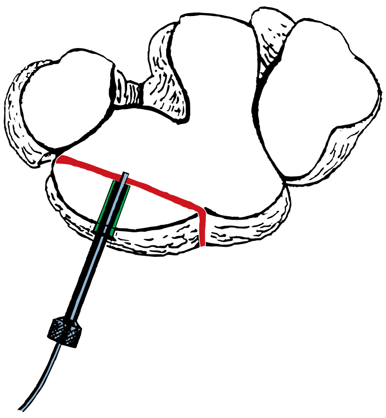


Fig. F5F: A K-wire placed in the glide hole serves as a marker over which the centering guide can be slid into position. This saves time and avoids undue soft tissue disturbance.

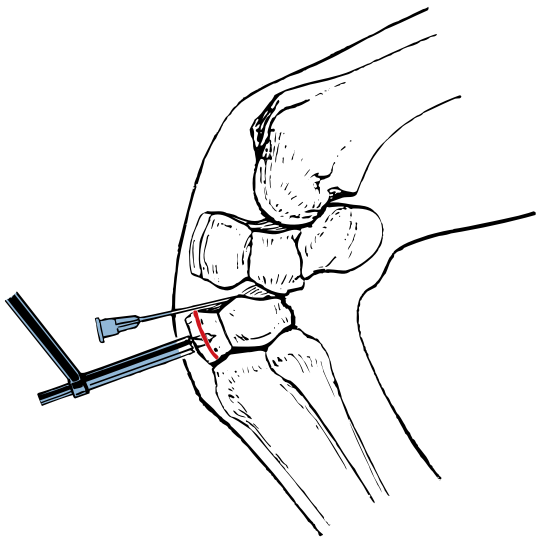


Fig. F5E: Other than the spinal needle, a good directional guide for drilling is the 90° relationship to the long axis of MC3. Maintaining this positioning insures that the joint surface will not be injured.

guide the direction of the drill (**Fig. F5D**). A general alignment aid is to keep the bit perpendicular to the long axis of MC3. This assures that the drill remains parallel to the articular surface of C3 (**Fig. F5E**). With displaced fractures it is easy to **check arthroscopically that the glide hole has reached the fracture**, since the drill can actually be seen entering the fracture gap. With nondisplaced fractures, careful measurements and/or intraoperative radiographs are necessary. After removing the 3.5 mm bit, a 2 or 3 mm K-wire is placed into the hole through the drill guide. The guide is then removed and **the centering insert is positioned by sliding it down the K-wire into the glide hole** (**Fig. F5F**). With displaced fractures, the fragment can then be manipulated with the insert and a 3 mm K-wire to further ascertain the position and

Verify complete penetration of the fragment arthroscopically.

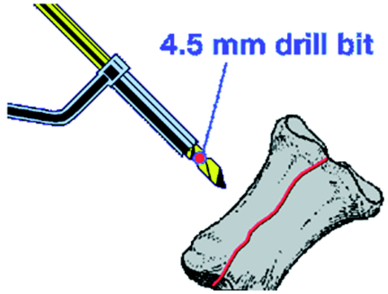
Use a K-wire as a guide for the centering insert.

Flex the carpus prior to drilling the thread hole.

For single facet fractures, use 3.5 mm x 32 or 35 mm cortex screws.

completeness of the glide hole. Do not attempt to manipulate the fragment with the drill bit since the bit may break.

The carpus is flexed, aiding reduction. Accuracy is checked again arthroscopically and the thread hole is drilled (Video DBASICS). Usually, it extends only about 40 mm, but palmar penetration does not constitute a problem. After making the countersink depression, the hole is measured and tapped routinely. **For fractures that involve only a single facet, a 32 to 35 mm long 3.5 mm diameter cortex screw is adequate** (Fig. X5A, Video 31018). If



Video DBASICS:
Animation about drill basics.

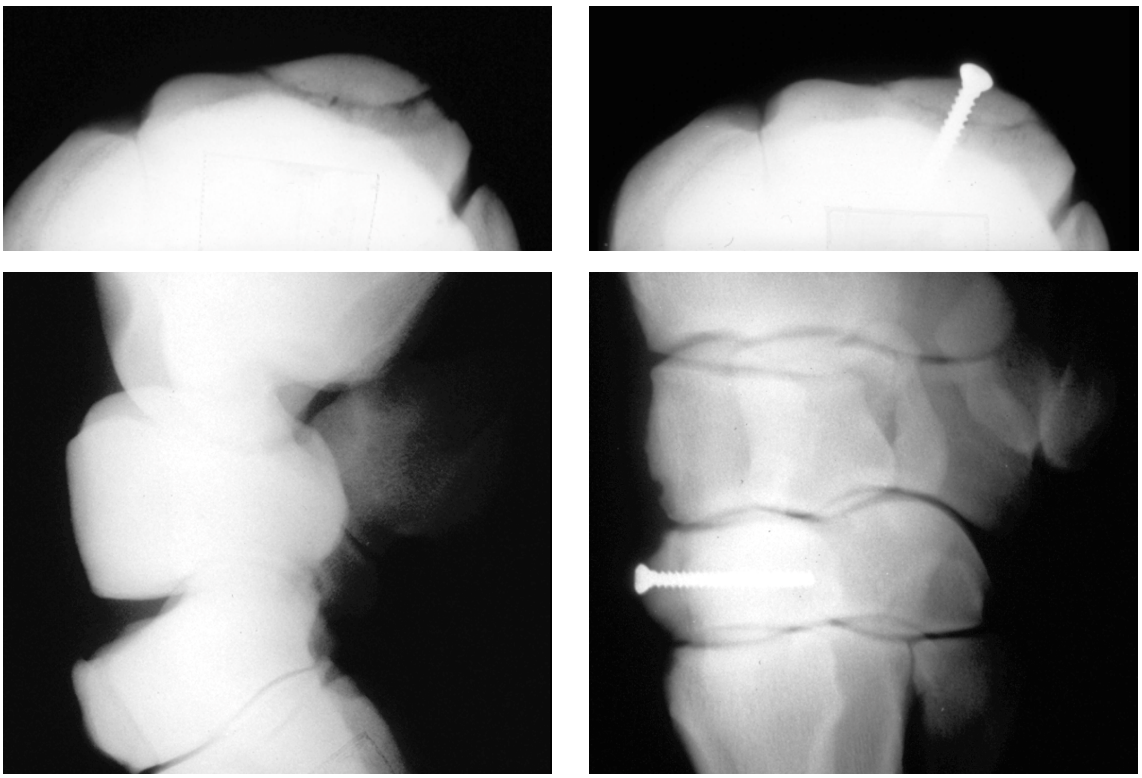


Fig. X5A: Smaller fractures of the face of C3 involving only one articular facet may be repaired with one carefully placed screw.

Fig. X5B: For broad fractures of the face of C3, affecting both articular facets, two 3.5 mm cortex screws are employed.

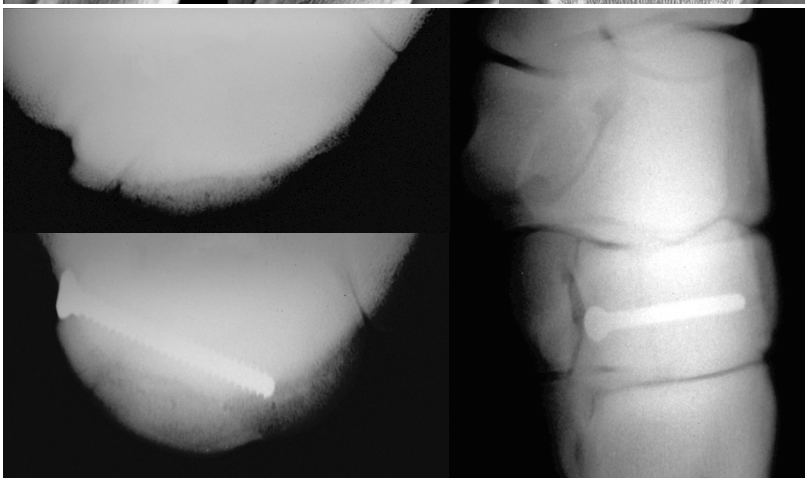


Fig. X5C: The flatter head of the 3.5 mm screw makes it the implant of choice in areas with narrow tolerance as in this sagittal fracture of C3.

Video 31018:
Slab fracture of C3.

the fracture is large, i.e., involving both facets, two or sometimes three 3.5 mm screws are used (**Fig. X5B**). Alternatively, 4.5 mm screws can be used; the larger screw is preferred whenever there is marked comminution along the fracture plane or whenever stability is otherwise questioned. The 3.5 mm screw is greatly preferred for sagittal fractures of the radial facet [8] because i**ts much smaller head allows it to be placed close to the C3-C2 articulation** (**Fig. X5C**) without excessive countersinking [9]. In large slab fractures that involve both facets, the second screw inevitably passes through the extensor carpi radialis tendon and/or its sheath. The stab

The smaller head of the 3.5 mm cortex screw is advantageous.

Passive flexion is an essential component of postoperative physical therapy.

For the surgeon not skilled in arthroscopy, repair via arthrotomy is a viable alternative.

incision splitting the tendon's fibers should be made while holding the limb in flexion to achieve reduction, since subsequent manipulation will shift the relative position of the stab and the fragment.

After the screw is inserted, the fracture line is probed and any remaining flaps are debrided. If there is a large fracture trough and a narrow remaining articular rim, the rim is removed with heavy rongeurs or a motorized burr.

Virtually every C3 slab can be repaired arthroscopically, although the advantages are questionable if the surgeon is not an experienced arthroscopist. **An arthrotomy consists of a straight 5–6 cm incision located approximately 15 mm medial to the extensor carpi radialis tendon**. The extensor carpi radialis tendon sheath should be avoided. A smooth tipped elevator can be placed in the incision and leverage used to retract the joint capsule. The fracture line is debrided with small angled curettes and/or bone picks. It is easiest to debride the fracture with the limb in partial flexion. Hard flexion closes the fracture line and tends to keep the fragment in reduction during placement of the screw. One or both screws must often be placed through a separate stab(s), since the desired position may not be directly under the arthrotomy incision. The standard lag screw technique is used as described above. An Esmarch bandage may be helpful and suction/irrigation is indispensable.

Only skin sutures are used in the arthroscopic incisions, usually over the screw. If the screw incision is longer than 8–10 mm, a single subcutaneous synthetic absorbable suture is used.

5.3 Postoperative treatment

A lightly padded bandage is used for recovery and to help minimize swelling in the postoperative period. **Passive flexion as a major component of physical therapy of the limb is strongly recommended to avoid loss of range of motion.**

5.4 Complications

Three specific cautions bear mentioning:

- Always keep a 2 or 3 mm diameter K-wire in the hole while changing bits, guides, and the tap. In this way, the hole will not be "lost" during its preparation. This is particularly important when placing a screw in the more central portion of C3 since the instruments and screw will be passing through the thickness of the extensor carpi radialis tendon and its sheath.
- Because the thread hole does not usually pass through the palmar cortex, the hole has a "bottom". Impacting the tap upon this unyielding barrier can result in stripped threads or a broken instrument. A small error in measurement and a screw that is slightly too long will result in failed compression since the screw head will not fully contact the fragment's cranial surface.
- Note that the hexagonal socket of the 3.5 mm screw head is shallow and can be easily stripped if the screwdriver is not carefully seated.

5.5 Results

The prognosis is not particularly good for a return to competition at former levels. **Although the majority of horses will return to racing, most will drop in class** [10]. The prognosis is better if the horse has raced previously, and even better if it has occasionally won. It is also improved by there being only minimal pre-existing degenerative joint disease. In general the prognosis is better for Standardbreds than it is for Thoroughbreds.

Sufficient healing time is essential to successful treatment. Although horses with nondisplaced fractures sometimes resume work within 3–4 months, 8–10 months is a more common convalescent time frame. Radiographs are taken at 2–3 month intervals to assess the progress of healing.

Most horses return to racing, albeit at a lower class.

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6 Metacarpals (-tarsals) two and four

Gustave E. Fackelman

6.1 Description

The fractures of the minor metapodeal bones for which internal fixation is indicated are those located in the proximal third. These are caused either by direct trauma or by strain during normal locomotion. **Research has shown that the proximal one-third of the second metacarpal bone is subjected to torsional strain during axial loading** [1], due probably to the unique characteristics of the proximal (carpometacarpal) articular facets (**Fig. F6A**), and the strong attachment of the middle third of the bone to the third metacarpal. Typically, there is a fusiform exostosis just below the carpus (**Fig. S6A**), mild to moderate lameness, and pain on direct palpation. The exposed locations of the fourth metacarpal and metatarsal bones make them prone to open fracture due to direct trauma. Such fractures have been treated by resection, either of the infected portions [2], or of the entire bone [3, 4]. Here, the bony proliferation may be extreme, the lameness more marked, and a draining tract present. Cosmetic results following radical resections are not consistent, and a potential complication is luxation of the remaining short proximal fragment through the surgical incision. Efforts to avoid this complication and improve the postoperative appearance by screw fixation of the fragment to the third

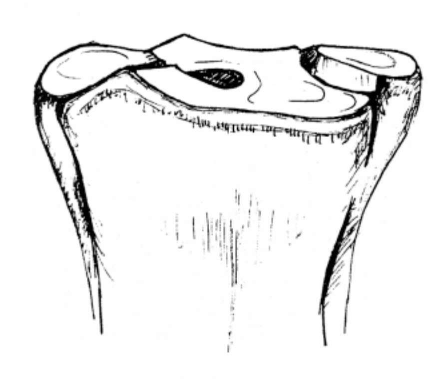


Fig. F6A: The proximal end of the second metacarpal bone (left) bears a joint surface, part of which is inclined caudomedially. Axial loading of the bone results in torque forces tending to twist it caudolaterally.

Fig. S6A: The exostosis that forms in response to fractures in the proximal one-third of the bone is typically fusiform, and located just below the carpus.

During axial loading of the limb, the proximal one-third of the second metacarpal bone is subjected to torsional strain.

Postoperative pain is common following fixation of the proximal por tion of the "splint" bone to the major metacarpal.

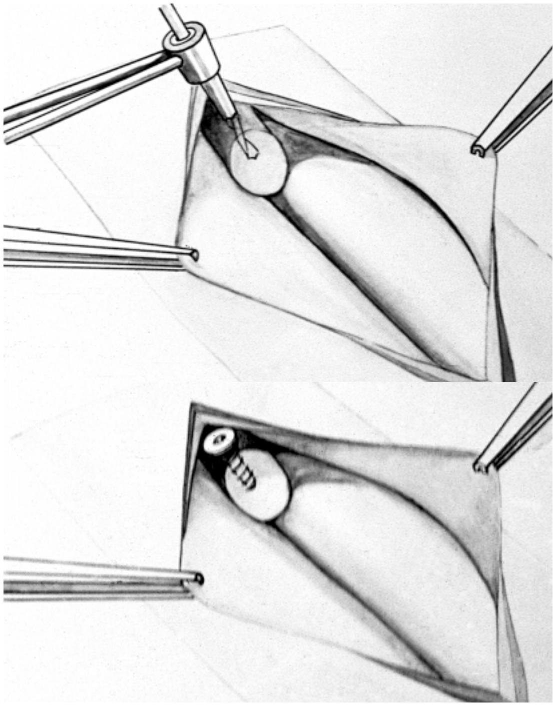


Fig. F6B: Following radical resection the fragment was drilled (above), and a fixation screw (thread hole in both bones) was placed to confer stability, while not disturbing the alignment of the proximal articular surface (below).

metacarpal (**Fig. F6B**) have **failed due to post-operative pain at the surgery site (Fig. X6A)** [5]. This appears to mimic a condition seen in humans when the syndesmosis of the distal fibula is traversed by a lag screw [6].

6.2 Surgical anatomy

The important landmarks are the proximal end of the fractured bone, the fracture site itself, and the axis of the distal portion of the "splint". The first two landmarks may be obscured by bony callus, in which case it is helpful to mark the level of the carpometacarpal joint with a 20 g hypodermic needle, and plan the operation relative to this marker. Later, resection of the callus will reveal the level and direction of the fracture, facilitating the placement and orientation of the implants. Measurement on radiographs determines at what level the synostosis between the minor and the major metacarpal begins.

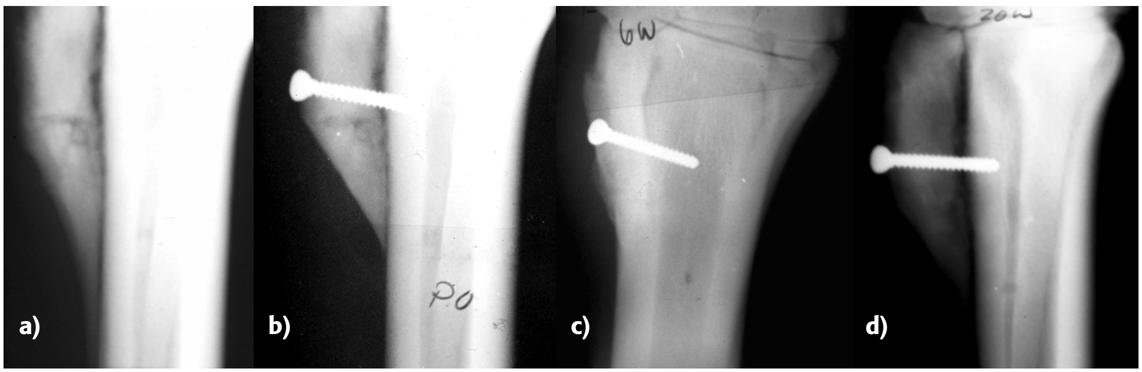
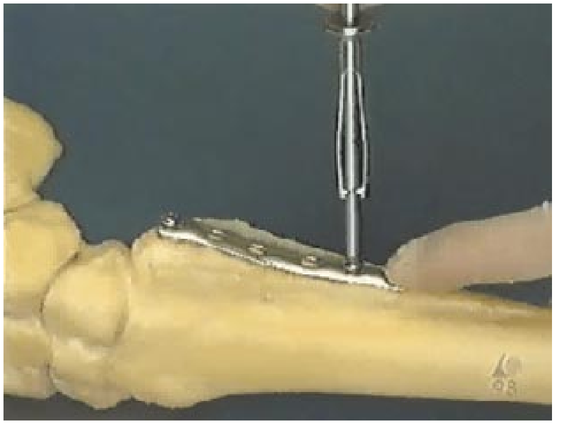


Fig. X6A: a) An old infected fracture—distal portion of bone resected. b) Fixation screw used to stabilize fragment and prevent luxation. c) Satisfactory healing at 6 weeks. d) Sterile bony lysis painful at 20 weeks, necessitating removal.

6.3 Surgical procedure

(**Video 31022**)

The incision is made from the level of the carpo-metacarpal joint distally to include the region of osseous union between the minor and the major metacarpals. After subcutaneous hemostasis has been achieved, the thickened periosteum is incised, and, using a sharp periosteal elevator, it is reflected from the underlying callus (**Fig. F6C**). In older fractures, extensive "sculpting" may be necessary to restore contours that approximate normalcy (**Fig. S6B**). When such satisfactory contours have been attained, and the location and direction of the fracture plane noted, a one-third tubular plate is shaped to match, and the preoperative plan is executed (**Fig. X6B**). **Usually the first two screws are placed in their holes eccentrically at a distance from the fracture, providing axial compression**, after



Video 31022:
Fixation of a proximal splint bone fracture (with a 6-hole 3.5 mm one-third tubular plate).

The first two screws are placed eccentrically *away* from the fracture plane, to effect axial compression.

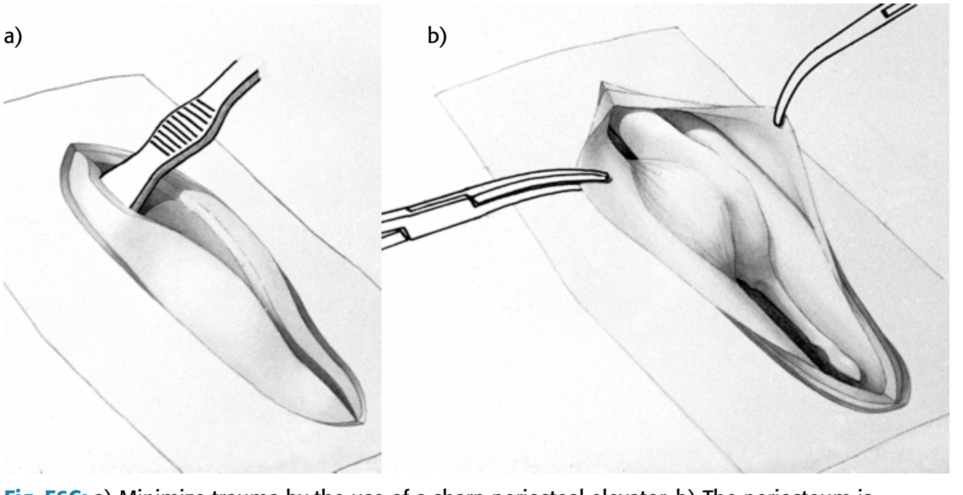


Fig. F6C: a) Minimize trauma by the use of a sharp periosteal elevator. b) The periosteum is reflected to expose the fractured bone.

Fig. S6B: The extensive callus (above) extends almost halfway down the metacarpus. The white stent (right side) indicates the more normal external contours achieved by de-bulking the callus.

Fig. X6B: Despite extensive resection there may still be greater-than-normal bone stock in the operative area (case shown in **Fig. S6B** 12 weeks postoperatively—healed fracture, no new callus).

Fig. X6C: Use a lag screw to bridge fracture sites wherever possible, as here in an area of comminution just below the articular surface.

which a lag screw is placed across the fracture plane if possible (**Fig. X6C**). The remaining screws are then placed in a neutral position. **Proximal to the synostosis it is important to place screws within the "splint" bone only, and not to invade the interosseous space** (**Fig. X6D**). Excess periosteal tissue is resected, and the remainder is closed over the plate (**Fig. F6D**). Closure is in layers, attempting to eliminate as much dead space as possible. Usually, a stent bandage is oversewn to relieve tension on the primary skin sutures, and to exert gentle pressure over the most critical portion of the surgical site.

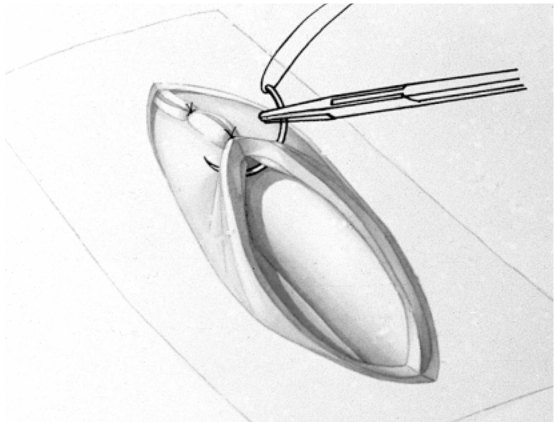


Fig. F6D: Callus removal results in redundant periosteum. Resect the excess tissue and suture the remainder snugly over the repair site.

The tips of the screws should not invade the space between the major and minor metacarpal bones.

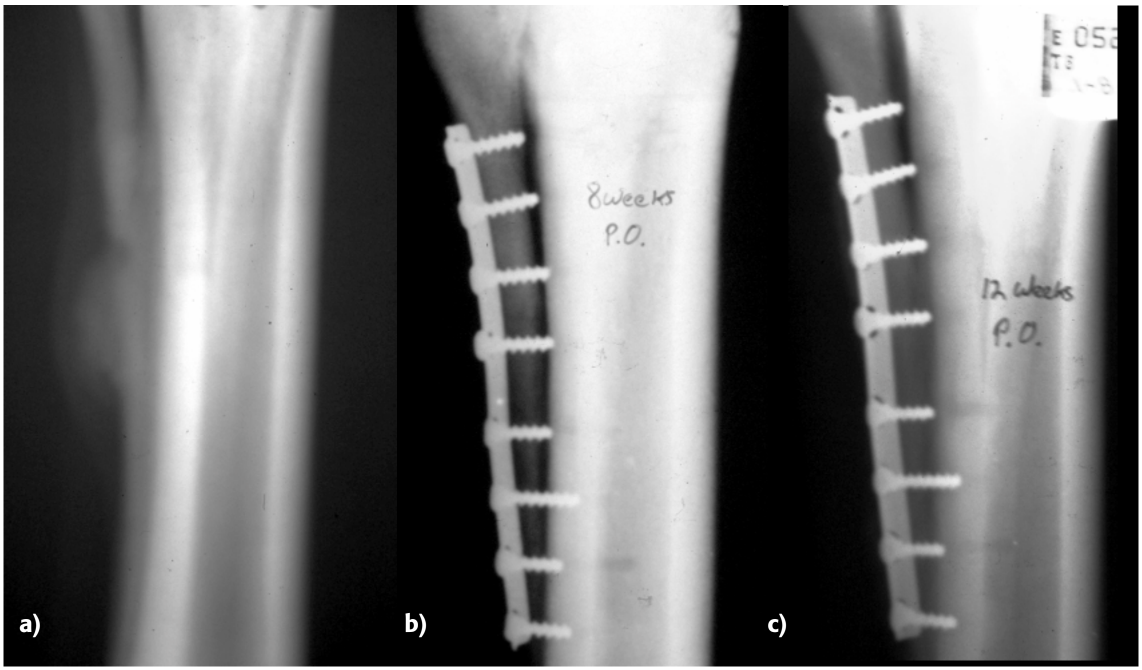


Fig. X6D: a) The fracture occured just above the area of synostosis. b) Screws proximal to the synostosis should not engage the third metacarpal bone. c) Cosmetic healing occurred and the plate remained in place for 8 years, after which the patient was lost to follow-up.

> Intolerance to cold, with resultant pain and lameness, may necessitate implant removal.

6.4 Postoperative considerations

A pressure bandage is applied postoperatively to aid in the prevention of seroma formation. The administration of perioperative antibiotics is continued for 24 hours. The horse is stall rested for 10 days until the skin sutures can be removed. Elastic bandaging is continued for 3 weeks. Controlled exercise is begun 1 month postoperatively, while exercise at will at pasture is discouraged for a full 12 weeks. Training is resumed at 4–6 months postoperatively, depending on soundness and radiographic healing. Typically, these fractures heal cosmetically, without the recurrence of the preoperative exostosis.

6.4.1 Complications

The only complication encountered with this surgery has been the need for implant removal due to intolerance to cold (**Fig. S6C**, **Fig. X6E**) Although this has been reported anecdotally for other fixations, the problem seems greater in this area of little skin and hair cover, with a relatively large surface area of metal lying subcutaneously. Owners should be made aware of this, since it alters the time frame for a return to training. It is recommended that strenuous exercise be postponed until the screw holes have filled in with bone, which can take up to 90 days.

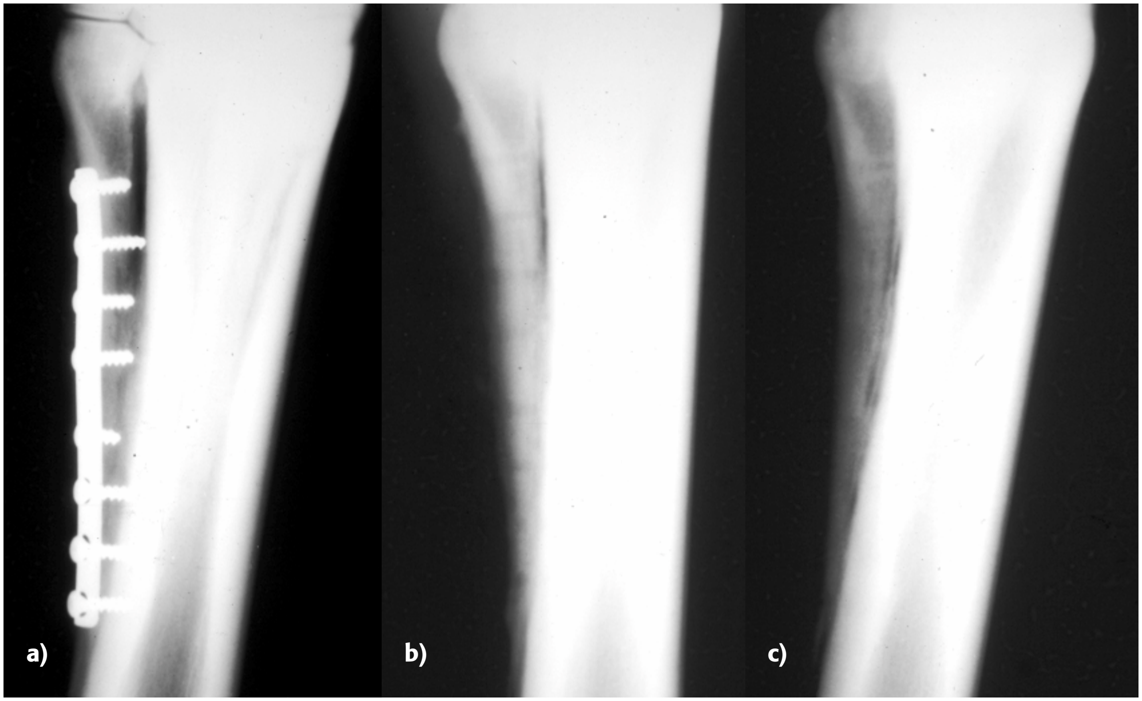


Fig. X6E: At 8 months postoperatively (a), the horse was back in work but showed occasional pain, especially in cold weather. The plate was removed (b), and training successfully resumed 60 days later (c).

Fig. S6C: The tangential view and the straight AP view show good cosmetic healing 3 months postoperatively in this open jumper.

6.5 Results

The results of this treatment have been uniformly successful, even when used in older fractures (**Fig. X6F**). Infected fractures also respond positively to fixation, since the stability conferred is rigid (**Fig. S6D**), expediting the resolution of infection and enhancing healing. Antibiosis is begun preoperatively based upon appropriate culture and sensitivity testing.

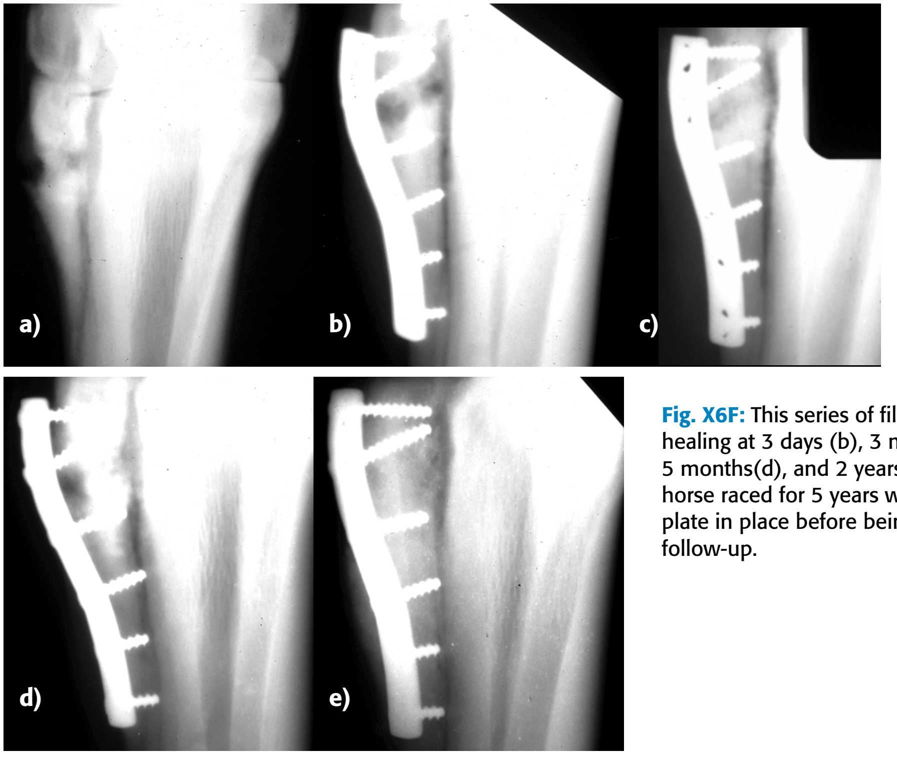


Fig. X6F: This series of films shows healing at 3 days (b), 3 months (c), 5 months(d), and 2 years (e). The horse raced for 5 years with the plate in place before being lost to follow-up.

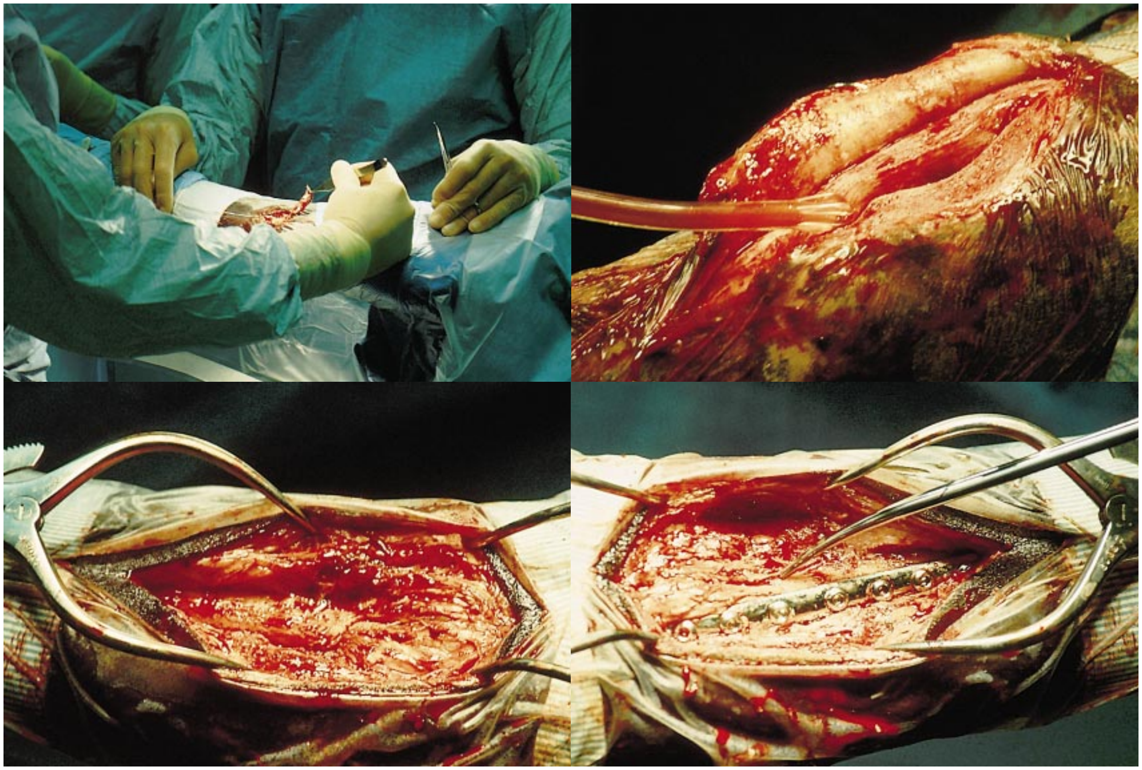


Fig. S6D:
Thoroughly debride infected fractures, and remove any callus that has formed prior to the application of the plate.

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6.6.1 Online references

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7 Metacarpal(-tarsal) condyles

Gustave E. Fackelman

7.1 Description

Fractures of the distal metacarpal and metatarsal condyles were among the earliest to be repaired by internal fixation [1]. Their relationships to the distal articular surface and to the long axis of the bone are relatively simple and technical problems are few. In general, these fractures are racehorse injuries, are more common in Thoroughbreds than in Standardbreds, and usually affect the lateral condyle (Fig. X7A). Fractures of the medial condyle may appear similar radiographically (Fig. X7B), but when examined more closely, they are far more extensive and require more aggressive treatment [2]. As with a number of other exercise induced fractures, condylar fractures appear to occur in stages. A **common anamnesis** includes: signs of **repeated bouts of lameness** associated with **pain** and **swelling in the fetlock region**; **passive flexion of the metacarpophalangeal joint appearing painful**; and, possible occasional **point pain** detectable **in the distal metaphyseal region**. These 2–3 day periods of lameness alternate with periods of apparent athletic soundness. Only after **repeated radiographs** are taken at different intervals and from various angles does the bony defect become visible [3]. There is **scintigraphic evidence** that there may be some predisposing (vascular) disorder of the distal metacarpus (Fig. X7C) that precedes actual bony failure [4], as has been observed in humans [5, 6]. The gradual nature of the failure may be connected with prevailing loading characteristics, as has been demonstrated in experimental animals [7]. In describing the repair procedure below, the metacarpus will be used as an example. Mention will be made of any significant deviations applicable to the same fracture form in the metatarsus.

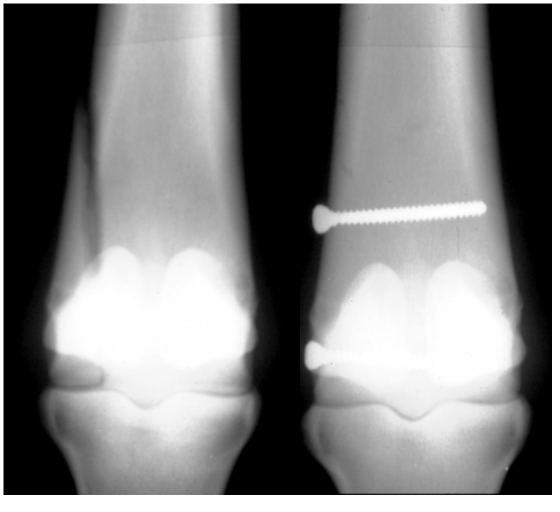


Fig. X7A: Follow-up radiographs show good fracture healing without periosteal proliferative change or degenerative joint disease.

Common anamnesis: repeated bouts of lameness with pain and swelling in the fetlock region, pain on passive flexion of the MC joint and point pain in the distal metaphyseal region.

Repeated radiographs and scintigraphy may be needed to make a definitive diagnosis.

Fig. X7B: The medial condylar fracture involves a great deal more of the shaft of the bone, and often “disappears” from radiographic views as it courses proximally.

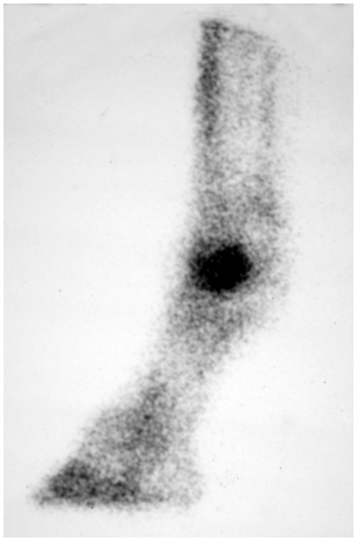


Fig. X7C: A bone scan of the distal metacarpus in a horse showing typical premonitory signs may show intense uptake of isotope before any radiographic evidence of fracture has appeared.

7.2 Preoperative considerations

The most important factor specific to these fractures to be considered preoperatively is the presence of **associated lesions**. Bilateral fractures, fragmentation along the fracture line, especially of the flexor surface of the condyle [3, 8], and, axial fractures of the proximal sesamoid [9] warrant particular mention. Appropriate radiographic projections should be performed to rule out these additional injuries, as they will affect the details of the operative procedure and the prognosis for its outcome. If the instability has persisted for some time, a synovitis may be present, with the possible onset of degenerative joint changes. Such changes in an animal actively engaged in competition should prompt the surgeon to ask in particular whether the horse has received intra-articular therapy of any sort. Using the AO Documentation System, this information would have been gathered as one of the preoperative "checkpoints" [10].

If the fracture affects the medial condyle a more thorough radiographic, and perhaps scintigraphic, examination is indicated to elucidate the true extent of pathology. These fractures, especially when located in a hind limb, may spiral all the way to the proximal articular surface. This entire plane must be brought under interfragmentary compression, and the screws employed possibly protected by the application of a neutralization plate (**chapter 1**, Basic principles of fracture treatment).

7.3 Surgical anatomy

In nondisplaced lateral condylar fractures most, if not all, of the surgeon's orientation is based on soft tissue landmarks, the incision(s) being simple stab(s). These same landmarks will serve in displaced fractures, but assume less importance, since the articular surface will be directly visualized.

One of the most **prominent landmarks**, serving to locate the **level of the metacarpophalangeal joint** and to indicate its caudal extent, is the **proximal eminence or "wing" of the proximal phalanx**. Both this and the adjacent base of the proximal sesamoid are closely associated with the palmar aspect of the epicondylar fossa of the third metacarpal bone. This fossa is filled with the substance of the collateral ligament (**Fig. F7A**), but the articular rim of the condyle itself may be palpated just dorsal to it. Using these landmarks facilitates centering of the most distal screw in the epicondylar fossa without radiographic monitoring (**Fig. F7B**), and helps prevent the most common error of placing the screw too far palmarly. If any question remains, a radiopaque marker should be placed on the skin and appropriate projections performed, respecting the precautions surrounding intraoperative radiography already enumerated (**chapter 3**, Pre- and postoperative considerations).

Check for additional lesions.

A prominent landmark to locate the metacarpophalangeal joint is the proximal eminence of the proximal phalanx.

Fractures of the medial condyle deserve further scutiny.

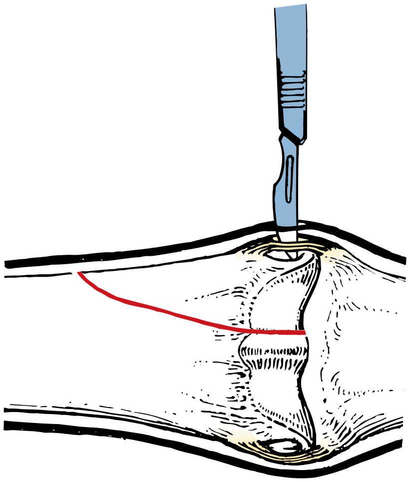


Fig. F7A: Guided by soft- and hard tissue landmarks, a stab incision is made through the skin parallel to the fibers of the lateral collateral ligament reaching the depths of the epicondylar fossa.

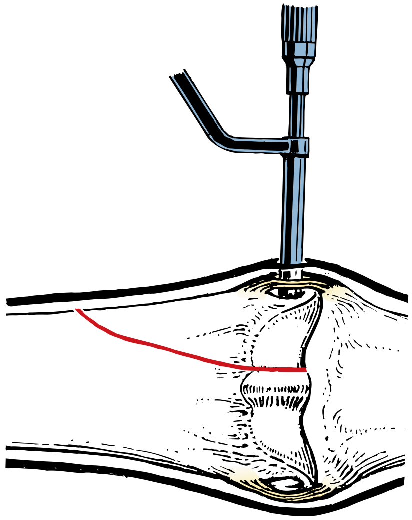


Fig. F7B: The most distal screw hole is centered in the epicondylar fossa, and drilled perpendicular to the long axis of the limb (i.e., parallel to the joint surface). Use of a 4.5 mm sleeve during drilling and tapping is the key to preventing injury to the collateral ligament.

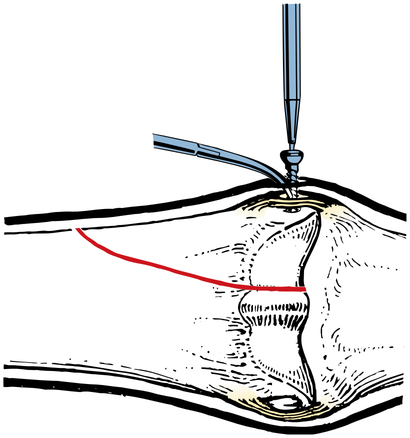
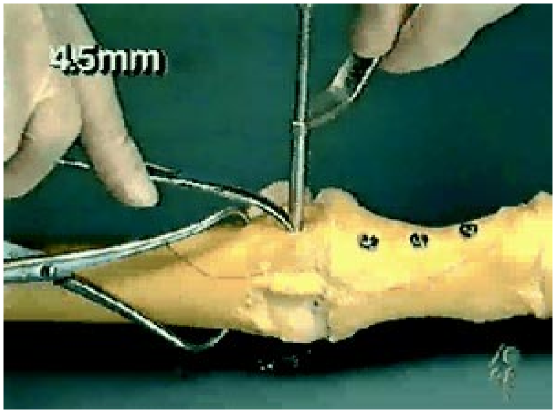
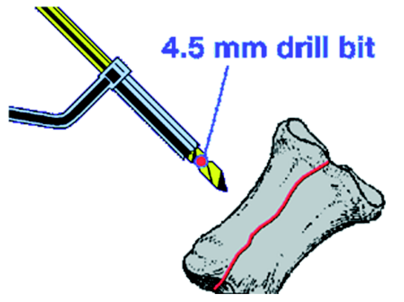


Fig. F7C: Insert the screw of appropriate size and length and tighten it.



Video 31015:
Fracture of the lateral condyle of MC3/MT3.

After the **distal screw** has been inserted (**Fig. F7C**), it can **serve as a point of reference for the placement of successive screws**. In addition, the long axis of the limb (easily appreciated due to circumferential draping) is used to orient the screws in the frontal plane. Bilateral fractures are treated in an identical fashion—it is usually preferable to turn the patient so that both fractures can be approached from their lateral sides.



Video DBASICS:
Animation of drill basics.

The distal screw serves as a point of reference for the placement of successive screws.

7.4 Surgical procedure

(**Video 31015**)

Using the landmarks described above, the ideal location for the most distal screw is determined. In the non-displaced uncomplicated fracture, lag screw fixation may commence according to the technique demonstrated in **Video DBASICS**.

Displaced fracture of MC3/MT3

1. Incision of the joint capsule along fracture.
2. Exposure of fracture plane.
3. Removal of debris between fragments (gentle displacement).
4. Reduction and fixation by reduction forceps with points.
5. Do not injure the opposite collateral ligament with the screw tip or any of the instruments.

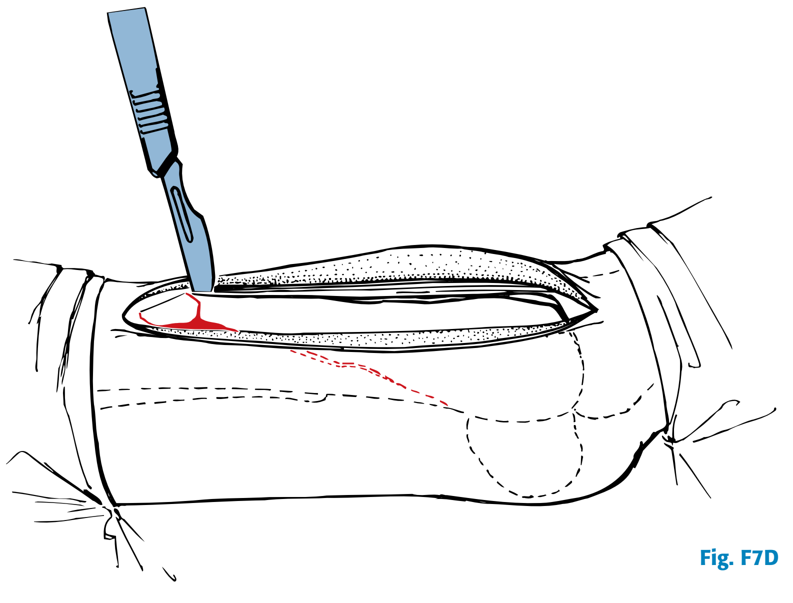


Fig. F7D

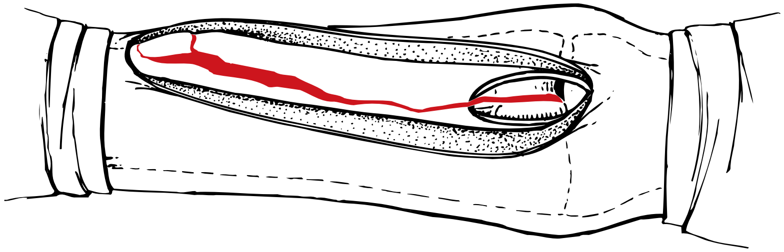


Fig. F7E

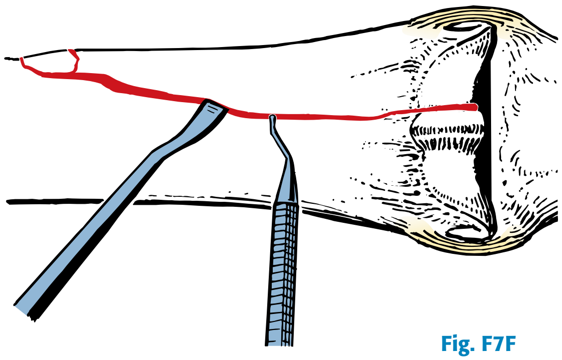


Fig. F7F

If displaced, the skin, remaining periosteum, and joint capsule are incised along the fracture (**Fig. F7D**). This exposes the entire fracture plane, including the articular component (**Fig. F7E**). The fracture line is cleansed of debris, and gently displaced to expose its flexor aspect. Any additional bony fragments are removed, working from the articular surface while taking care not to cause any additional cartilaginous damage (**Fig. F7F**). When the plane of the fracture is completely clean, it is reduced and held in place by the large pointed reduction forceps (**Fig. F7G**). Reduction is only considered adequate when the articular surface is completely smooth

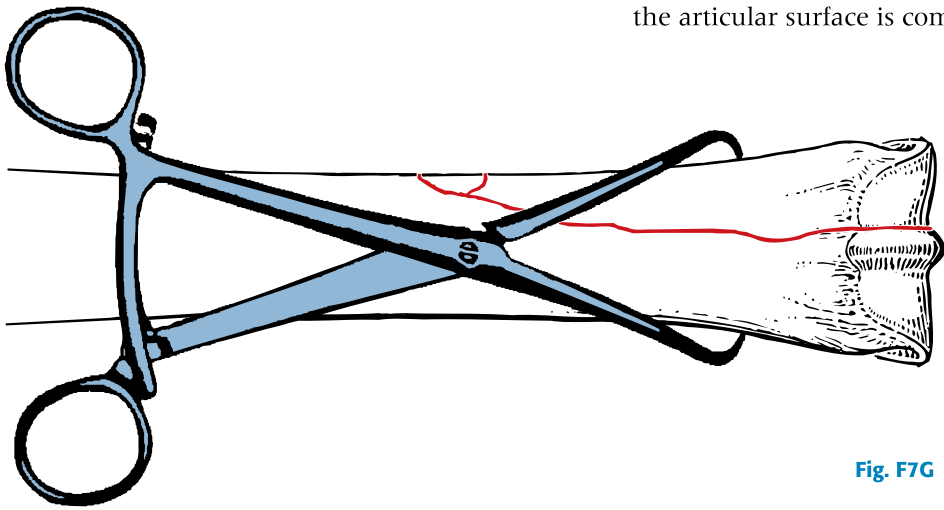


Fig. F7G

and the fracture line has been obliterated. Placement of the most distal screw may now proceed as described for nondisplaced fractures (**Fig. F7C**). **Take care not to allow the tip of the screw (or of any of the preceding instruments) to injure the opposite collateral ligament, as this can result in persistent postoperative lameness.** Successive 4.5 mm diameter cortex screws are placed in lag fashion, proceeding proximally at an interval of 2–3 cm, while maintaining perpendicularity to the fracture plane. Small fragments at the tip of the main fracture are often attached to periosteum and, if convenient, may be replaced in their respective defect(s) in mosaic fashion. Smaller chips are discarded.

The fibrous layer of the joint capsule is closed using a resorbable material such as polyglactin 910. A similar material is employed in a subcuticular pattern, and the skin is closed using a material (usually non-absorbable) of the individual surgeon's choice. A sterile dressing is applied to the surgical site, and a padded elastic bandage is used to hold the dressing in place and to control swelling.

7.5 Postoperative care

Fractures of the lateral condyle require no protection by external fixation, while the more extensive lesions of the medial condyle should be protected by casting, at least for the recovery period and probably for an additional 3–4 weeks postoperatively. Passive flexion exercise, and light hand walking should be instituted as soon as the condition of the soft tissues permits. **Non-steroidal anti-inflammatory drugs** can be used to good advantage in the early postoperative period to **reduce swelling** and **allow gentle passive manipulation** of the operated articulation. Such movement improves cartilage nutrition, and the eventual functional condition of the joint. Typically, follow-up radiographic examinations are performed 6 and 12 weeks (**Fig. X7A**) postoperatively to assess the progress of healing. Given positive findings, the level of exercise can be escalated to include longer periods in hand or under saddle, if the animal is easier to control in this way. Swimming may be used to good advantage to maintain cardiovascular fitness. Heavier training under weight bearing conditions should not be instituted until 6 months postoperatively.

Only rarely do the implants employed in this surgery need to be removed [11], although anecdotal evidence of intolerance to cold exists, and probably deserves investigation in cases of protracted low level lameness with no other obvious cause.

7.6 Results

Given freedom from complicating lesions such as those referred to above, the treatment of condylar fractures by internal fixation bears a good prognosis for a return to athletic performance [2]. **Nondisplaced fractures bear a more favorable prognosis than displaced fractures** [11]. How much each of the associated lesions contributes to the reduction of the prognosis is difficult or impossible to predict with any accuracy, but their effects are worth mentioning. There appears to be little difficulty in restoring the horse with multiple lesions to usefulness for riding, hunting, or show purposes, but its racing potential may be seriously compromised.

The tip of the screw should not injure the opposite collateral ligament.

Nondisplaced fractures bear a more favorable prognosis than displaced fractures.

Non-steroidal anti-inflammatory drugs can be used in the early postoperative period to reduce swelling and allow gentle passive manipulation of the operated articulation.

7.7 References

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8 Proximal sesamoids: screw fixation

Dean W. Richardson

8.1 Description

Midbody fractures of the proximal sesamoid bone (PSB) remain a challenge for the orthopedic surgeon. **Conservative treatment usually results in separation of the fragments** due to the distracting forces of the suspensory ligament proximally and the distal sesamoidean ligaments distally. The bones appear to be intrinsically **slow to heal, presumably because of a marginal primary blood supply**, minimal surrounding soft tissue for extraosseous blood supply and absence of a true periosteum. There are several **options for surgical treatment** including **hemicerclage wiring, distal to proximal lag screws, and proximal to distal lag screws**. All of these can be modified by the use of cancellous bone grafts and different sized screws.

Midbody fractures of the proximal sesamoid bone are primarily racehorse injuries and are seen in both Thoroughbreds and Standardbreds. In the Thoroughbred there appears to be a predilection for the right front medial proximal sesamoid bone. Midbody fractures are occasionally seen in horses performing other types of activities and at pasture. Young foals chasing their dams are also susceptible to sesamoid fractures.

8.2 Surgical anatomy

The surgical approach varies somewhat depending on the surgeon's selection of screw direction. Frequently, the obliquity of the fracture plane dictates the easiest direction in which the screw can be inserted. A fracture coursing from the proximal axial aspect of the bone to the distal abaxial aspect would be much easier to repair with a proximal to distal screw since the implant would then be perpendicular to the fracture plane. Placing a screw, particularly a single screw, at an angle to the fracture plane makes shifting of the fragments more of a problem. With either screw direction, the articular surface of the bone should be exposed so that any loose articular fragments can be removed and alignment can be directly assessed during reduction.

The incision is curved from the proximal aspect of the palmar (plantar) pouch over the abaxial surface of the sesamoid then back toward the articular base of the bone (**Fig. F8A**) If a distal to proximal screw is to be inserted, the distal part of the incision is carried further distally to adequately expose the attachments to the base of the proximal sesamoid bone. The apex of the curved incision is usually very close to the neurovascular bundle, so the depth of the initial incision should be closely monitored.

Conservative treatment usually results in separation of the fragments.

Intrinsic healing may be slow due to a marginal blood supply.

Options for surgical treatment:
1. Hemicerclage wiring.
2. Distal to proximal lag screw(s).
3. Proximal to distal lag screw(s).

Start the drill hole as far proximally and axially as possible.

Pack a small cancellous bone graft into the most palmar (plantar) aspect of the fracture.

The dorsally based flap is reflected enough to allow a linear incision in the palmar pouch extending from its proximal aspect down to the proximal margin of the proximal phalanx. The articular surface is examined and debrided as necessary.

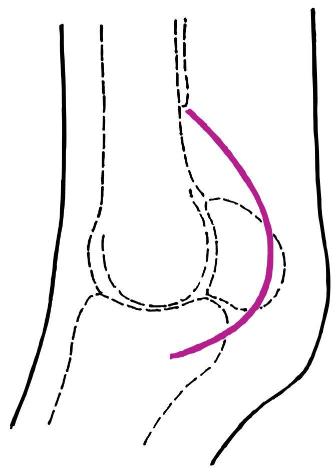


Fig. F8A: The basic skin incision used in the screw fixation of sesamoid fractures curves over the abaxial face of the bone including the palmar (plantar) pouch of the fetlock joint. For distal to proximal screw placement, it may have to be extended somewhat further distally.

8.3 Surgical procedure—proximal to distal lag screw

A #10 scalpel blade is used to make a stab in the suspensory insertion on the proximal aspect of the sesamoid, approximately 5 mm palmar to the articular margin. The stab must split the suspensory fibres longitudinally. A 3.5 mm drill bit is used to make the glide hole in the proximal fragment (**Fig. F8B**). **It is very important to start the hole as proximally and axially as possible** in order to facilitate crossing the fracture plane at a 90° angle. Drilling the hole too far abaxially can also predispose splitting of the apical fragment. In displaced fractures, accuracy of glide hole placement is easily appreciated by palpation and direct visualization. The hole should not extend beyond the fracture plane so that a maximum number of threads can be prepared in the basilar fragment. A 2 or 3 mm K-wire is inserted into the glide hole and the centering insert sleeve is placed over it. The sleeve can then be used to manipulate the proximal fragment and help bring about reduction (**Fig. F8C**). Large pointed bone reduction forceps are used to maintain reduction while drilling and tapping the thread hole, but it seems easier to drill the glide hole without the reduction forceps in place. If the fracture is not displaced or proves immovable, intraoperative radiography is essential to accuracy in glide hole depth, screw position, and screw length. After the hole is prepared for the screw (**Video DBASICS**), a **small cancellous bone graft** is packed **into the most palmar (plantar) aspect of the fracture**. The amount should correspond to the defect seen following reduction. Frequently, less than 1 cm^3 of can-

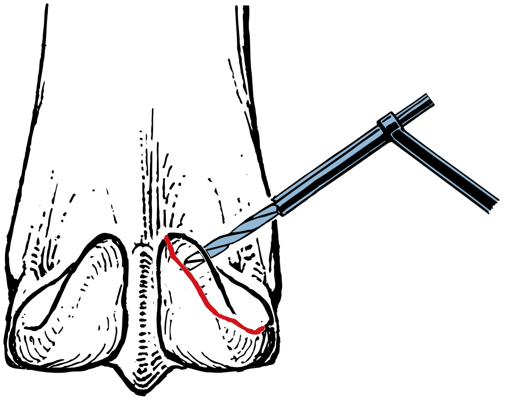


Fig. F8B: A 3.5 mm glide hole is prepared in the proximal fragment perpendicular to the fracture plane.

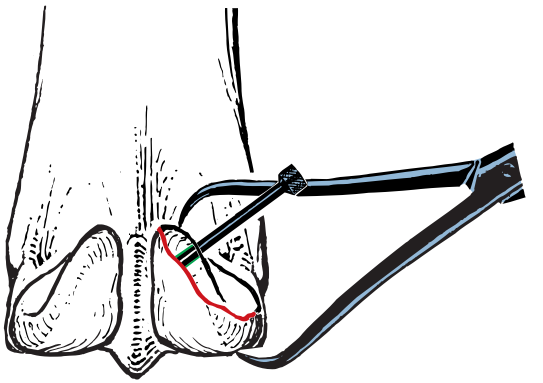
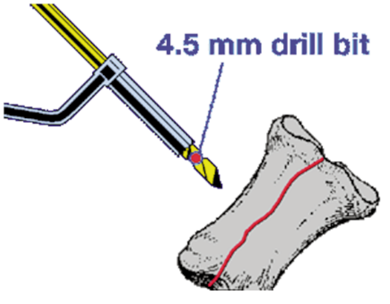


Fig. F8C: The centering drill sleeve is placed in the 3.5 mm glide hole, and may be used to manipulate the fragment. Positioning is maintained with the large reduction forceps with points.



Video DBASICS: Animation of drill basics.

cellous bone is required. The **cancellous bone** is easily **harvested from the tuber coxae through a small stab incision** and a 5.5 mm drill hole. In fractures with minimal displacement and a small gap, the graft is inserted from the articular surface. In more severely displaced fractures, the graft can be inserted through a small incision along the bone's palmar abaxial margin.

In most midbody fractures the placement of two 3.5 mm lag screws (**Fig. F8D**, **Fig. X8A**) or a single 4.5 mm screw is possible. In large horses, it is possible to insert two 4.5 mm screws, but this is not usually necessary. The improved rotational stability of two screws is an advantage since these fractures may twist slightly with final screw tightening.

Harvest the bone graft through a small stab inscision over the tuber coxae.

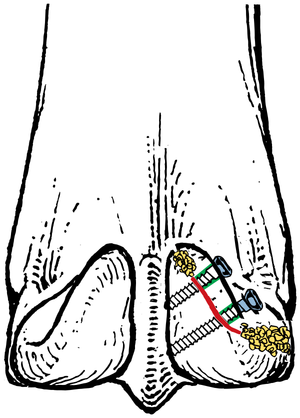


Fig. F8D: Two 3.5 mm screws can be applied to large articular abaxial fractures, and any defects or areas of comminution are filled with a fresh autogenous cancellous bone graft.

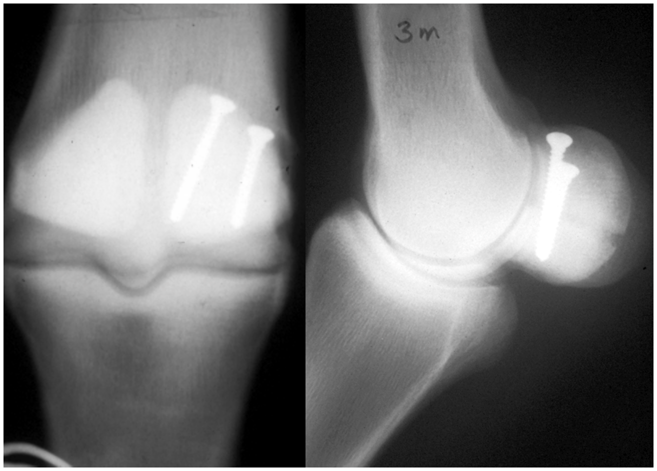


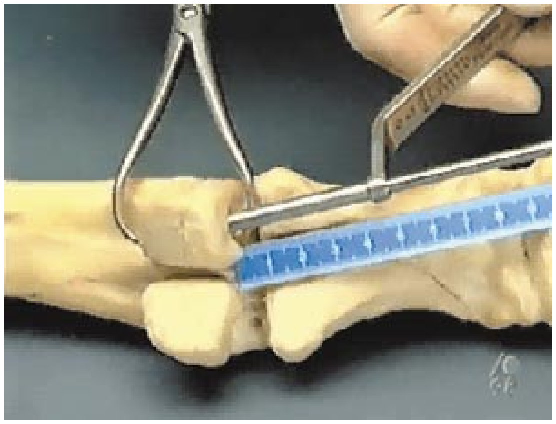
Fig. X8A: In most horses, two 3.5 mm diameter screws may be placed comfortably traversing a midbody fracture from proximal to distal.

8.4 Surgical procedure—distal to proximal lag screw

(**Video 31016**)

Distal to proximal screw placement is best when the fracture plane runs proximal-abaxial to distal-axial.

Alternatively, **screws can be inserted in a distal to proximal** direction. This is particularly advantageous if the **fracture plane runs proximal-abaxial to distal-axial**. The approach is similar to that described above except that it may be necessary to retract the neurovascular bundle dorsally. The soft tissue at the base of the sesamoid is dissected to expose the origin of the middle (oblique) and superficial (straight) distal sesamoidean ligaments. A stab incision is made



Video 31016: Lag screw fixation in sesamoid fractures.

through the junction of these ligaments up to the base of the bone. The drill guide is placed in the middle of the base of the sesamoid and aimed toward its apex. Reduction is maintained with the fetlock in partial flexion using a large, pointed bone reduction forceps placed through the soft tissues (**Fig. F8E**). The surgeon may have to try several different clamp positions to attain optimal reduction whilst avoiding compromising lag screw placement. Some surgeons prefer to use **a specially designed sesamoid clamp** [1] **that was made to simultaneously hold reduction and serve as a drill guide** (**Fig. F8F**). All of the drilling and the final screw placement can be done through the clamp because of its offset jaws and removable drill sleeves (**Fig. F8G**).

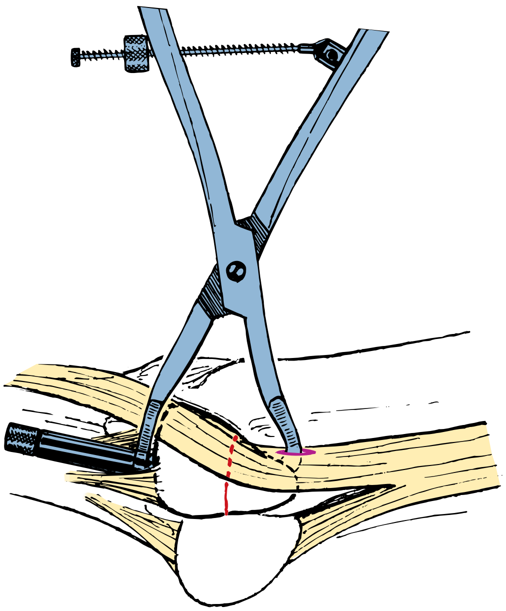


Fig. F8F: An alternative means of temporary fixation is provided by the specially designed sesamoid clamp.

The sesamoid clamp is designed to maintain reduction while serving as a drill guide.

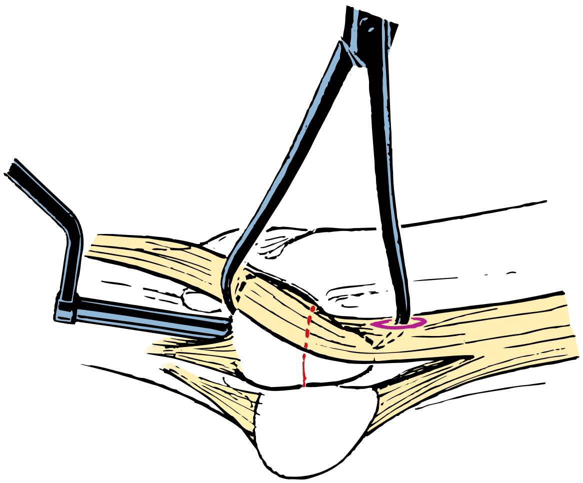


Fig. F8E: Reduction is maintained using the large pointed reduction forceps placed through the soft tissues, and located on the bone so as to faciliate drilling and tapping.

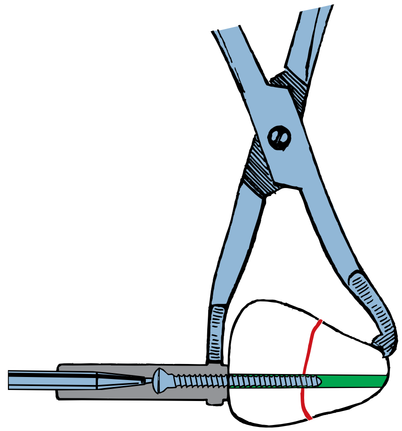


Fig. F8G: Owing to its internal dimensions and offset design, the sesamoid clamp may be left in position through perparation of the tapped hole and insertion of the screw.

Use the clamp to incline the reduced bone abaxially while changing the fetlock angle.

However, these instruments are not available anymore. A small incision is made in the fibrocartilaginous pad at the apex of the sesamoid bone. The offset tip of the clamp grips the apical fragment through this small stab incision. With either technique, the surgeon may experience **difficulty in positioning the drill over the heel bulbs**. Using the clamp to incline the reduced bone abaxially while changing the fetlock angle helps alleviate this problem. Intraoperative radiography is still necessary to check screw placement. However, better visualization of the exit site of the drill makes assessing drill and screw position easier with this technique than that of proximal to distal placement.

Additional techniques [2], in some ways analogous to those used for repair of fractures of the human patella [3], will be discussed in the following chapter.

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9 Proximal sesamoids: tension band wiring

Dean W. Richardson

9.1 Description

Initial pertinent comments and basic surgical anatomy are identical to those in **chapter 8**, Proximal sesamoids: screw fixation.

9.2 Surgical procedure

Tension band wiring is technically less complex than lag screw insertion in the proximal sesamoids and is a more versatile technique, adaptable to various degrees of comminution and fracture obliquity [1]. The approach involves a curved incision (**Fig. F9A**) extending from the tip of the splint bone palmarly over the neurovascular bundle, then distally over the proximal 1–2 cm of the proximal phalanx and the extensor branch of the suspensory. The subcutaneous tissue is incised dorsal to the neurovascular bundle and is dissected with the overlying skin to expose the proximal sesamoids and joint capsule. An incision is made into the joint through the collateral sesamoidean ligament to expose the articular surface of the proximal sesamoids. The fracture alignment is checked, and the fracture line is debrided from the articular surface. The neurovascular bundle and attached subcutaneous tissues are dissected from the palmar aspect of the proximal sesamoids and **a 4–5 cm longitudinal incision is made into the tendon sheath along the palmar aspect of the proximal sesamoids** (**Fig. F9B**). This incision should be made leaving enough tissue to suture securely when closing. A 14 g 2" (5 cm) needle is inserted under the base of the proximal sesamoids from the abaxial articular margin into the tendon sheath, holding the fetlock in palmar flexion and retracting the deep digital flexor tendon with a smooth instrument to avoid penetration by the needle. A 20–30 cm piece of 1.25 mm (16 g) wire is inserted through

Enter the tendon sheath palmar (plantar) to the proximal sesamoids.

This technique is adaptable to various degrees of comminution and obliquity.

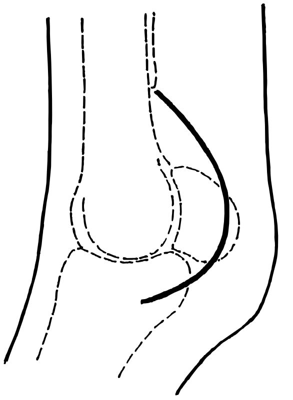

Fig. F9A

Use a 2.5 mm drill bit to penetrate the proximal fragment.

the needle and its end is retrieved from the tendon sheath (**Fig. F9C**). A stab incision is made parallel to the suspensory ligament fibers approximately 5–7 mm palmar (plantar) to the articular margin of the apical fragment. **A 2.5 mm bit is used to drill a hole through the apical fragment, also in an abaxial-dorsal to axial-palmar direction.** The hole should be made approximately through the middle of the apical fragment. The drill bit should only be passed through the bone since it will tend to twist the fibers of the tendon sheath rather than penetrate them sharply (**Fig. F9D**). The bit is removed and a 14 g 2" (5 cm) needle is used to puncture the tendon sheath. The bevel of the needle is turned toward the surgeon and the tip of the wire

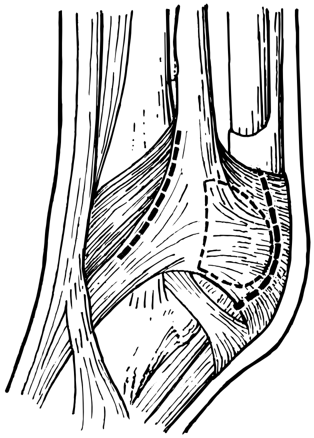

Fig. F9B

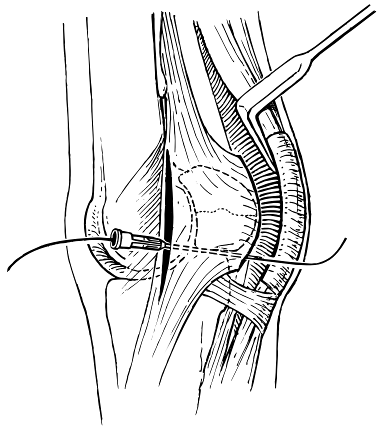

Fig. F9C

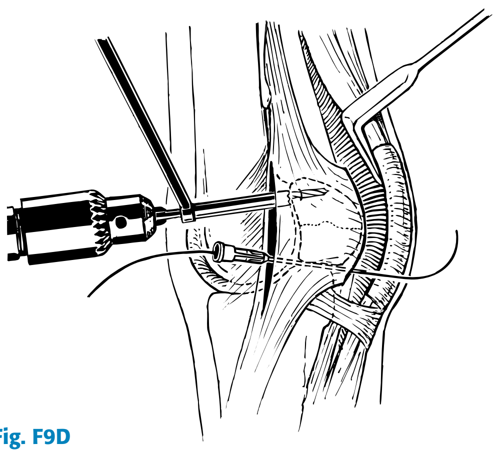

Fig. F9D

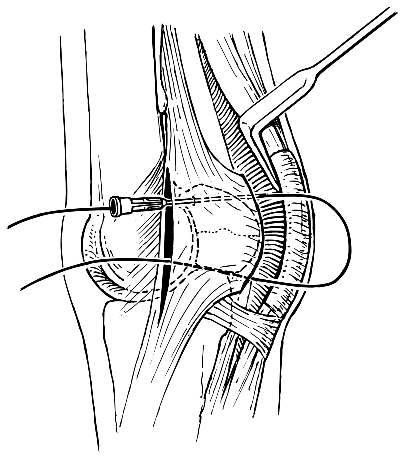

Fig. F9E

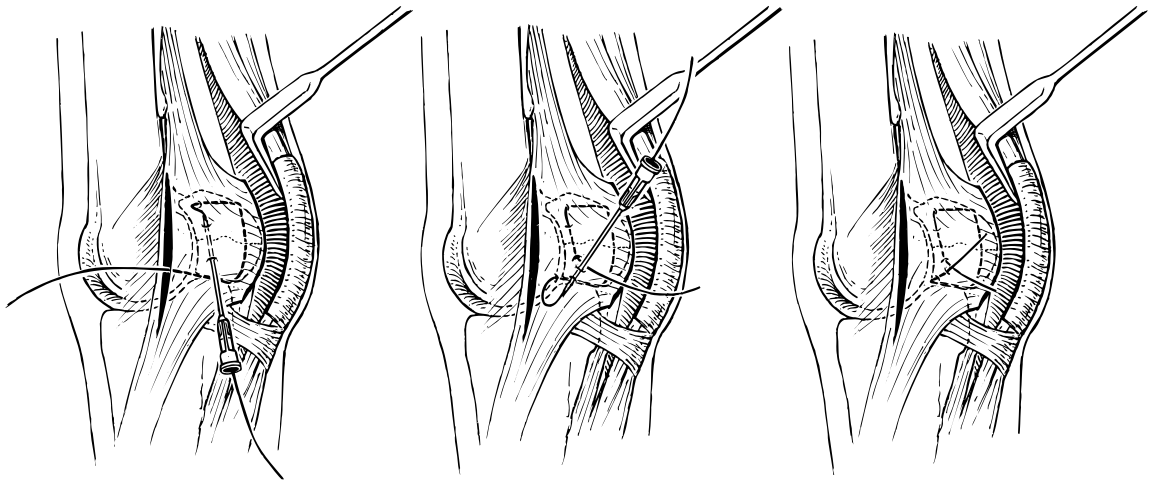

Fig. F9F

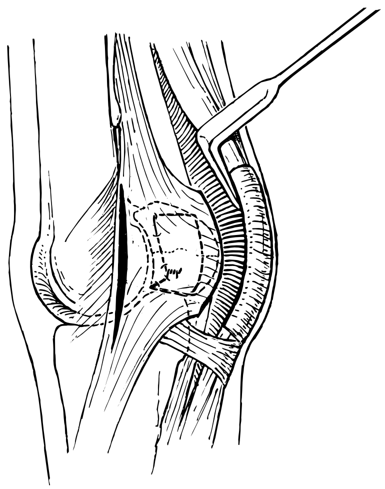

Fig. F9G

already in the sheath is inserted into the needle. **The wire is passed through the hole, either through the needle or by pushing the needle through the hole with the wire (Fig. F9E). This is the most difficult part of the procedure**. An alternative is to pass the wire initially through the proximal needle and a second smaller wire through the distal needle. The two wires are connected with a flattened sheet bend and tugged under the base of the bone. The wire ends are then passed through a needle under the soft tissue on the abaxial aspect of the sesamoid (Fig. F9F) so that the wire can be tightened on the bone's surface (Fig. F9G). Besides assuring that final wire tightening does not occur over the soft tissue, this positioning moves the wire twist away from the articular margins where it could possibly cause problems. **Prior to final tightening, a cancellous bone graft harvested from the tuber coxae** is placed in the fracture line. Usually the graft is packed from the articular surface but it can also be inserted from the abaxial side through a small stab in the fracture

The most difficult part of the procedure is threading the wire through the proximal fragment.

Add a bone graft from the tuber coxae to the fracture site.

Wire breakage is rare if 1.25 mm diameter wire is used.

Check articular reduction as the wire is tightened.

plane. With severely displaced fractures, there may be enough disruption of the dorsal surface of the tendon sheath to enable the graft to be placed directly into the palmar aspect of the fracture line. The amount of bone required is usually small (2–3 ml or less); the graft can be taken by making a 1 cm stab over the tuber coxae, drilling a hole in the outer cortex with a 5.5 mm bit, and scooping out bone through the drill hole with a #2 curette. An adequate volume of bone can be obtained quickly with this simple technique. **The wire is tightened with pliers, twisters, or preferably, Fastite® wire tighteners (Synthes®) while checking articular reduction.** Depending on the configuration of the fracture and the position of the wire, overtightening of the wire can lead to shifting of the fragments and articular malalignment. The incision is closed in layers with interrupted synthetic absorbable sutures in the tendon sheath and joint capsule, a continuous pattern subcutaneously and routine skin sutures.

9.3 Postoperative care

A cast or compression boot is placed for anesthetic recovery but can be removed in the early postoperative period. If the fracture is particularly unstable or there is doubt concerning the repair, the cast should be left for 4–6 weeks.

9.4 Complications

The primary potential complication of the technique is that the wire can fatigue and break. **This complication has occured rarely in cases where 1.25 mm wire was used.** If wire breakage occurs and there are referable clinical signs, the wire is removed. A rare complication is fracture of the wire in the sheath with distal migration of a piece of the wire.

9.5 Results

The advantage of the wiring technique is that it is straightforward and versatile. Its primary disadvantage is that exact anatomic reduction of the fracture is difficult. Gapping of the fragments is perhaps not such a bad thing as long as a graft is used. The bone may heal in a "lengthened" position and lessen the stress at the fracture line when the suspensory apparatus is fully loaded. The results of surgery in a typical case (**Fig. X9A**) and in a case with severe instability (**Fig. X9B**) may be seen in the accompanying radiographs. **Fig. X9C** shows a lateral radiographic view with a failed wire at the distal and palmar edge of the bone.

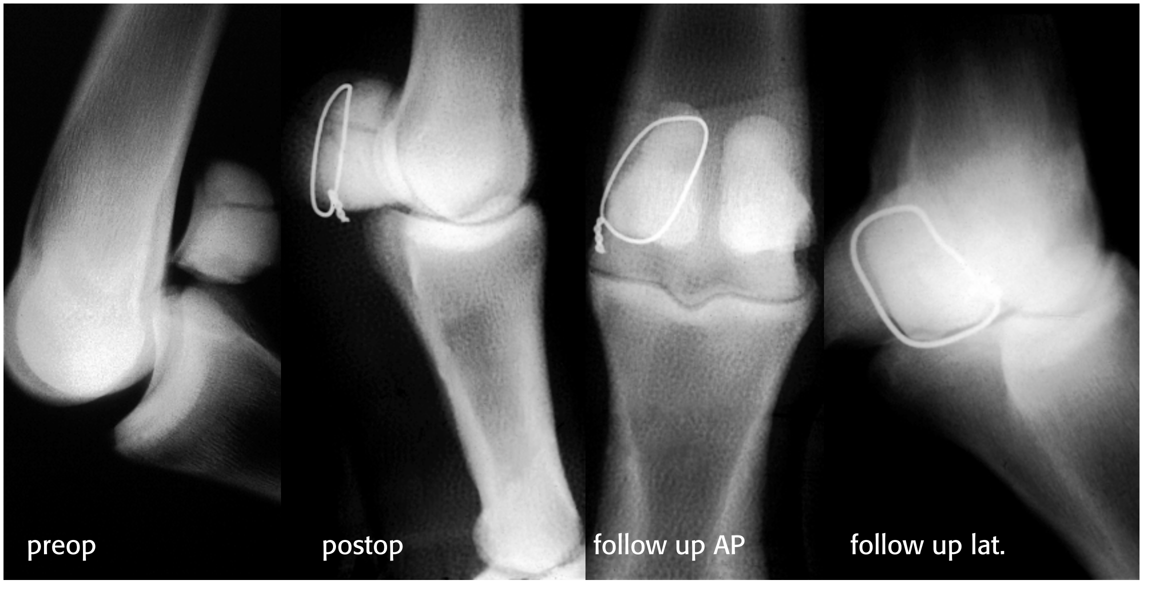

Fig. X9A

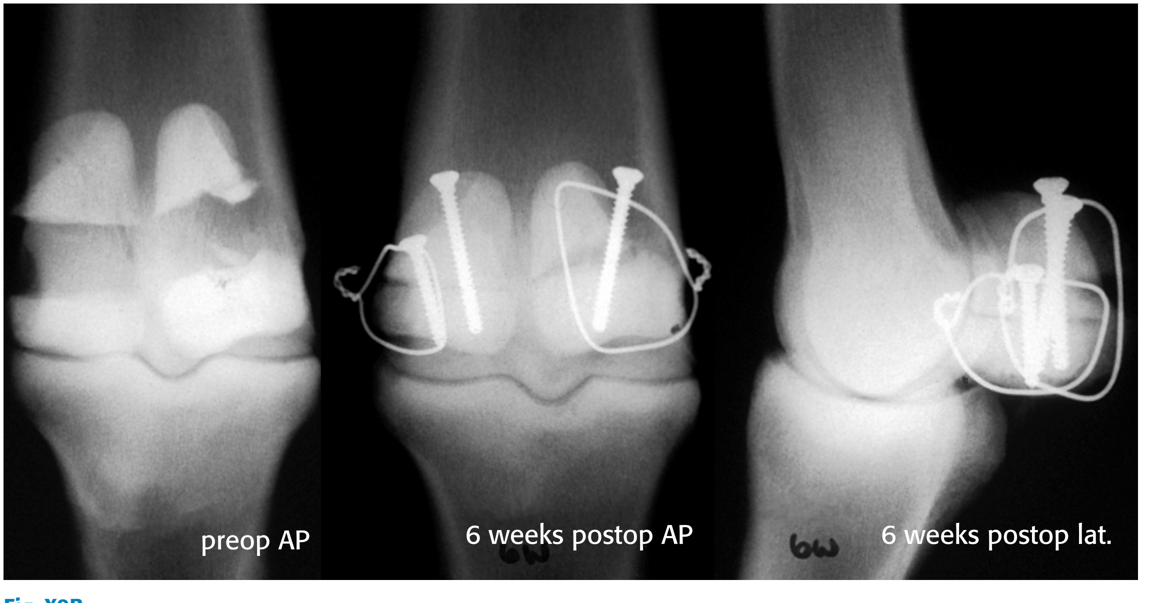

Fig. X9B

Fig. X9C: Lateral radiographic view with a failed wire at the distal and palmar edge of the bone.

9.6 References

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9.6.1 Online references

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10 Proximal phalanx: simple

Larry R. Bramlage

10.1 Description

Sagittal fractures of the proximal phalanx occur primarily in racing horses performing on solid footing such as turf or tracks with little overlying cushion [1, 2]. However, they can occur in any horse that can anchor its foot and create a torsional stress. The fractures initiate at the sagittal groove of the proximal phalangeal articular surface and propagate distally [3, 4]. Fractures are identified in all stages, from those involving only the fetlock joint surface to those that bisect and possibly eventually lead to comminution. **Most fracture planes extend from the proximal joint surface to the dorsal cortex** and then down the palmar/plantar cortex, finally extending into the small medullary cavity in the distal third of the bone, bisecting the top two-thirds of the phalanx [5]. **Nearly all fractures have this component in common**. More severe fractures then propagate from this medullary cavity laterally, medially, or distally and, with continued loading, may split the bone into multiple pieces (**Fig. F10A**).

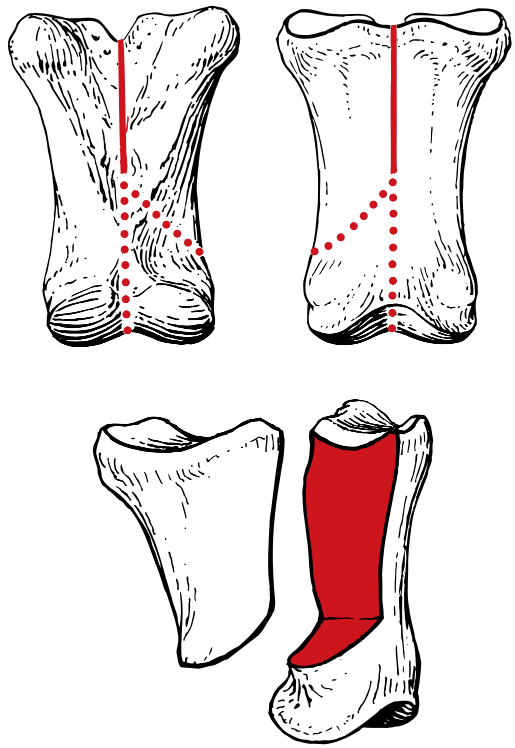


Fig. F10A: At the level of the medullary cavity the fracture plane often deviates laterally or medially, or it may be continued straight and distally into the pastern joint.

Nearly all fractures emanate from the proximal articular surface.

10.2 Preoperative considerations

Healing is expedited by internal fixation.

Minor fractures of only the proximal articular surface cause transient lameness and may require only exercise restriction to prevent crack proliferation and allow healing. If the fracture invades the dorsal or palmar/plantar cortex then **the speed and quality of healing can be maximized by internal fixation**. High quality radiographic examination is necessary to accurately assess the full extent of the pathology present.

10.3 Surgical anatomy

The most proximal screw is centered in the dorsal two-thirds of the bone.

The sagittal component of the fracture is ideal for lateral to medial lag screw fixation and reconstruction of the proximal articular surface. The surgical approach is made medially or laterally over the smaller component (usually lateral) to allow lag screw fixation to the parent portion. In nondisplaced fractures exposure of the fracture plane is not necessary. The desired location for the proximal screw is parallel to the fetlock joint surface just distal to the sagittal groove and centered within the axial weight-bearing area. This will place the screw proximal to the extensor branch of the suspensory ligament. The surgeon must remember that the palmar/plantar third of the palpable proximal phalanx is a "wing" containing no articular surface. Hence **the screw is centered in the dorsal two-thirds of the bone**. (**Fig. F10B**). The distal fibers of the fetlock joint capsule form a margin that reflects the depth of the median sagittal groove, and the first screw is located just distal to these fibers. It is directed parallel to the surface of the fetlock joint (**Fig. F10C**).

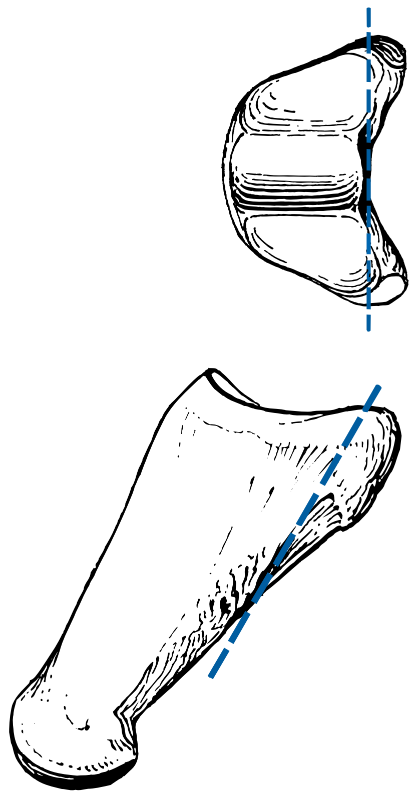


Fig. F10B: The palmar/plantar portion of the proximal surface is mainly condylar. The screws are to be placed beneath the major articular portion of the bone (dorsal to the dotted line.)

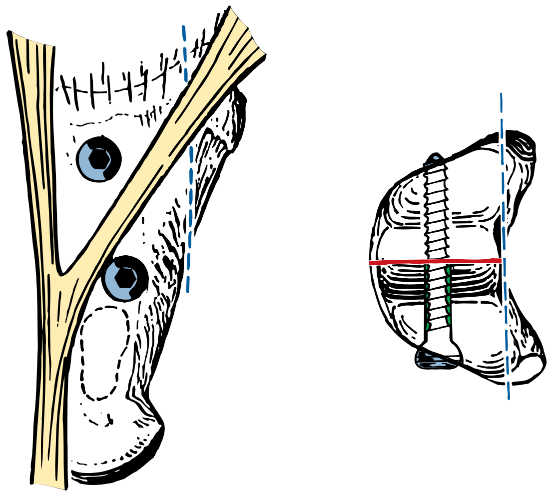
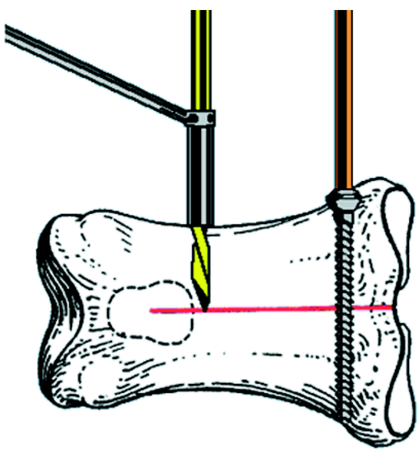


Fig. F10C: The desired locations of the screws are just proximodorsal and just distopalmar/plantar to the extensor branch of the suspensory ligament. To provide optimum stability, they are centered beneath the articular portion of the bone.



Video P1LAGSCR: P1 lag screw fixation.

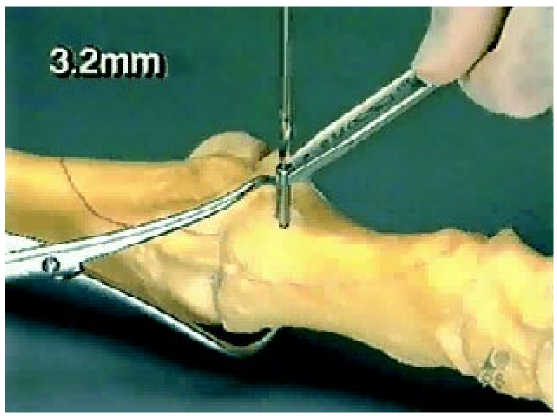
10.4 Surgical procedure

(**Video 31014**, **Video P1LAGSCR**)

The 4.5 mm drill bit is used through the 4.5 mm tap sleeve to create the glide hole in the cis cortex. The tendency to drill perpendicular to the tapering contour of the bone must be resisted. The depth of the glide hole is estimated from the preoperative radiographs. It is essential to cross the fracture plane with the glide hole. The centering guide is used to drill the 3.2 mm hole in the trans cortex.

The countersink is used to trim the cis cortex establishing a bearing surface for the entire circumference of the spherical screw head. **Failure to trim the higher palmar/plantar cortex will result in bending, weakening, and possibly breakage of the screw head.** The depth gauge is used to determine the length of screw desired. The hook should engage the higher, proximal border of the hole to ensure selection of a screw that will adequately engage the cortex.

Inadequate countersinking can lead to deformation or failure of the implant.



Video 31014: Midsagittal fracture of the proximal phalanx.

Tap the entire trans cortex, but do not injure the overlying soft tissues.

The second screw comes to lie in the palpable center of the bone just distal to the extensor branch of the suspensory ligament.

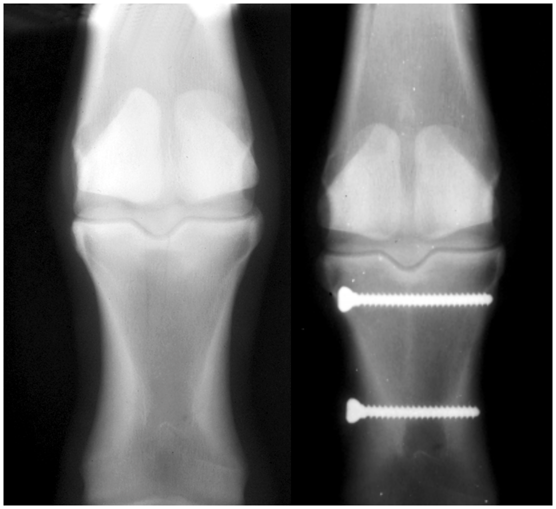


Fig. X10A: Dorsopalmar views of a simple proximal phalanx fracture shows its appearance pre- and postoperatively.

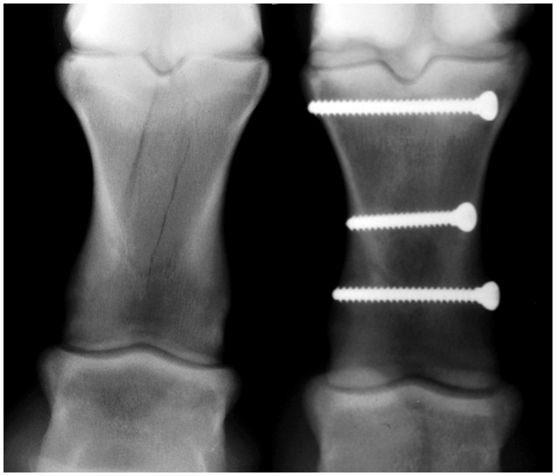


Fig. X10B: The fracture seen in this dorsopalmar view passes through the entire length of the proximal phalanx, and there is displacement along the fracture plane.

The 4.5 mm tap is used through the 4.5 mm tap sleeve to create threads in the parent bone. **Care is taken to thread the entire trans cortex, while not endangering the soft tissue beyond the bone**. The appropriate length screw is then inserted and tightened to compress and stabilize the fracture. The hexagonal tipped screwdriver is left in place within the screw head to act as a guide for more distal screws.

Usually, the second screw is placed parallel to the first in all planes. **It is located in the palpable center of the bone just distal to the extensor branch of the suspensory ligament.** The technical considerations are identical to those respected during insertion of the first screw.

The most common fractures require only two screws for compression and stabilization (**Fig. X10A**). If fractures of unusual or complicated configurations are encountered and more screws are necessary, they are inserted using the same technique, placing the screws in lag fashion across all fracture planes for the maximum stabilization and the highest quality healing (**Fig. X10B**). Where possible, screws should be positioned so as to avoid important soft tissue origins and insertions.

10.5 Postoperative treatment

Postoperatively, a cast or other appropriate external support is used to protect the fracture during recovery. It can then be removed and replaced by a bandage. The horse is normally walking soundly within a few days. With routine fractures, one month of stall rest is followed by one month of hand walking. Radiographs are taken at 60 days. In most cases the proximal phalanx fracture will be healed by then and the horse can resume exercise at will. If the fracture has not healed, exercise is delayed pending radiographic union. In complicated fractures, prolonged cast immobilization and exercise restriction is necessary, the duration of which is determined by the severity of the fracture.

10.6 Complications

With proper attention to detail, complications are rare. Common technique errors include: failure to properly locate the screws, thus reducing the quality of the fixation or endangering the joint or soft tissues; failure to adequately countersink the screw head, resulting in bending; failure to adequately engage the trans cortex, with stripping of the threads from the bone; and failure to maintain aseptic technique resulting in postoperative infection. Even with a less than ideal technique, healing is often still attainable. **Degenerative arthritis is rare, but painful non-union of the articular surface of the fetlock can occur if adequate compression is not achieved.**

10.7 Results

The prognosis for resumption of athletic activity after internal fixation of simple proximal phalanx fractures is excellent. More complicated fractures carry a more grave prognosis commensurate with their severity.

Protect the repair with a cast during recovery from anesthesia.

10.8 References

1. **Barr AR, Denny HR, Waterman AE, et al.** (1988) Proximal phalangeal fractures in the horse. *Vet Comp Ortho Trauma*; 2:86.
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5. **Markel MD, Richardson DW** (1985) Non-comminuted fractures of the proximal phalanx in 69 horses. *J Am Vet Med Assoc*; 186:573.

10.8.1 Online references

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With inadequate compression, degenerative arthritis is rare, but painful non-union may occur.

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11 Proximal phalanx: comminuted

Dean W. Richardson

11.1 Description

Comminuted fractures of the proximal phalanx occur most commonly in racehorses working at high speeds, although they are also seen in animals at pasture. They rarely afflict horses under 2 years of age. In racehorses the forelimbs are affected twice as often as the hindlimbs but there appears to be no significant predilection for the left or right side.

Accurate radiographic interpretation is essential for a complete understanding of the extent of the fracture. **A minimum of four views must be taken in every horse with a proximal phalangeal fracture**. Overlooking a fracture line in a frontal or oblique plane could thwart an attempt to treat an assumed simple sagittal fracture and prove disastrous.

Internal fixation of these fractures should only be undertaken if there is a reasonable expectation that reconstruction will result in a column of bone that will sustain weight bearing forces within a short limb cast. Many fractures of the proximal phalanx are so severe that internal fixation with screws alone, or even with plates, is unlikely to succeed. As a general rule, **surgical reconstruction should not be attempted unless there is a single intact strut of bone that extends from joint to joint.** This allows the comminuted fragments to be reattached accurately enough to the large piece, and to each other, so that the reconstructed cortices will not collapse. In some instances, there may be a simple transverse fracture in the strut that still allows reconstruction. If internal fixation is not feasible, some form of external skeletal fixation (pins incorporated in a fibreglass cast or an appropriate sized external fixator) must be considered. Obviously, the major advantage of internal fixation is that better function of the fetlock joint can be expected and limb length can be reliably preserved.

Take a minimum of four projections of the fractured phalanx.

11.2 Preoperative considerations

As soon as the diagnosis is made, the limb should be protected with a cast or commercial boot [a] that encloses the hoof and extends to the proximal metacarpus, or with one [b] or another [c] variety of splint that aligns the dorsum of the cannon bone with that of the pastern and the hoof wall. Horses should receive broad spectrum antibiotics and non-steroidal anti-inflammatory drugs as soon as possible. Horses in intense pain may benefit from stronger analgesics and sedatives such as butorphanol or xylazine, but care should be taken not to make the horse ataxic. If there is profuse sweating and fluid loss, replacement fluids

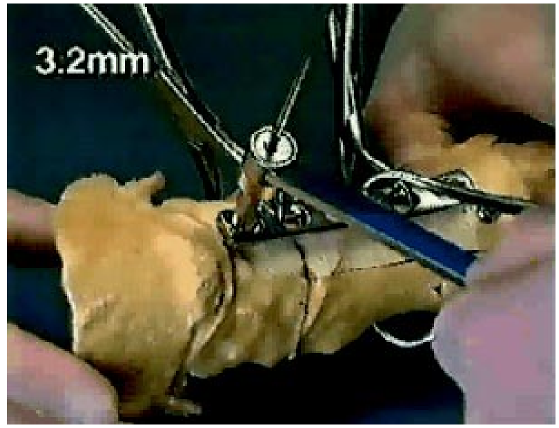
Only attempt surgical reconstruction if there is a strut reaching from joint to joint.

and electrolytes should be given intravenously. Induction of general anesthesia should be performed with an appropriate splint or cast in place and preferably with a sling or table side technique.

11.3 Surgical anatomy

Reconstruct the fracture through an open approach.

Although it is possible to repair such a fracture by placing screws through stab incisions, accurate **reconstruction is greatly facilitated by a more aggressive open approach**. The potentially serious soft tissue damage incurred by the exposure is justified by the accuracy of the internal fixation. In particular, transection of a collateral ligament is necessary to completely expose the proximal joint surface. "H"-flap or "barn-door" incisions and plating of unstable fractures appear to be associated with high infection and failure rates [1].



Video 31027: Fixation of a multifragment proximal phalangeal fracture.

11.4 Surgical procedure

(Video 31027)

Position the horse with the intact strut of bone "down."

The horse should be positioned in lateral recumbency such that the intact strut of the bone is down. In most cases, the intact fragment is medial, and the following description assumes this situation. A tourniquet is not necessary. The skin incision begins at the proximal dorsal edge of the lateral palmar pouch of the metacarpophalangeal joint and curves dorsally over the sagittal fracture line in the proximal phalanx. The distal extent of the curved skin incision ends at the lateral proximal margin of the middle phalanx (Fig. F11A, Fig. S11A). The subcutaneous tissues are incised down to the surface of the extensor tendon and joint capsule. The skin and subcutaneous tissues are retracted and a deep incision made into the palmar pouch. The palmar pouch incision is simply continued around the distal lateral margin of the metacarpal condyle (Fig. F11B). Varus stress is applied during transection of the collateral ligament at the level of the joint surface (Fig. S11B). Cutting the ligament at this level leaves enough tissue for closure (Fig. F11C). This incision is then continued to the dorsal edge of the sagittal fracture plane. The scalpel is then inserted into the fracture line and the extensor tendon split along the length of the fracture. A periosteal elevator is used to lift adherent tissues from the dorsal fracture margins. A scalpel is necessary to expose the surface of the dorsal lateral fragments more completely.

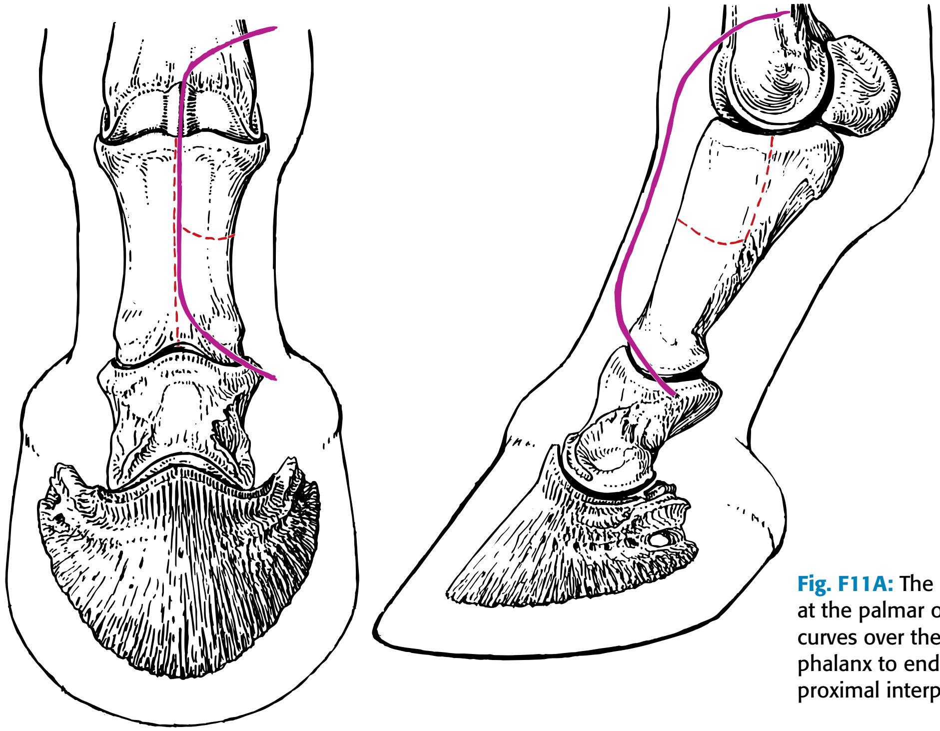


Fig. F11A: The skin incision begins at the palmar outpouching and curves over the face of the proximal phalanx to end at the level of the proximal interphalangeal joint.

Fig. S11A: After incision, the skin and subcutaneous tissues are gently mobilized and a flap is created.

Elevation of the flap using a Hohmann retractor as a lever facilitates exposure and helps assure the creation of a single plane of dissection.

Lavage of the exposed tissues should be performed with liberal amounts of saline containing broad-spectrum antibiotics (e.g., polymyxin B + bacitracin + neomycin or other aminoglycoside) throughout surgery. A spray bottle is very helpful for this purpose and is a more economical method than a bulb syringe.

Copious lavage of the exposed soft tissues.

The fetlock is dislocated to expose the proximal joint surface and relax the distally attached tendons and ligaments. The fragments can

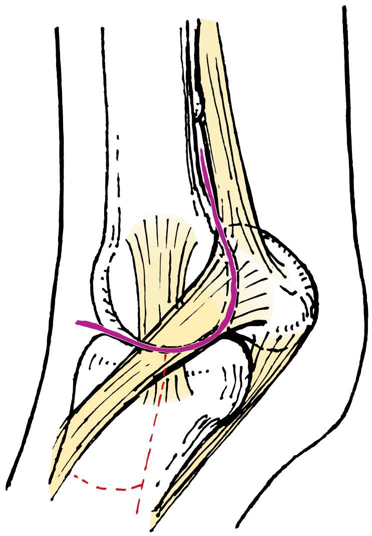


Fig. F11B: The deep incision enters the palmar outpouching, continues through the collateral ligament, and along the articular rim of the proximal phalanx.

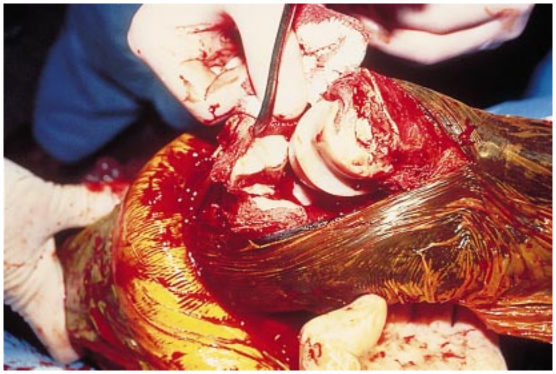


Fig. S11B: With the collateral ligament and the joint capsular attachments severed, the metacarpophalangeal joint may be dislocated to reveal the course and extent of the fractures.

Begin reconstruction at the proximal articular surface.

then be gently separated (if necessary) with a Hohmann retractor to allow debridement of fracture hematoma or interposed bony debris (Fig. F11D). **Reconstruction of the fracture always begins at the proximal joint surface**. It is easiest to repair the deepest fragment (i.e., medial palmar wing) and proceed laterally then distally. The fractures of the palmar wings of the proximal phalanx are repaired with a lag screw directed in a dorsal to palmar direction approximately 1 cm below the joint surface. This then allows lateral to medial screws to be positioned another 1 cm distally, proximal enough to engage the thicker portion of the comminuted fragment but distal enough to avoid the midsagittal groove of the proximal phalanx. After the proximal joint surface is reconstructed, additional screws are placed in

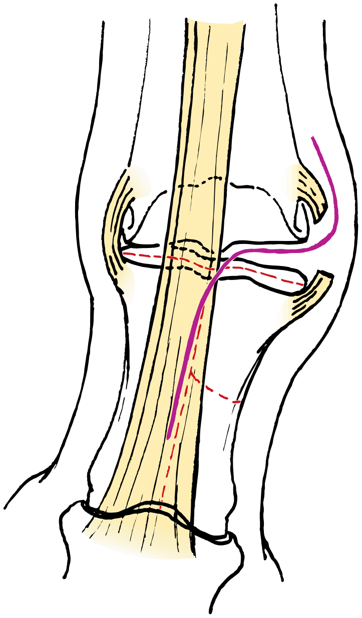


Fig. F11C: Applying varus stress faciliates severance of the ligament at its midsection, allowing ample material for suturing. The incision is then carried distally following the main sagittal fracture line.

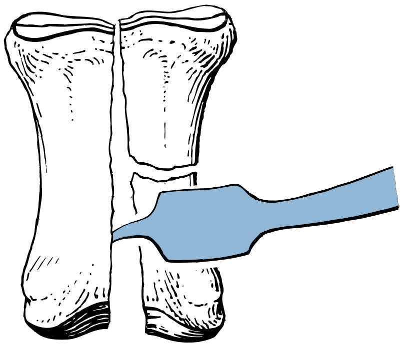
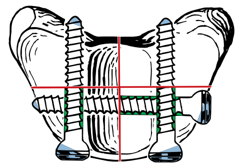
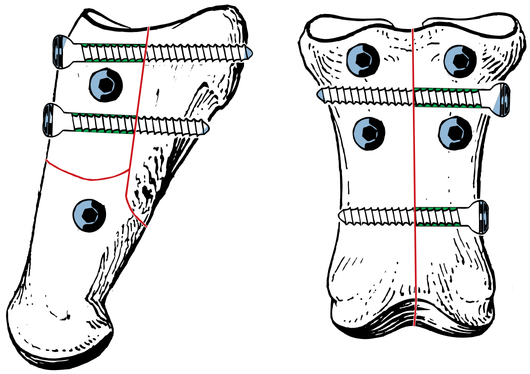


Fig. F11D: Using a Hohmann retractor, the main fragments may be gently separated, and the fracture planes inspected for any additional bony debris.

Fig. F11E: The subarticular screws serve to restore the integrity of the proximal joint surface, while the more distally located implants place the remainder of the fracture plane(s) under interfragmentary compression.





the distal portions of the proximal fragments and remaining non-articular fragments in the mid and distal portions of the bone (**Fig. F11E**). Care is taken to precisely align the fragments since the goal is to reconstruct supporting cortices. It is helpful to keep the screws almost the same transverse plane in order to prevent interference. **Although 5.5 mm screws are considerably stronger, 4.5 mm screws are usually used in an effort to minimize the chances of bits, taps, or screws interfering with one another**. This also allows the flexibility of replacing a stripped 4.5 mm screw with a 5.5 mm implant. Frequently there are narrow dorsal articular wedge fragments or slender mid-diaphyseal fragments that are best repaired with 3.5 mm screws. Minor comminution at the distal articular margin that does not compromise stability is usually ignored. Occasionally a **buttress plate may be used to strengthen the fixation and maintain axis**. Since this is often associated with primary arthrodesis of the proximal interphalangeal joint, it will be discussed in **chapter 21**, Proximal interphalangeal arthrodesis: plate fixation.

The collateral ligament is sutured with interrupted #1 synthetic absorbable suture. The remainder of the tissues (joint capsule and extensor tendon) are apposed with #0 simple interrupted or tension (near-far/far-near or cruciate) sutures. Subcutaneous and subcuticular sutures are usually #00 continuous synthetic absorbable sutures. The skin can be sutured or stapled. Drains are not used. A fiberglass cast enclosing the foot and extending to the proximal metacarpus is applied. The fetlock should be slightly flexed and the heel elevated about 10°–15°.

The screws usually used are 4.5 mm in diameter.

Use buttress plating and primary proximal interphalangeal arthrodesis to strengthen fixation and maintain axis.

11.5 Postoperative considerations

Recovery from general anesthesia ideally takes place in a fashion that minimizes trauma. Deep foam mats, assistance with tail ropes, and judicious use of sedatives are all useful and practical. The duration of antimicrobial prophylaxis is usually less than 24 hours although horses with extensive soft tissue damage may be treated longer. Phenylbutazone is continued as needed. Most horses require less than 2 g/day to remain comfortable. The cast must be checked each day for evidence of discomfort, heat, or drainage. If the horse wears the cast well, **the cast should be left in place for 4–6 weeks**. If the fracture repair was considered tenuous, a second cast should be applied for an additional 4–6 weeks. Horses are strictly confined to a stall until there is radiographic evidence of fracture healing and an apparent return to normal strength of the digital flexors.

The postoperative cast may be left in place for 4–6 weeks.

11.6 Prognosis

Internal fixation of comminuted proximal phalangeal fractures should be considered a salvage procedure with a poor chance of the horse returning to athletic function . Horses with fractures too comminuted to repair with screws have an even poorer prognosis [1–3]. With careful case selection and appropriate technique, moderately comminuted fractures have a good prognosis. In a series of 26 consecutive cases repaired in this manner, 24 healed without major complication. An example of such a case is given in the accompanying radiographs (Fig. X11A). During the same time-span, only seven out of 11 horses with severely comminuted fractures treated with transfixation techniques survived and these required much more extensive hospitalization and expense.

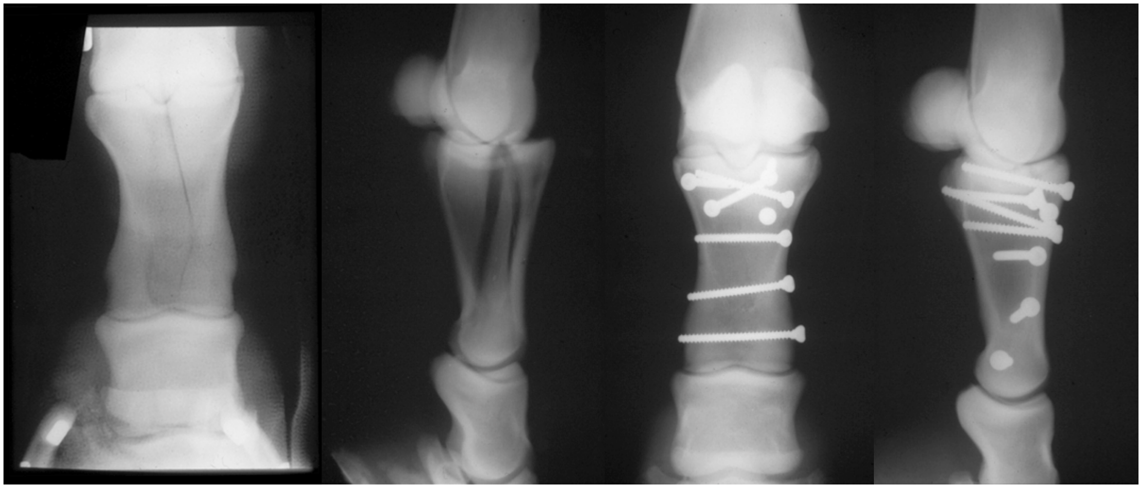


Fig. X11A: Pre- and postoperative radiographs demonstrate the appearance of a fracture treated in the manner described herein.

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2. **Ellis DR, Simpson DJ, Greenwood RE, et al.** (1987) Observations and management of fractures of the proximal phalanx in young Thoroughbreds. *Equine Vet J*; 19:43–49.
3. **Richardson DW, Nunamaker DM, Ross MW** (1992) Management of comminuted fractures of the proximal phalanx in 37 horses. *Proc Am Assoc Equine Pract*; 38:156.

a Farley Compression Boot, Equine Orthotics Inc., 218A E Eau Gallie Blvd, Suite 55, Indian Harbour Beach, FL 32937, USA.

b Kimzey Leg Saver Splint, Kimzey Welding Works, PO Box 1051, Woodland CA, USA.

c Monkey Splint, Primary Structures, PO Box 333, Huntingdon Cambs PE 17 2LW, England.

11.7.1 Online references

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12 Distal phalanx

Gustave E. Fackelman

12.1 Axial fractures

12.1.1 Description

Midsagittal fractures of the distal phalanx occur due to a single traumatic incident that results in rapid spreading of the hoof wall. As such, they are more common in horses that are unshod and that run over hard or stony ground. The distractive forces to which the bone is exposed split it almost exactly in half [1–7] (Fig. F12A). Through internal fixation, **interfragmentary compression and greater stability can be achieved than is possible by corrective shoeing alone** [1–3, 5, 6]. However, in this bone, more than in any other, it will probably be necessary to remove the implant(s). This is due to the tendency for osteolytic changes to develop around the screw head. In the late post-operative period (12–24 weeks), these areas often become secondarily infected, prolonging treatment. **Although some screws have remained in place throughout the operated animals' careers, time has shown these patients to be the exceptions.** The surgeon usually makes the owner aware of these aspects of the treatment, so that plans may be made for the second (removal) surgery 90–120 days after insertion. More recently developed implants such as the cannulated screws [3] (Fig. S12A, Fig. S12B) may alter this *modus operandi*.

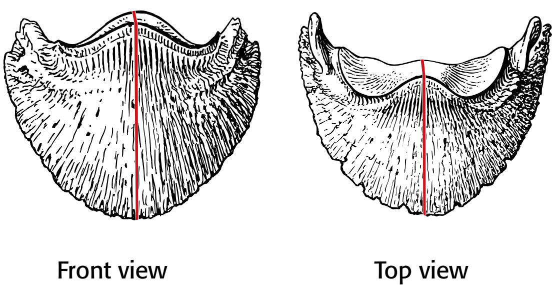


Fig. F12A

Unlike other fractures, most of the screws used here are later removed.

Interfragmentary compression creates greater stability than is possible by corrective shoeing.

12.1.2 Surgical anatomy

Repair is facilitated by the 90° relationship that the fracture plane bears to the sole surface and to the dorsal hoof wall. The desired direction of the screw is: parallel to the sole surface and perpendicular to the long axis of the limb. Since the sole surface thereby becomes a major determinant of the ultimate direction taken by the implant(s), the hoof must be scrupulously balanced prior to surgery. The landmarks for the surgical approach are: the tip of the frog, and a point determined radiographically that is halfway between the articular surface and the semilunar canal, measured on a line drawn parallel

Use a straight instrument placed across the surface of the sole as a guide for drilling.

to the dorsal hoof wall (Fig. F12B). The latter point determines the location of the opening in the hoof wall, while **a straight instrument (e.g., the shaft of the countersink) placed symmetrically across the surface of the sole, just behind (1 cm) the tip of the frog, serves as a guide for drilling** (Fig. F12C).

Fig. S12A: The guide pin for the cannulated screw is inserted to the desired depth.

Fig. S12B: The 7.3 mm cannulated screw of predetermined length is inserted over the guide pin which is afterwards removed.

Use radiographs to identify a point halfway between the semilunar canal and the joint surface.

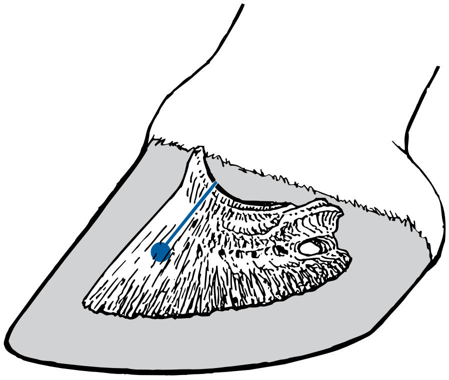


Fig. F12B

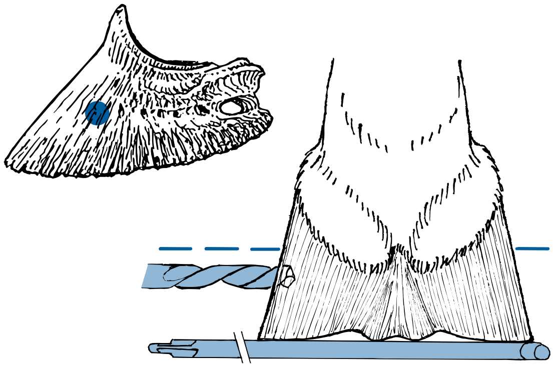


Fig. F12C

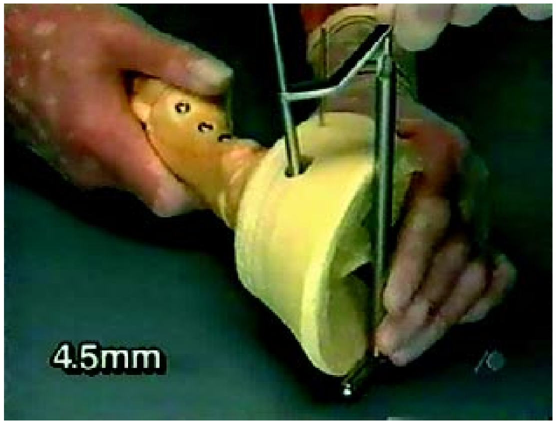
12.1.3 Surgical procedure

(**Video 31017**, **Video 3PHAL_AX**)

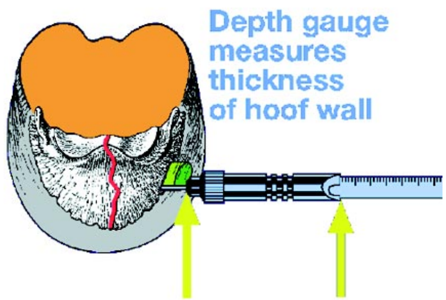
At least 24 hours preoperatively, the hoof is carefully balanced, and cleansed of any debris. The wall is lightly rasped to remove the stratum tectorium and any remaining extraneous material. A bandage is applied and soaked in a tamed iodine solution (e.g., Betadine®). This is left in place overnight, and allows for the absorption of disinfectant into the porous hoof wall. The horse is placed on the operating table with the affected limb uppermost, at which time the bandage is removed.

A series of radiopaque markers (e.g., small washers, lead shot) are taped to the hoof wall, and an accurate lateral radiographic projection is prepared. Using the markers as a guide, a notch is made in the hoof wall indicating the intended point of entry. The surgeon seeks to locate the screw according to the above-mentioned landmarks, i.e., halfway between the articular surface and the semilunar canal, on a line drawn parallel to the dorsal hoof wall. With the notch as a point of reference, callipers are used to take a symmetric measurement of the entire width of the foot (**Fig. F12D**) at that level. The resultant figure is recorded.

After the standard preoperative preparation (**chapter 3**, Pre- and postoperative considerations) of the foot up to the level of the fetlock joint, an adhesive transparent drape is placed covering the entire hoof. Care is taken in the placement of the drape to allow the surgeon to clearly visualize the structures of the sole and the intended point of entry into the hoof wall. The remainder of the limb and the rest of the animal are draped routinely (**chapter 3**, Pre- and postoperative considerations). Provisions are made



Video 31017:
Midsagittal fracture of the distal phalanx.



Video 3PHAL_AX: Animation about axial fracture of the distal phalanx.

Use radiopaque markers to identify the best point to penetrate the hoof wall.

An approximation of hoof wall thickness at the point of entry may be obtained using the depth guage.

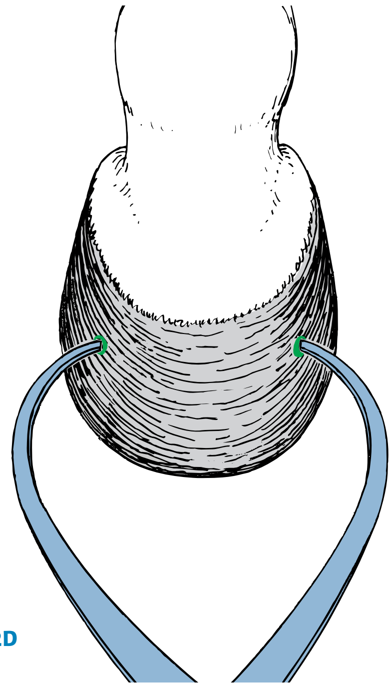


Fig. F12D

for intraoperative radiographs that may be taken without disturbing the aseptic environment.

The hoof wall is opened with a 11 mm drill bit. This is quick and easy and results in a neat hole, although there are other alternatives, such as a trephine or an oscillating saw. Either of the latter methods results in a larger opening, which provides greater latitude in screw placement, but damages more horny tissue.

Using the depth gauge, the hoof wall thickness is measured (Fig. F12E). This measurement is doubled, and the resultant figure is subtracted from the calliper reading of the total width of the foot. The final figure represents the length of screw necessary to just traverse the bone at the operative site.

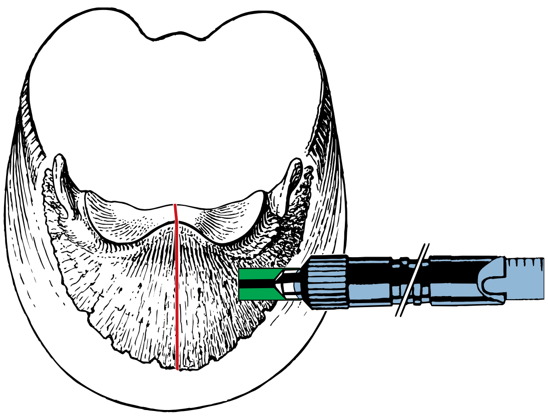


Fig. F12E

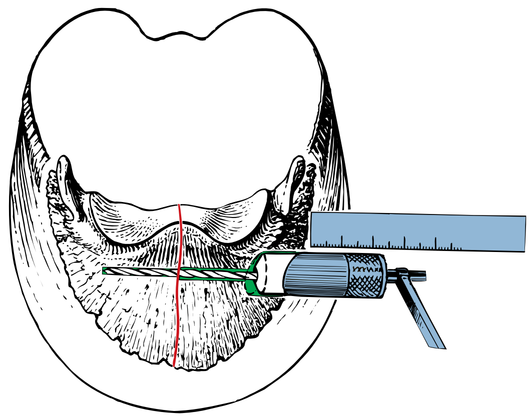
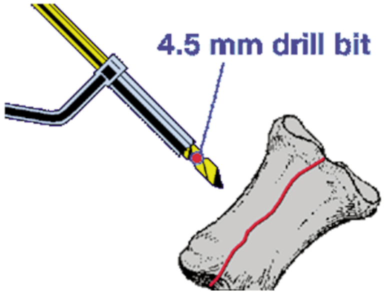


Fig. F12F



Video DBASICS: Animation of drill basics.

The glide and thread holes in the bone are prepared and the screw is inserted as illustrated in the **Video DBASICS**, but **the surgeon is well advised to monitor progress through the bone with a millimeter scale placed close to the operative site** (**Fig. F12F**). The porous nature of the distal phalanx creates a feeling of crossing many "defects" during drilling, only one of which will be the fracture. If the surgeon is anticipating the fracture at a given depth (measured radiographically) and perceives a momentary reduction in resistance to drilling when that point is reached, then he/she will be aware of the adequate depth of the glide hole. This avoids the necessity of multiple intra-operative radiographs. Immediate postoperative radiographs are taken to ascertain the appropriate length of implant (i.e., adequate to engage the parent portion of the bone, but not so long as to engage the opposite hoof wall).

12.1.4 Postoperative treatment

The defect in the hoof wall is packed with a nonsticking dressing, and bandaged with light pressure. This is covered with a thin coating of fiberglass casting material. **The casting material serves both to add stability and to create a clean environment appropriate for healing**. Administration of preoperative antibiotics, usually a combination of penicillin and an aminoglycoside, is initiated the day before surgery, and continued for a full 5days postoperatively. The horse is given 10 days stall rest, after which it may be hand grazed and hand walked. The cast is removed at 6 weeks postoperatively and follow-up radiographs are taken. At this point, the defect in the hoof wall should be clean and dry, and it can be protected with an acrylic patch. The horse is shod with a bar shoe with stout side clips, and the surface of the sole is filled with hard acrylic. Periods of exercise may be increased in duration, but should not be intensified. Riding horses can be exercised under saddle, but only at the walk for the next 6 weeks.

Screw removal is performed through a hole in the hoof wall similar to the one employed for insertion. The new hole may be placed relative to the scar that resulted from the earlier one, at a distance commensurate with the amount of growth of the wall since surgery. Following removal, the hole is packed, and it is again protected with fiberglass. Restricted exercise is continued for 3 weeks, after which time the defect can be patched, a shoe reset, and the level of exercise gradually increased.

A fiberglass shell cast on the hoof provides some stability and maintains a clean environment for healing.

Monitor progress of the drill bit through the bone with a millimeter scale.

The most common complication is late stage infection.

12.1.5 Results

The healing of midsagittal fractures by internal fixation bears a favorable prognosis. Soundness is almost guaranteed if degenerative changes have not already appeared at the time of surgery (**Figs. X12A–C**, **Figs. X12D–F**).

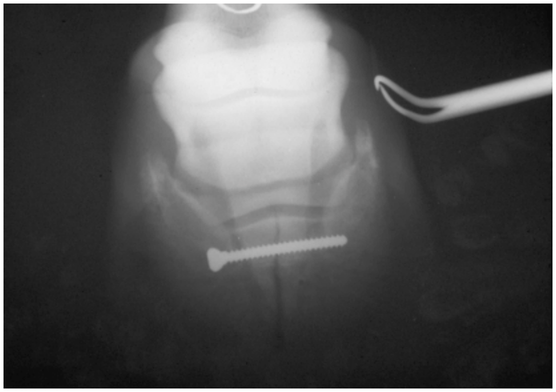


Fig. X12A

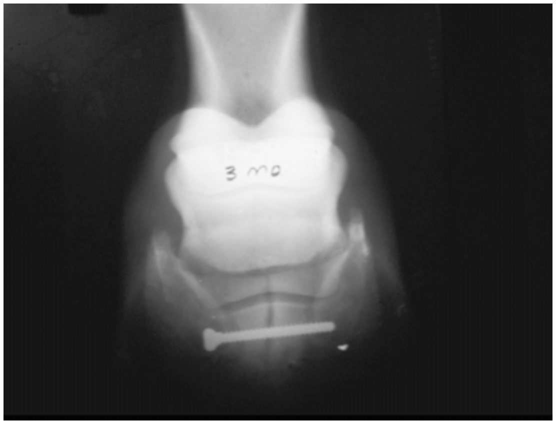


Fig. X12B

12.1.6 Complications

The most common complication encountered will be the late stage infection already noted above. If this is aborted by elective removal of the implant, considerable time and discomfort can be saved.

The next most common set of problems surrounds errors in the orientation of the implant relative either to the fracture or to the surrounding hoof wall. Since the surgeon never actually sees the bone or the fracture, orientation must be based upon local landmarks. A preoperative sketch or plan, practice on cadavers or models, and carefully performed pre-, intra-, and post-operative radiographs are strongly advised.

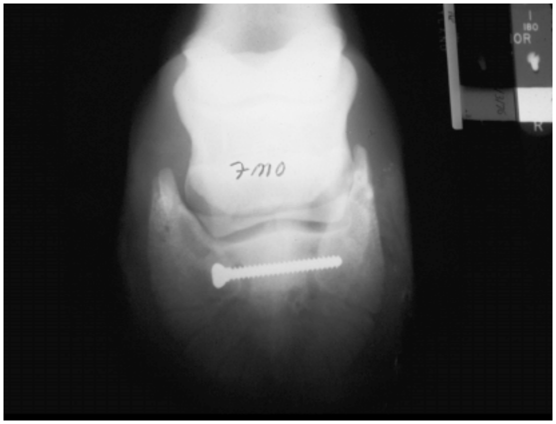


Fig. X12C

12.2 Abaxial fractures

12.2.1 Description

The typical abaxial fracture of the distal phalanx usually affects the right front medial or left front lateral "wings". There is a breed predilection for Standardbred racehorses, and it has been theorized that this has to do with their cornering on a relatively flat, hard portion of the track at speed. The fracture begins proximally at the abaxial aspect of the articular margin of the middle phalanx, and extends distally and further abaxially to involve a varying amount of the spongy bone of the alar process. **The angulation of the fracture may make it difficult to visualize radiographically, but any linear radiolucency not radiating from the center of the phalanx should be considered suspicious and worthy of further investigation**. Due to the relatively greater vascularity in this region, significant osteolysis takes place along the fracture plane and within the substance of the fracture fragment in general.

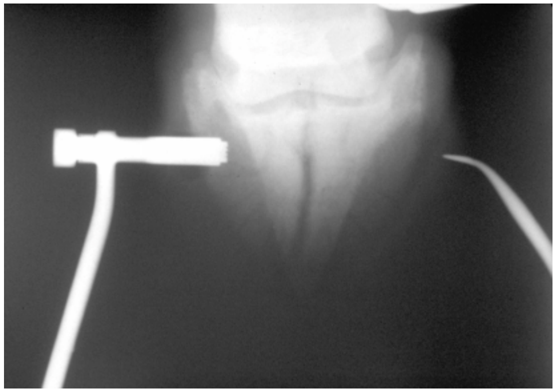


Fig. X12D

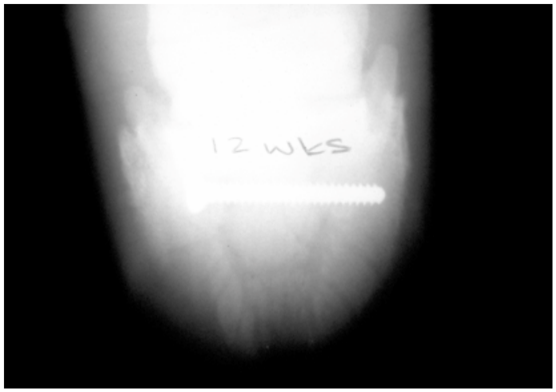


Fig. X12E

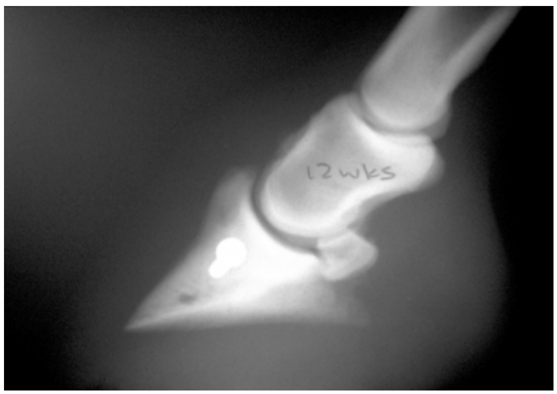


Fig. X12F

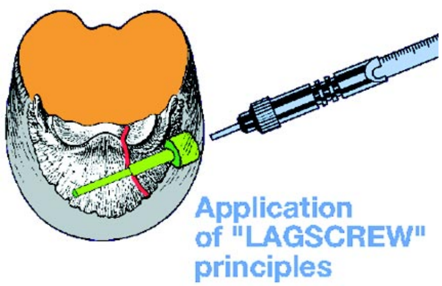
Angulation of the fracture may make radiographic visualization difficult.

Carefully monitor the depth of penetration with a millimeter scale.

12.2.2 Surgical anatomy

The approach to internal fixation of these fractures is the same as that described for midsagittal lesions, with the following exceptions:

- the entry point through the hoof wall is located just behind the center of the approximately tetrahedral fracture fragment;
- the surface of the sole is used as a landmark for the direction of insertion in the transverse plane, but in the frontal plane the screw is directed dorsally and somewhat proximally (approximately parallel to the coronary band) to achieve good purchase in the parent portion of the bone; and,
- it must be recognized that the nature of the osseous tissue of the alar process is quite cancellous, sometimes necessitating the use of a washer to prevent the screw head being drawn into the bone during compression of the fracture.



Video 3PHAL_AB: Animation about abaxial tracture of the distal phalanx.

12.2.3 Surgical procedure

(**Video 3PHAL_AB**)

With the exception of the different means of orientation made necessary by the angular plane of the fracture, the surgical procedure is identical to that described above for midsagittal fractures. **It is even more important to monitor the depth of penetration, as the softer bone is penetrated quickly, and the fracture line may easily be missed**. At the conclusion of the procedure, tangential radiographs are taken to assure that the tip of the screw does not extend beyond the bone's surface.

12.2.4 Postoperative treatment

The postoperative schedule is essentially the same as that noted above, except that the removal of the screw should take place closer to 90 days postoperatively. Otherwise, osteolytic changes and infection may ensue.

12.2.5 Results

Healing of abaxial fractures of the distal phalanx bears a favourable prognosis if the surgical procedure is technically correct, and the implant is removed in a timely fashion (**Figs. X12G-K**).

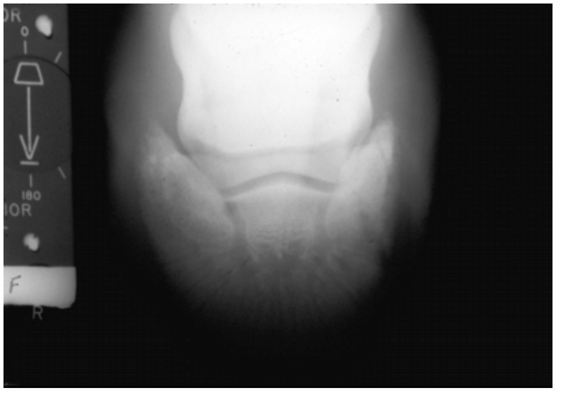


Fig. X12G

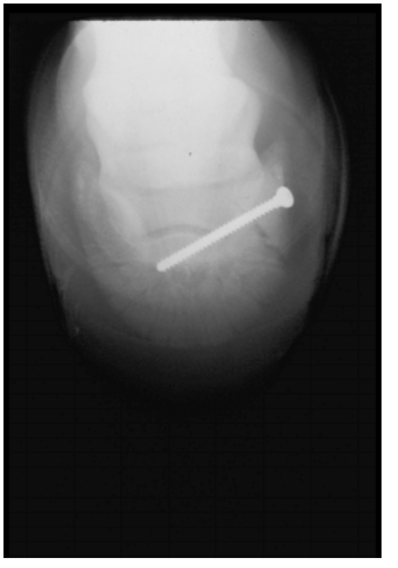


Fig. X12H

Fig. X12I

Fig. X12J

Fig. X12K

12.2.6 Complications

The problems encountered in the healing period are the same as those already noted for mid-sagittal fractures. The nature of the lesion and its location mean, however, that untoward sequelae may develop more rapidly in the case of abaxial fractures.

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13 Humerus

Mark D. Markel

13.1 Introduction

Fractures of the humerus occur in three distinct groups of horses [1, 2]:

- in foals and weanlings secondary to sudden impact such as a fall or kick;
- in racing animals following a fall or **more commonly secondary to fatigue failure of the bone**; and
- in horses used for jumping or steeplechase events following a fall (Fig. X13A).

Fractures of the humerus can be either complete or incomplete, with incomplete fractures most commonly diagnosed in race horses. Incomplete fractures are particularly difficult to diagnose but the increasing use of nuclear scintigraphy on race tracks has enhanced the likelihood of diagnosis of these injuries [2]. Race horses with incomplete fractures (Fig. X13B) are removed from active work and given stall rest for 60–90 days followed by additional small pasture confinement for 30–60 days [3]. **Follow-up radiography and nuclear scintigraphy help confirm successful healing of the fracture.** Complete fractures can be divided into fractures of the proximal humerus including greater tubercle and deltoid tuberosity fractures [2, 4–6]; mid-diaphyseal transverse and spiral/oblique fractures; and distal metaphyseal,

Fig. X13A: Lateromedial radiograph of a mid-diaphyseal oblique humeral fracture in a foal.

Humeral fractures are commonly preceded by fatigue failure in racehorses.

Healing of incomplete fractures is monitored with both radiography and scintigraphy.

Fig. X13B: Lateromedial radiograph of the distal humerus demonstrating periosteal callus (arrow) associated with an incomplete distal humeral fracture in a racehorse.

condylar, and epicondylar fractures. Fractures of the humerus are relatively rare because of the bone's short, thick configuration and its surrounding heavy musculature. Foals are affected much more commonly than adults [1, 2].

The anatomic location of the humerus makes external coaptation impractical.

13.2 Fractures of the proximal humerus

13.2.1 Description

Complete fractures of the proximal humerus are inherently stable because of the support provided by the supraspinatus, infraspinatus, subscapular, deltoid, and biceps tendinous insertions. These fractures are typically managed non-surgically but if significant displacement of greater than 2 cm occurs, a limited craniolateral approach may be made to the humerus and the fracture stabilized with dynamic compression plate (DCP) fixation [2]. Fractures of the greater tubercle can be approached through a limited craniolateral incision and repaired with 5.5 mm cortex or 6.5 mm cancellous bone screws inserted in lag fashion [2, 4]. Fractures of the deltoid tuberosity can be approached through a limited version of the cranial approach to the humeral diaphysis [5]. Repair can be accomplished with 5.5 mm cortex or 6.5 mm cancellous bone screws applied in lag fashion in foals or through the use of a narrow DCP to provide tension band plating in heavier animals.

13.2.2 Preoperative consideration

Fractures of the humerus are too proximal to successfully immobilize, therefore, **external coaptation of the limb is not necessary.**

13.2.3 Surgical anatomy

The approach to the proximal aspect of the humerus is through the tissue plane between the brachiocephalic muscle and the deltoid muscle border overlying the infraspinatus tendon attachment on the greater tubercle [2]. Care should be taken during the surgical procedure not to enter the sheath of the biceps tendon.

13.2.4 Surgical procedure

The animal should be placed in lateral recumbency. A 10–15 cm skin incision should be positioned between the distal end of the scapular spine and the midhumerus centered over the deltoid tuberosity. The incision should parallel the cranial edge of the deltoid muscle so that a tissue plane between the brachiocephalic muscle and the deltoid muscle border can be created down to the greater tubercle. The deltoid and brachiocephalic muscles are elevated and retracted to expose the lateral surface of the proximal humerus. In proximal humeral fractures of the metaphysis or proximal diaphysis, fracture fixation should be accomplished with a narrow 4.5 mm DCP applied to the craniolateral border of the humerus. The plate should extend from the cranial portion of the greater tubercle to the deltoid tuberosity. Rotation and abduction or adduction of the humeral shaft is used to accomplish reduction. For fractures of the greater tubercle [2, 4], the humerus often needs to be rotated in order to achieve reduction of the fracture. Reduction is confirmed by digital palpation, and fixation is achieved with 5.5 mm cortex or 6.5 mm cancellous bone screws inserted through the fracture fragment into the distal-medial cortex of the humeral diaphysis. Screws should be oriented to counteract the pull of the infraspinatus tendon. Fractures of the deltoid tuberosity can be repaired either with 5.5 mm cortex or 6.5 mm cancellous bone screws applied in lag fashion in a cranial to caudal distal direction or in adult animals through the use of a narrow DCP applied as a tension band [2, 5]. Conservative treatment is an alternative option.

13.2.5 Postoperative treatment

External coaptation is not utilized postoperatively. The animal should be assisted in recovering from anesthesia. If a buoyancy recovery system is available, the chance of implant failure during recovery is reduced. Perioperative broad spectrum antimicrobial therapy accompanied by anti-inflammatory treatment should be administered for a minimum of 5 days following surgery. Anti-inflammatory therapy may be required for a prolonged period depending on the degree of lameness the animal exhibits. The contralateral limb should be bandaged. Animals should be stall confined until radiographic evidence of union has occurred.

13.2.6 Complications

The major complication following repair of the proximal humerus is catastrophic failure of the implants, either during recovery or after surgery. This is particularly true in adults where early in the course of healing the fixation relies solely on the implants for stability. If, at any time, increased lameness is observed, repeat radiographs should be performed to determine whether implant failure has occurred.

Catastrophic failure of implants is the major complication seen.

13.2.7 Results

The prognosis for horses with proximal humeral fractures is guarded, although the prognosis for horses with these fractures is better than for horses with diaphyseal or distal metaphyseal fractures [7, 8]. In a retrospective study of equine humeral fractures, nine animals presented with proximal humeral fractures, five were destroyed without treatment, three were managed conservatively, and one was treated surgically [7]. The outcome was successful in the case of two out of the three conservatively treated animals and the one surgically treated animal. **The prognosis for animals with greater tubercle or deltoid tuberosity fractures is good as long as the fracture is not severely comminuted** [4–6]. As is true for most fractures in the horse, foals have a better prognosis than adults for a successful outcome. In horses with incomplete proximal humeral fractures that are treated conservatively, the prognosis is good to excellent for return to soundness following complete healing of the fracture [2].

Simple fractures of the greater tubercle or the deltoid tuberosity bear a good prognosis.

13.3 Mid-diaphyseal fractures of the humerus

13.3.1 Description

Mid-diaphyseal fractures of the humerus can be managed in three ways. Two relatively recent reports claim that non-surgical management of these fractures is at least as good as surgical management with regard to long-term functional outcome and survival rates [7, 8]. Of the surgical options, double plate fixation can be attempted in both adults and foals (**Fig. X13C**), whereas interlocking nail fixation should be reserved for animals weighing less than 200–250 kg [2, 9]. Fractures in foals weighing less than 150 kg may be stabilized using a single broad DCP placed on the cranial cortex. Generally, fracture fixation should be attempted in adults only when the fracture has minimal comminution with an intact caudal cortex, or in transverse fractures where there is little likelihood that conservative management will result in a successful outcome.

13.3.2 Preoperative considerations

Assess radial nerve function preoperatively.

Complete fractures of the diaphysis typically cause the horse to carry its limb with a dropped elbow and the carpus and fetlock in flexion [1, 2]. Importantly, the status of the radial nerve should be assessed since diaphyseal fractures can traumatize and even sever the radial nerve, resulting in a hopeless prognosis. Additionally, fractures of the olecranon should be ruled out since they cause similar clinical signs. **Preoperative assessment of the radial nerve can include electrodiagnosis in the form of nerve conduction velocity determination by evaluation of spinal somatosensory-evoked potentials or muscle action evoked potentials.** Since the radial nerve does not have an autonomous sensory zone, the use of peripheral skin desensitization as an indicator of radial nerve damage is not recommended. In chronic injury, electromyography of the antebrachial extensor muscles can be used to evaluate radial nerve function. Other important preoperative considerations include the degree of fracture comminution and the weight of the animal. In severely comminuted fractures and/

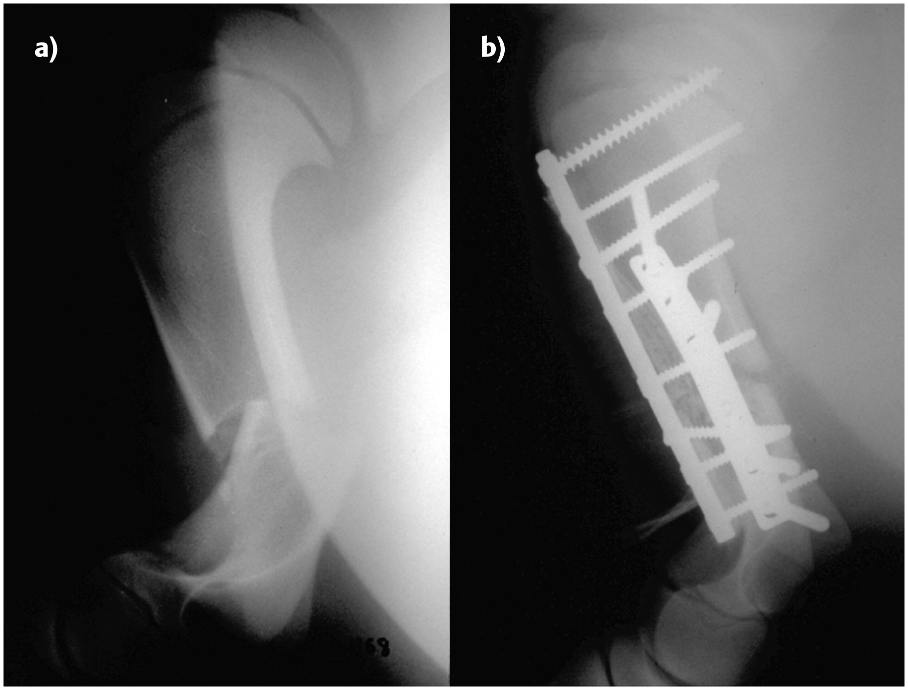

Fig. X13C: a) Lateromedial radiograph of a transverse distal diaphyseal humeral fracture in a foal.
b) Postoperative radiograph demonstrating double-plate fixation with cranial and lateral dynamic compression plates.

or in animals that weigh more than 500 kg, the prognosis for successful repair of the fracture is grave and should probably not be attempted. Additionally, if the caudal cortex in adult horses is disrupted and cannot be reconstructed there is a high likelihood of fixation failure following surgery.

13.3.3 Surgical anatomy

For plate fixation of diaphyseal fractures, the cranial approach to the humerus should be utilized [10, 11]. This exposes the flat, smooth, cranial surface of the humerus for placement of a broad DCP. In adults, a second plate needs to be applied due to the size of the animal, and should be placed laterally, immediately caudal to the deltoid tuberosity. The skin incision is made from the cranial eminence of the greater tubercle to the cranial border of the radius over the extensor carpi radialis muscle. The superficial branch of the cephalic vein must be ligated and severed in order to approach the bone. Proximally, the brachiocephalic muscle is divided in order to expose the deltoid tuberosity. Distally, the attachments to the brachiocephalic muscle are severed from the humeral crest. If a lateral plate must be applied, the insertion of the deltoid muscle is severed from the tuberosity in order to expose the humerus. The biceps brachii on the cranial surface of the humerus is retracted medially and **care must be taken when manipulating the brachialis muscle**

Avoid damage to the radial nerve when manipulating the brachialis muscle.

to avoid traumatizing the radial nerve that is located on its caudal border. In order to achieve exposure distally, the origins of the extensor carpi radialis muscle on the humerus are severed and the muscle is retracted laterally.

If the fracture is to be repaired using intramedullary interlocking nail fixation [2], the cranial approach can be used but a modified lateral approach is favored for most fractures. For the lateral approach, an incision is made from the greater tubercle to the caudal aspect of the lateral epicondyle. The incision should be centered over the deltoid tuberosity and the cranial border of the lateral head of the triceps. The brachiocephalic muscle is incised proximally to expose the craniolateral aspect of the proximal humerus. As described for the application of the lateral plate in the cranial approach, the deltoid muscle insertion is incised to expose the proximal humeral metaphysis. Distally, the lateral head of the triceps is separated from the extensor carpi radialis and the brachialis muscles to allow identification of the distal humerus. Again, caution must be taken when manipulating the brachialis muscle to avoid trauma to the radial nerve on its caudal aspect. The cranial aspect of the distal humerus is exposed through dissection of the origin of the extensor carpi radialis muscle. Importantly, **the continuity of the radial nerve should be verified since severance of this nerve by the fracture would warrant euthanasia of the animal**.

> For application to the cranial surface, the distal end of the plate must undergo considerable contouring.

> Severance of the radial nerve at the diaphyseal level of the humerus is an indication for euthanasia.

13.3.4 Surgical procedure

For diaphyseal fractures repaired with one or two DCPs, the cranial portion of the humerus is exposed through a skin incision made over the cranial surface of the humerus. Following identification of the radial nerve, the brachialis muscle is retracted either craniomedially or caudolaterally during placement of the plates [10, 11]. Since the overwhelming majority of these fractures are either oblique or spiral with significant overriding, a fracture distractor is typically applied to the greater tubercle and the distal humeral condyles to achieve reduction. Sometimes, a calf-jack seated in the axillary region and applied to the distal limb may be necessary in order to assist with reduction. Fracture reduction is maintained through the use of bone holding forceps, cerclage wire fixation, or lag screw fixation outside of the plane of the DCP. A 4.5 mm DCP is then applied to the cranial surface of the humerus following contouring of the plate. **The distal aspect of the plate needs to be modified considerably in order to be adequately contoured to the curvature of the distal cranial humerus**. 5.5 mm cortex screws should be used to apply the plate, with 6.5 mm cancellous bone screws used in areas of soft bone. In adults and animals weighing more than 150 kg, plate luting with methylmethacrylate is recommended. Cancellous bone graft should also be considered in order to speed healing of the fracture. In animals that weigh more than 150 kg and therefore require a second plate to be placed caudal to the deltoid tuberosity, a narrow or broad 4.5 mm DCP should be applied laterally with 5.5 mm cortex screws. Again, this plate should be luted. Suction drains should be placed deep in the wound over the cranial plate. Continuous suction should be maintained after surgery. The muscles that were transected, including the brachiocephalic and deltoid muscles should be reattached and the extensor carpi radialis and brachiocephalic muscles apposed. Tension sutures should be placed in the skin and a stent applied over the wound.

For interlocking nail fixation, the fracture should be reduced as described for double plate fixation, and normograde reaming of the proximal humerus performed via the humeral fossa [2]. To access the humeral fossa, the biceps brachii is retracted medially following incision of its lateral fascial attachments to the craniolateral aspect of the humerus. The supraspinatus muscle is bluntly dissected, and the humeral fossa and medullary canal of the humerus is reamed to a diameter of 13 mm. A suitably sized interlocking nail is inserted from the humeral fossa past the fracture gap into the distal metaphysis of the humerus using an alignment jig. **Cortex screws measuring 5.5 mm are placed through the bone and nail, making certain to fully engage the opposite cortex**. In soft foal bone, a washer may be required to prevent the heads of the interlocking screws from penetrating the cortical bone. Ideally, three screws proximal and three screws distal to the fracture should be applied. The lateral fascial attachment of the biceps muscle should be reattached to the craniolateral humerus and the insertion of the deltoid muscle and extensor carpi radialis muscle reattached. Tension sutures should be placed in the skin and a stent placed over the wound. Since interlocking nail fixation is normally applied only in foals, positive suction drains may not be necessary.

Other methods described for the repair of diaphyseal fractures of the humerus in foals include stacked pinning with multiple intramedullary pins (**Fig. X13D**) or single intramedullary rod fixation [1, 7, 8]. Although successful stabilization of fractures may occur with these techniques, pin migration is a common occurrence. If fixation of oblique fractures is attempted, wire cerclage should accompany it to enhance torsional rigidity. Normograde insertion of the pins via the humeral fossa is recommended.

Perform normograde 13 mm reaming via the humeral fossa for interlocking nail fixation.

13.3.5 Postoperative treatment

Animals should be assisted in arising during recovery from anesthesia. As described for proximal humeral fractures, recovery in a buoyancy tank, if available, may help prevent failure of the implants. Support bandaging of the contralateral limb and deep bedding may assist with prevention of laminitis in the contralateral limb. Perioperative antimicrobial therapy and nonsteroidal anti-inflammatory drugs are recommended after surgery.

13.3.6 Complications

Use 5.5 mm cortex screws to transfix the interlocking intramedullary nail.

Catastrophic failure of the bone or implant is relatively common in diaphyseal fractures that are repaired surgically [7, 8]. This is particularly true in animals weighing more than 150 kg. Other potential complications include persistent radial nerve paralysis secondary to the initial injury or to trauma to the radial nerve that occurs during surgery. If the radial nerve has been traumatized, persistent paresis or paralysis usually ensues with little chance of complete recovery. **Another reported complication in foals is varus deformity of the contralateral carpus, secondary to excessive weight bearing during growth**. This deformity can theoretically be treated via transphyseal bridging of the lateral distal radius. Due to the long duration of many of these surgeries, postoperative infection is always a possibility.

A postoperative complication in foals may be angular deformity of the opposite limb.

Complications associated with stack pinning or single intramedullary nail fixation include migration of the pins proximally through the humeral fossa or distally into the elbow joint.

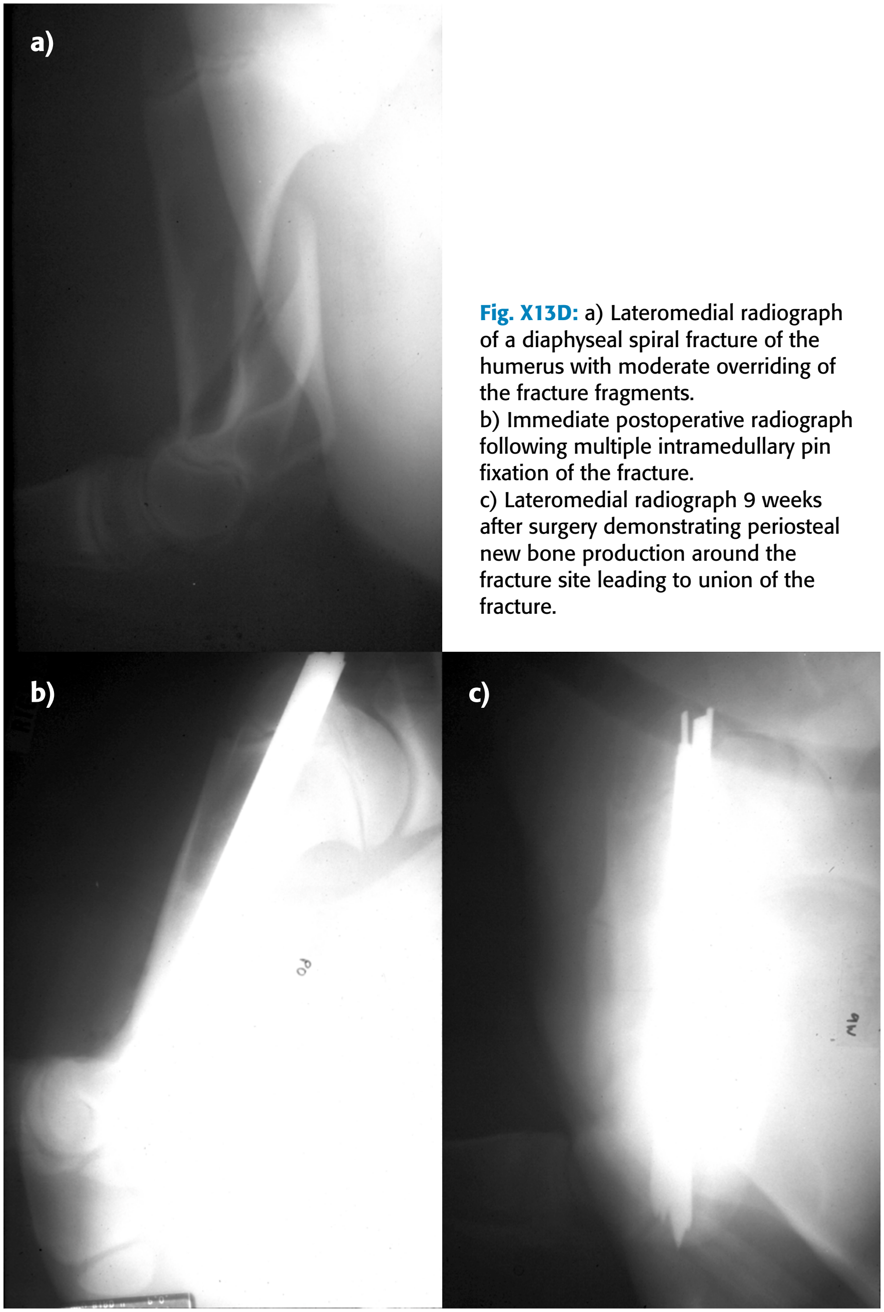

Fig. X13D: a) Lateromedial radiograph of a diaphyseal spiral fracture of the humerus with moderate overriding of the fracture fragments.
b) Immediate postoperative radiograph following multiple intramedullary pin fixation of the fracture.
c) Lateromedial radiograph 9 weeks after surgery demonstrating periosteal new bone production around the fracture site leading to union of the fracture.

13.3.7 Results

Animals with diaphyseal fractures of the humerus have a guarded prognosis for survival following surgery [7, 8]. Recent reports indicate that conservative management of **horses with diaphyseal humeral fractures typically have at least as good a prognosis, if not a better prognosis for survival, as horses that have undergone surgical management of the fracture** [7, 8]. To date, there have been too few humeral fractures repaired in adult horses to know whether surgical repair should be strongly recommended. In foals weighing less than 150 kg, successful repair of the fracture with either plate fixation or interlocking nail fixation has been reported and the prognosis for these animals is fair.

Conservative treatment may be better than operative treatment.

13.4 Distal metaphyseal condylar fractures of the humerus

13.4.1 Description

Fractures of the distal condyle of the humerus and epicondylar region can occur in foals and in adults. These fractures typically involve the medial condyle and/or epicondyle and may require lag screw fixation with or without the application of a DCP utilizing a medial approach to the elbow [2, 12].

13.4.2 Preoperative considerations

Since fractures of the distal condyle or epicondylar region typically occur secondary to external trauma, **fracture fragments within the elbow joint may accompany these fractures.** Radiographs should be carefully evaluated to determine whether arthroscopic removal of fragments is required. Other preoperative considerations are similar to those described for diaphyseal fractures.

The high energy involved in creating these fractures may result in intra-articular fragments.

13.4.3 Surgical anatomy

The medial condyle is often involved in injuries of the distal humerus requiring lag screw fixation through a medial approach. A 15 cm vertical incision is centered over the radius and the superficial transverse pectoral muscle [13]. The transverse pectoral muscle is dissected bluntly between its fiber planes that run in a slight cranioventral direction. The superficial fascia overlying the neurovascular plexus and flexor carpi radialis muscle is incised. The fascial sheath of the flexor carpi radialis is incised along its cranial border, and the muscle belly is retracted caudally to expose the distal humerus.

13.4.4 Surgical procedure

Depending on the fracture configuration, following a medial approach to the distal humerus, lag screw fixation of the fracture is accomplished with 5.5 mm cortex screws or 6.5 mm cancellous bone screws [2]. If deemed necessary, a narrow DCP can be used to stabilize the fracture. Typically the fascial sheath over the extensor carpi

Distal metaphyseal fractures bear a guarded prognosis.

radialis muscle is left open and the transverse pectoral muscle is closed along with the subcutaneous tissue and skin. Tension sutures should be placed in the skin accompanied by the application of a stent over the surgical wound.

13.4.5 Postoperative treatment

All animals should be assisted during recovery from anesthesia. If a buoyancy flotation tank is available, it may prevent failure of the implants during recovery. Perioperative antimicrobial therapy and nonsteroidal anti-inflammatory drugs should be administered for at least 3–5 days after surgery. Longer administration of nonsteroidal anti-inflammatory therapy may be required if the animal suffers persistent lameness. Protection of the contralateral limb through support bandaging, appropriate shoeing, and deep bedding, helps alleviate laminitis in adults and development of angular limb deformity in foals.

13.4.6 Complications

Similar to the preceding two fracture forms, the most common complication is implant and/or bone failure. Although less common, radial nerve paralysis is possible secondary to a distal metaphyseal injury.

13.4.7 Results

Animals with distal metaphyseal fractures should be given a guarded prognosis for survival. Published reports indicate that conservative therapy may be as successful as surgical management of these fractures [7, 8, 12]. Less than a 50% prognosis for survival should be anticipated, with foals having a much higher prognosis than adults.

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14 Radius

Jörg A. Auer & Gustave E. Fackelman

14.1 Description

Complete radial fractures are to be distinguished from incomplete fractures. In most cases, only complete fractures of the radius are treated by means of internal fixation. Incomplete fractures are usually managed by stall rest and limitation of movement by cross-tying to prevent recumbency [1]. In foals, transverse or short oblique fractures of the mid-diaphyseal region and proximal oblique fractures of the proximal metaphysis are most frequently diagnosed [2]. Most of these fractures occur as a result of a kick. Adult horses most frequently acquire comminuted fractures of the diaphysis or the proximal or distal metaphysis. The antebrachiocarpal or elbow joint is rarely involved. Occasionally, simple long or short oblique fractures are encountered also in the adult horse. Again, the cause of the fracture is in most cases blunt trauma (kicks or falls). **Since the medial aspect of the bone is only covered by the periosteum, subcutaneous tissue, and skin, type I or type II open fractures frequently occur in this region.** If this is the case, the prognosis is significantly worse. Careful preoperative management is of paramount importance if internal fixation is to succeed. Therefore, emphasis has to be placed on first-aid immobilization of the fracture and expedient transport to a well-equipped clinic staffed by a knowledgeable surgeon [3].

In mid-diaphyseal fractures of foals younger than 6 months of age, only one plate is applied, placed on the cranial or slightly craniolateral aspect [2]. The cranial aspect of the radius is exposed to strong, almost purely tensile forces [4, 5], assuring solid fixation by means of one single plate. These animals weigh less, which further reduces the strain to which the implant will be subjected. A prerequisite for successful treatment is solid bone-on-bone contact at the caudal cortex after reduction. In most cases, short oblique metaphyseal fractures necessitate two plates, even in foals. Shorter plates are employed and care is taken that both plates do not end at the same transverse level.

Treat mid-diaphyseal fractures in foals with one craniolateral plate.

In all adult horses, two plates are applied at a 90° angle to each other [6]. The compression plate is applied to the cranial or slightly craniolateral aspect, while the lateral or, in selected cases, the medial plate is applied as a neutralization plate. Long plates laterally spanning the entire length of the radius are difficult to apply because the middle portion of the straight plate extends beyond the curved caudal edge of the bone. This makes screw insertion difficult or even impossible [6]. Therefore, it is advisable to contour the plate in such a way that it fits onto the lateral (or medial) aspect in the distal half of the bone, and on the craniolateral (or craniomedial)

Open fractures are common due to minimal soft tissue cover.

Contouring will involve torsional as well as axial bending.

The tension side of the bone is slightly craniolateral.

The preferred approach is between the extensor carpi radialis and the common digital extensor.

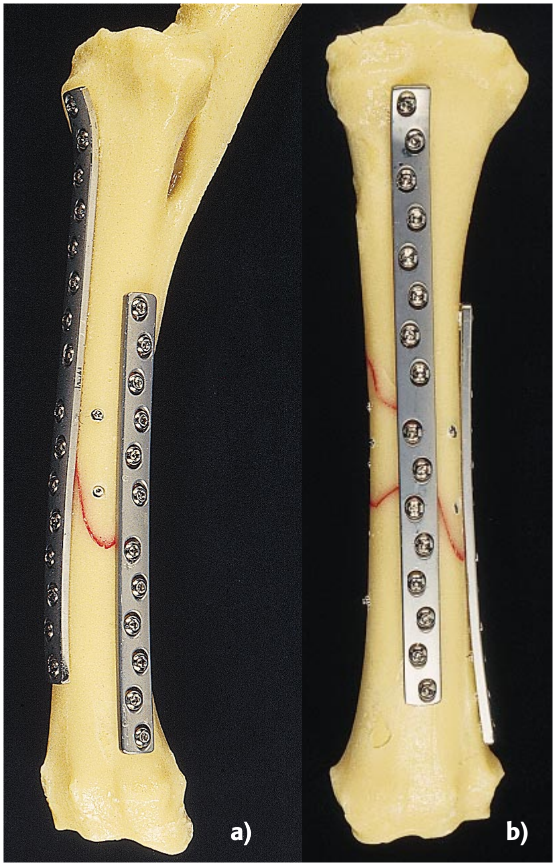


Fig. S14A: Lateromedial (a) and craniocaudal (b) view of a mid-diaphyseal multifragment radial fracture in a plastic bone specimen, repaired with two 3.5 mm cortex screws applied in lag fashion and two broad DCPs. One plate is applied to the cranial aspect of the bone and the other one to the lateral aspect. Please note that together the two plates span the entire bone.

aspect in the proximal region (**Fig. S14A**). **This involves some torsional bending of the plate in addition to axial bending.** Practicing plate contouring on cadaver bones prior to using the technique in surgery is very helpful.

14.2 Surgical anatomy

Viewed from the lateral aspect, the radius has a gently curved shape with the diaphysis being located more cranially than the metaphysis. **This shape of the bone results in a strong tension side at the cranial or somewhat craniolateral aspect of the bone**. Only the most proximal aspect is covered by muscle (brachialis and biceps brachii) in addition to skin, subcutaneous tissues, and periosteum [**7**]. The other muscles are located at the caudal aspect of the limb, some of them covering the lateral and cranial portions. The approach to the bone is dependent somewhat upon the configuration of the fracture. **It is preferably carried out through the craniolateral aspect and between the extensor carpi radialis and the common digital extensor** (**Fig. F14A**) [**7**]. The intermuscular septum between these muscles is sharply transected and the radius is exposed by blunt dissection. In displaced fractures, the fragments and the sharp edges of the bone are palpated, taking care not to puncture the surgical gloves. Double gloving is encouraged to increase protection of the fingers and to prevent contamination of the surgical site. Typically, the periosteum at the fracture site has been circumferentially disrupted by the initial trauma. A large hematoma forms in this region and is evacuated as the fracture ends are exposed. At a)

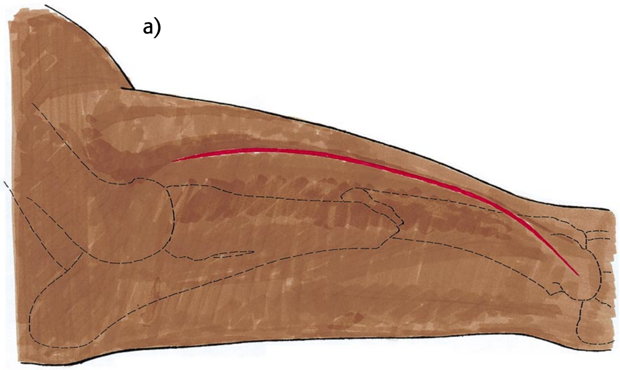
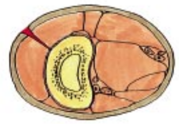


Fig. F14A: The radius is preferably approached at the dorsolateral aspect between the extensor carpi radialis and the common digital extensor muscle. A straight or slightly curved skin incision is performed, starting proximally at the level of the elbow joint and extending distally to the carpal region. a) Side view, b) cross-sectional view.

b)



a)

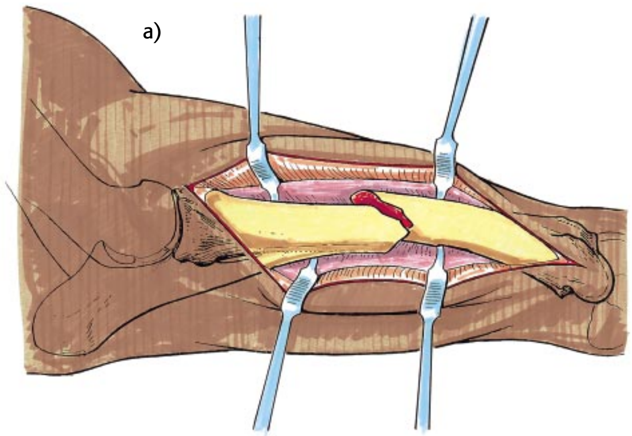
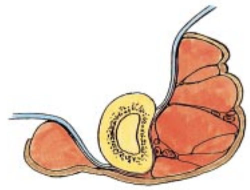


Fig. F14B: After transecting the intermuscular septum, evacuating the hematoma, incising and reflecting the periosteum longitudinally with the help of Hohman retractors, the bone is widely exposed. a) Side view, b) cross-sectional view.

b)



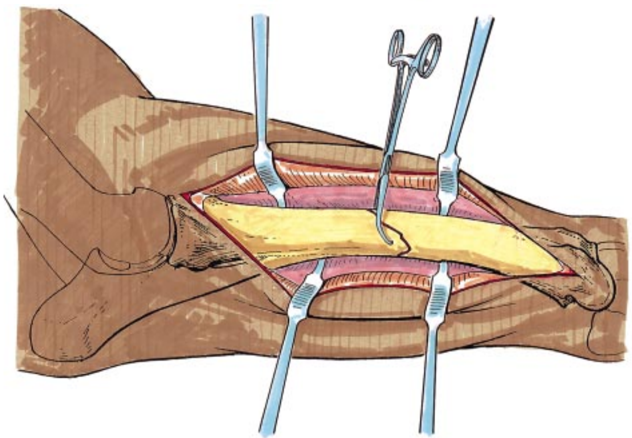


Fig. F14C: After reduction, the short oblique fracture is temporarily maintained in position through application of one or two large pointed reduction forceps.

Split and elevate the periosteum along the craniolateral aspect of the bone.

Apply continuous gentle traction to overcome muscle spasm.

Insert lag screws to maintain initial reduction.

the craniolateral aspect the periosteum is split along the entire length of the bone and elevated (**Fig. F14B**). By applying this technique, excessive dissection of tissue planes with its inherent danger of seroma formation is diminished. After adequately exposing the bone, reduction of the fracture is achieved either by specific manipulations or by applying tension to the limb. **In severely displaced fractures—it is advisable to have an assistant, gloved and prepared for aseptic surgery—apply continuous tension to the limb.** In doing so, the contracted muscles are slowly elongated against the continuously increasing tension applied. Alternatively, the fragment distractor may be applied to the limb or traction may be applied with a hoist, the horse being in dorsal recumbency. In any case it is important that extension to the desired length be gradual. Tenting of the two main fragments out of the incision, thus bringing corresponding points along the fracture plane into contact and then slowly straightening the bone ("toggling and angulation"), may also be used for reduction. However, it cannot be used in a comminuted fracture. Here the major fragments are fitted to each other like pieces of a puzzle. Their positions are maintained by cortex screws inserted as lag screws. Proceeding in this fashion, the entire length of the bone is reconstructed.

Reduction may be temporarily maintained using pointed reduction forceps (**Fig. F14C**).

14.3 Surgical procedure

14.3.1 Adult horse

The fractured bone is reduced and kept in place with reduction forceps and/or tension. It is stabilized by the application of lag screws and plates. The fracture configuration is the main determinant of the locations of the plates. **To begin, two to three cortex screws (3.5 mm or 4.5 mm) are inserted across the fracture plane(s) using lag technique** (**Fig. F14D**). Ideally, one can avoid the locations reserved for plate placement. Should this prove impractical, the screw may later be used through the plate. However, contouring over this protruding screw head can be difficult. A successful exchange requires

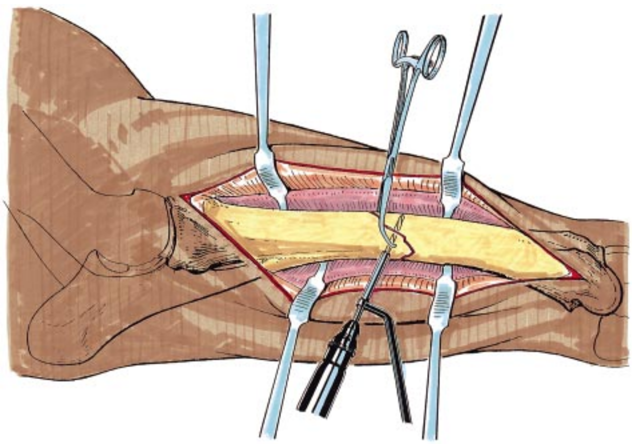


Fig. F14D: A hole is prepared to accept a 3.5 mm cortex lag screw across the fracture plane to maintain anatomic reduction. Care is taken to avoid later interference with the plate and plate screws.

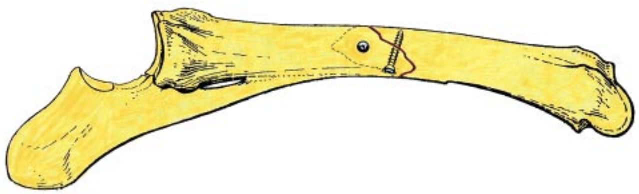
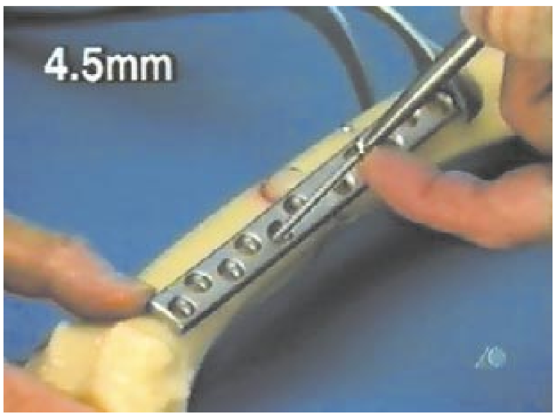


Fig. F14E: The bone is maintained in reduction by two 3.5 mm cortex screws applied in lag fashion across the fracture plane.

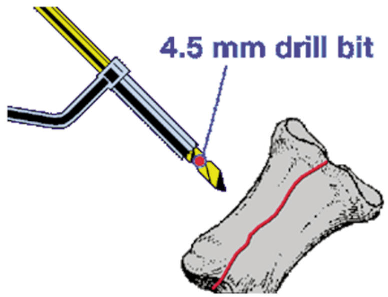
maintenance of bone alignment throughout and substitution of the original screw by another of the same diameter, but 4 mm longer. **Another option is the application of 3.5 mm cortex screws, whose heads can be countersunk so that the entire screw is embedded in the bone** (**Fig. F14E**). This allows the application of a plate directly over the screw head. In any case where interfragmentary screws are applied for preliminary fracture fixation, care must be taken to avoid contact between the plate and lag screws. These interfragmentary screws are applied using the basic steps for screw insertion previously discussed (**Video DBASICS**).

The ideal lengths of broad DCPs are determined and the implants selected and contoured to fit the bone (**Video 31010**). Overbending is performed at the level of the fracture to allow even compression of the bone ends at both the cis and trans cortices. The cranial plate is applied to the bone and held in position by means of the pointed reduction forceps or by an assistant. A plate hole distant from the fracture line is selected and, using plate screw technique, a 4.5 mm or 5.5 mm cortex screw is inserted (**Video PBASICSA**)

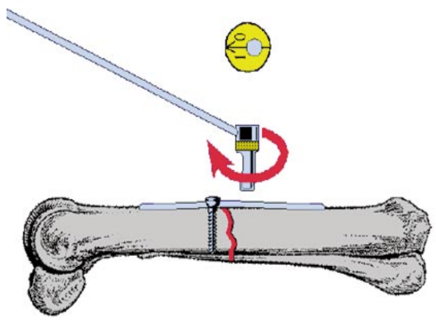
For initial fixation, countersink 3.5 mm screw heads so that they are entirely within the bone.



Video 31010: Radial fracture.



Video DBASICS: Animation of drill basics.



Video PBASICSA: Plate basics animation.

Slide the plate toward the fracture to place the first screw in "load" position.

Avoid impingement of screws and instruments upon implants already in place.

but not completely tightened. The next screw to be inserted will be on the other side of the fracture plane. **The plate is drawn toward the fracture, placing the first screw in an eccentric or "loaded" position**. The correct placement of the plate is confirmed and the second screw inserted in the loaded position using the plate screw technique and the yellow load guide. The two screws are tightened alternately, bringing the fracture under axial compression (**Fig. F14F**). If necessary, one additional screw on either side of the fracture line can be inserted under load conditions. Prior to completely tightening the latter screws, it is best to loosen the previous screws. This allows utilization of the full compression potential of the plates. When satisfactory compression is achieved, the reduction forceps can be removed. It is then advisable to apply the second (lateral or medial) plate by means of several screws in the neutral position.

All the plate screws should be inserted perpendicular to the long axis of the bone. The second plate should be positioned such that its holes interdigitate with those of the initial plate (**Video X14A**). **This is done to avoid interference with previously placed implants** [6]. Impingement of a drill bit or tap upon a screw may result in instrument breakage. This complication can still occur, especially if several oblique lag screws have been placed. The lateral plate is applied as a neutralization plate initially with two screws (**Fig. F14G**). All the remaining screws in both plates are inserted, and those which cross a fracture plane are applied as lag screws. Once all screws have been inserted, final tightening is performed, alternating between the two plates (**Fig. F14H**).

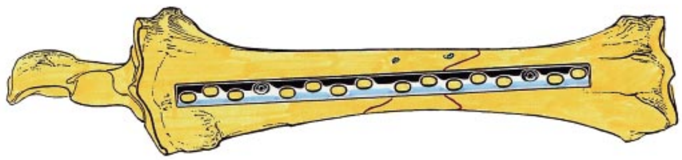


Fig. F14F: The cranial plate has been applied to the bone, placing the fracture under compression.

Fig. F14G: Subsequently a neutralization plate is applied with two screws to the lateral aspect of the bone.

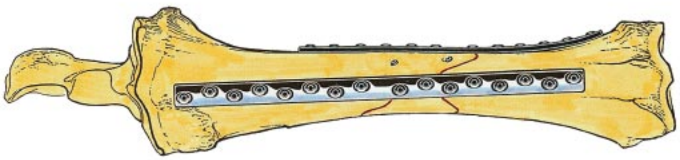


Fig. F14H: All the plate screws are inserted and tightened.

Video X14A: Radius fracture progressives.

Fig. S14B: Two DCS plates of different lengths are depicted, demonstrating their configuration. The plates are manufactured from 316 L stainless steel. The cross-section measures 16 x 5.8 mm. The two holes next to the barrel are round and allow insertion of 6.5 mm cancellous bone screws.

Metaphyseal fractures of the radius are more difficult to treat because the smaller main fragment provides insufficient space for insertion and adequate grip. In all such cases, including foals, double plating is indicated. Despite the fact that double plating, using regular broad DCPs may be successful, the use of an angled blade plate (ABP) [8], a dynamic condylar screw implant (DCS) [9], or a cobra head plate [10] is superior. The cross-section of all three plate types is identical (same width as broad DCP, but 1 mm thicker). **These special plates are especially useful in metaphyseal fractures with one smaller fragment into which only a limited number of screws may be inserted.** The difficulties encountered during ABP application, especially in hard equine bone, have made this implant unpopular. Therefore it will not be discussed further. In contrast to the ABP, the DCS system is more user friendly, and its application will be briefly described.

Use specially designed plates to obtain better fixation of short metaphyseal fragments.

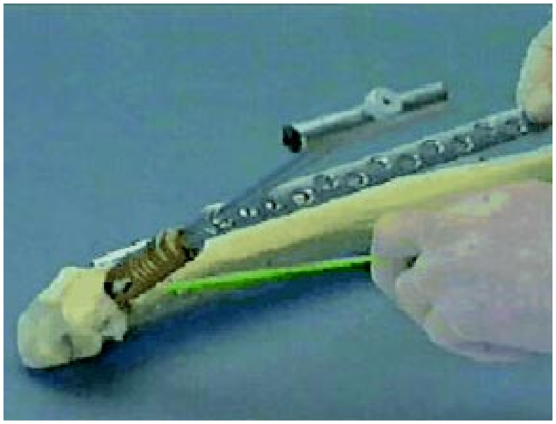
The DCS plate (Fig. S14B, Video 31013) is an ideal fixation device for large animals, partly due to its superior strength, as compared with the broad DCP. The DCS plate would normally

Using a 2.5 mm drill bit, predrill the bone to accept the guide pin.

Place the guide pin with meticulous attention to detail.

be applied to the lateral or medial aspect because the thickness of the proximal and distal aspect of the bone in a sagittal plane can be insufficient to accept the smallest available length of DCS, measuring 55 mm. This part of the plate must be applied in the frontal plane. All the instruments and implants needed for insertion of the DCS plate possess a 2.5 mm central canal to accept the guide pin.

The guide pin, with its trocar point and associated threads, is inserted through a guide sleeve applied to the surface of the bone, but **the bone must be predrilled with a 2.0 mm or 2.5 mm drill bit**. This is carried out through the same guide. The 2.5 mm guide pin of known length is then inserted to the desired depth (Fig. F14l). **Correct placement of the guide pin is the most difficult, time-consuming, and critical step in the entire procedure** [11].



Video 31013: Fixation of a distal radius fracture (using a DCP & DCS).

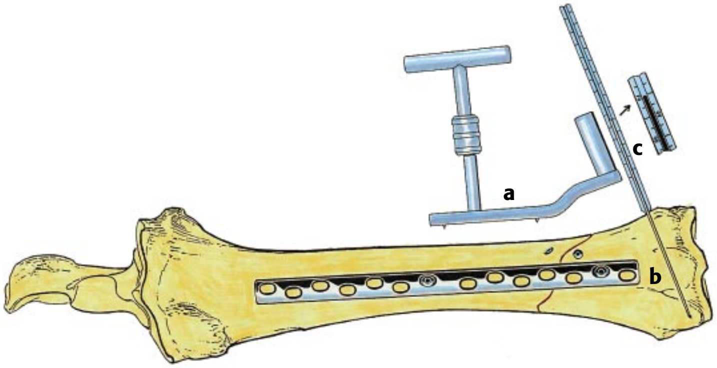


Fig. F14l: Prior to DCS plate application the distal radius fracture was reduced and temporarily fixed with two 3.5 mm cortex screws, applied in lag fashion across the fracture plane. Subsequently a 14-hole broad DCP was applied in compression to the tension side of the bone. Using the 2.5 mm drill bit through the DCS angled guide (a) the distal radial cortex is penetrated, prior to insertion of the threaded 2.5 mm DCS/DHS guide wire (b) through the predrilled hole and with the help of the DCS angled guide. The DCS/DHS measuring device (c) is placed over the guide wire, once the desired depth is reached and the penetration depth of the guide wire is determined (see insert: 70 mm).

It is important to verify correct placement by radiography or image intensification. The measuring device is placed over the guide pin and the desired length of the condylar screw determined by simple subtraction (**Fig. F14I**). The triple reamer (**Fig. F14J**), which simultaneously prepares the 8 mm hole for the shaft of the DCS, the 12.5 mm hole for the barrel of the DCS plate, and a beveled edge at the barrel-plate junction, is assembled (**Fig. F14J**) and set to the desired length (**Fig. F14J**). It is then placed over the guide pin and brought down to the surface of the bone. During the preparation of the hole, frequent flushing is the key to decreasing friction and heat production. The depth of **the hole should be approximately 5 mm shorter than the length determined to facilitate maintenance of the guide pin** (**Fig. F14J**). After reaming to the desired depth, the hole is tapped using the 12.5 mm tap through the short tap sleeve (**Fig. F14K**). The metric scale engraved on the tap permits easy monitoring of the tapping depth. After flushing the prepared hole, the DCS of desired length is assembled with a connecting device and placed into the T-handled introduction device. Thereafter, insertion of the DCS

Stop the triple reamer 5 mm short of the end of the guide pin.

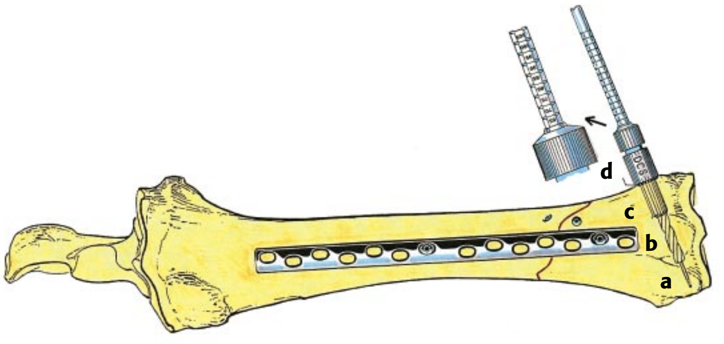


Fig. F14J: The DCS triple reamer is assembled and set for the drilling depth desired (see insert: 65 mm), which is 5 mm less than the penetration depth of the guide wire and assures the latter's firm seating in the bone during the entire procedure. The triple reamer is placed over the guide pin (a) and the shaft hole for the screw (b), the barrel hole for the plate (c), as well as the beveled contour for the barrel-plate junction (d) are prepared.

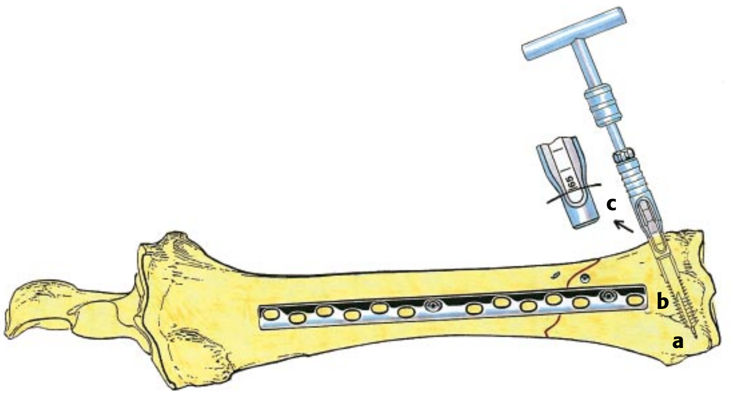


Fig. F14K: The DCS/DHS centering sleeve (c) is mounted over the DCS/DHS tap (b). The tap is subsequently placed over the guide wire (a) and slid into the barrel hole of the same diameter, which facilitates seating of the centering sleeve in the same barrel hole. The shaft hole is tapped to the desired depth (see insert: to a depth of 65 mm).

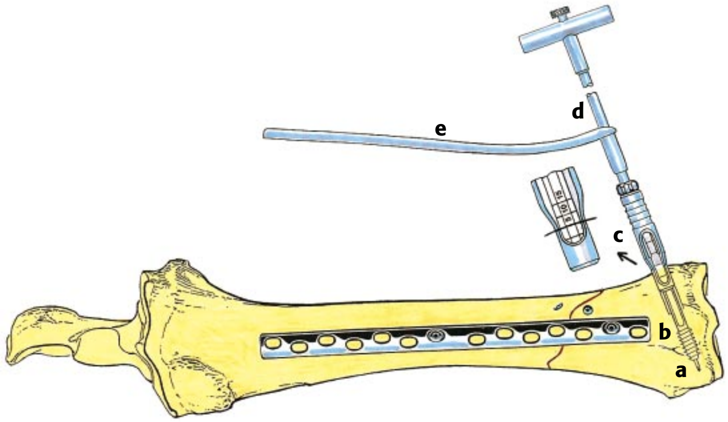


Fig. F14L: The DCS/DHS coupling screw is inserted into the wrench (d) and the DCS plate (e) of desired length (12-hole plate) slid over the wrench, prior to connecting the 60 mm DCS/DHS screw (b) to the coupling screw. After mounting the centering sleeve (c) over the wrench, the entire assembly is placed over the guide wire (a) and the screw inserted into the bone to the desired depth of 65 mm (see insert: setting on the wrench: 5 mm).

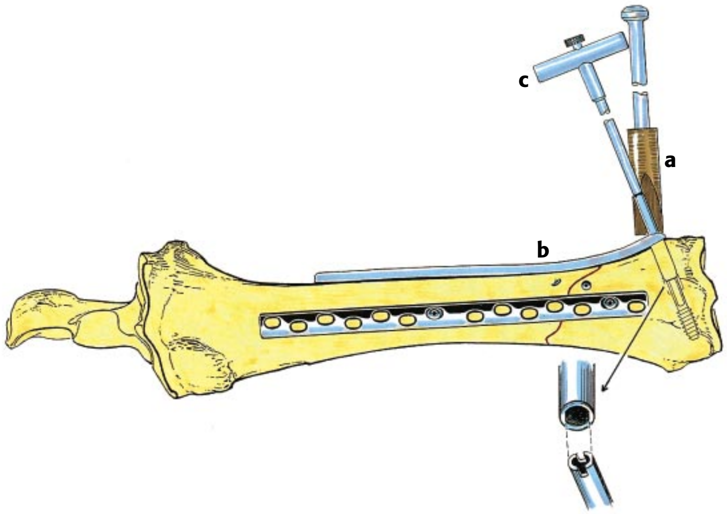


Fig. F14M: After tightening the DCS/DHS screw and adjusting the horizontal bar of the wrench (c) parallel to the long axis of the DCS plate (b), the plate is seated over the DCS/DHS screw with the help of the DCS/DHS Impactor (a) and a mallet (not shown). Orientation of the instruments and implants in the described fashion is important because the DCS/DHS screw (lower insert) and the plate barrel (upper insert) have identical contours, which have to be aligned to allow sliding of the barrel over the screws shaft.

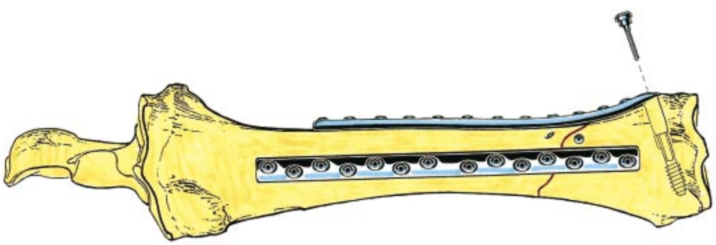


Fig. F14N: The DCS/DHS compression screw is inserted through the barrel and tightened into the DCS/DHS screw. Insertion of the remaining screws and final tightening of all screws completes the procedure.

is routine (**Fig. F14L**). The opposite sides of the DCS shaft are flattened (**Fig. F14M**). The cross-section of the screw shaft and the lumen of the plate barrel have an identical area, which prevents rotation of the screw. Therefore, the axis of the horizontal bar of the T-handle screw insertion device needs to be positioned parallel to the long axis of the bone to allow correct orientation of the plate. **Note that neither the plate/barrel angle of 95° nor the 4–5 cm adjacent to the plate barrel junction should be changed**. Using the impactor and a mallet the plate is seated firmly over the DCS onto the bone surface. The two most distal plate holes are round, preventing their use for dynamic axial compression, but allowing the insertion of cancellous bone screws. As required, axial compression may be provided by applying one or two of the remaining 4.5 mm or 5.5 mm cortex screws in the load position. Interfragmentary compression may also be achieved by inserting any screw crossing a fracture plane as a lag screw. To complete the fixation all the remaining screws are inserted and tightened, alternating between the two sides of the fracture plane (**Fig. F14N**). The plates are staggered slightly to facilitate screw placement and to ensure that both plates do not end at the same place. Generally, it is accepted that one of the plates should span the entire length of the bone (in metaphyseal fractures). In diaphyseal and oblique fractures both plates should span the entire length.

Do *not* attempt to alter the geometry of the end of the plate through bending.

The cobra plate (**Fig. S14C**), an adaptation of the human hip arthrodesis plate (**Fig. S14D**), presents a simpler alternative for general equine practice. It may not be quite as strong as the DCS system, but this shortcoming is probably of insignificant magnitude given the application of a second plate. The plate is preformed and approximates the distal metaphyseal contours

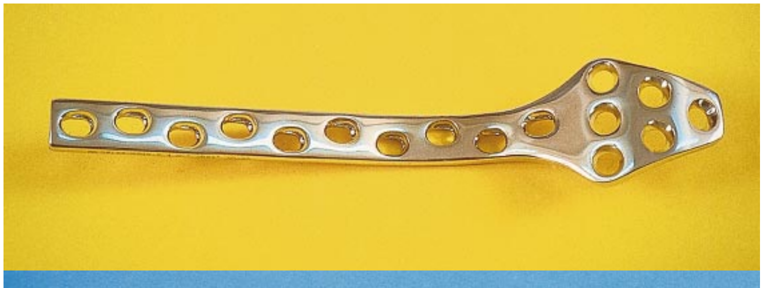


Fig. S14C: The cobra plate has six round holes in its "hood" that will accept 5.5–6.5 mm screws and allow angulation of about 15°. A good purchase can be achieved in short, thick fragments.

Fig. S14D: The present day cobra plate (above) stems from the human hip arthrodesis implant. The ancestor also served the need to get a firm grip on a limited area of corticocancellous bone.

In the radius, the cobra plate is best applied to the medial aspect.

Plate luting increases the strength of internal fixation.

of the radius and the femur. In the former it is **best applied to the medial aspect.** The distal "cobra head" contains six round holes, any of which will accept 6.5 mm cancellous bone or 5.5 mm cortex screws, while the shaft has standard oblong DCP holes for 4.5 mm or 5.5 mm equipment. If all the holes can be utilized in the fracture in question, the holding power is great and the rotational stability probably better than that enjoyed by the DCS, though this has not been tested (**Fig. X14B**).

Following fracture reduction and temporary fixation, one of the distal screws is inserted, the alignment and distribution of the other screws is checked, and one of the shaft screws is placed in the load position, compressing the fracture and determining the plate's final orientation. Next the remaining distal screws are inserted, varying their angles slightly to avoid interference. Finally, the remaining shaft screws are placed in the neutral position. The second (usually lateral) plate is placed in a manner identical to that described above.

Plate luting has been advocated to increase the strength of particular constellations of internal fixation [12]. It begins by applying the plate to the bone using standard technique. After it is fixed in position, the screws are loosened, the plate elevated, and the contact area between the plate and the bone filled with polymethylmethacrylate (PMMA). The screws are then reinserted and tightened firmly. Since the PMMA is still soft, tightening of the screws results in its even distribution and a seamless interface between bone, PMMA, and plate. Penetration of the fracture plane by PMMA

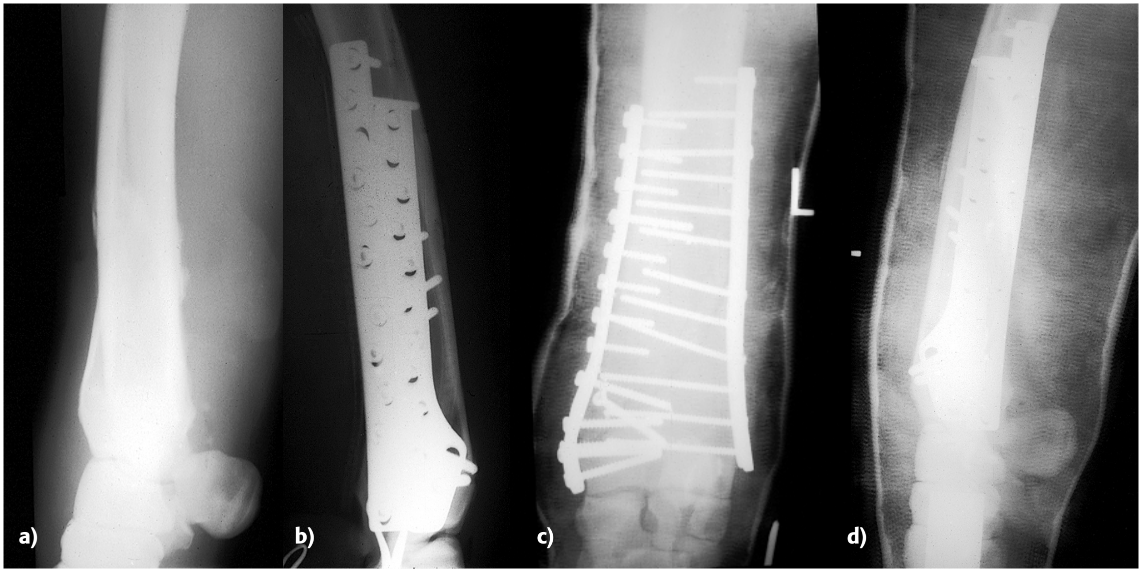


Fig. X14B: Preoperative (a) and immediate postoperative (b) lateral radiographs show repair of an infected 1-week-old radial fracture in an 8-year-old Quarter Horse. Postoperatively, a cast was applied to the limb for additional support (c, d). Stability was sufficient to allow control over infection and permit bony healing.

should be avoided because it prevents fracture healing in that area of contact. However, penetration of the oblong holes in the plate by PMMA is desirable because it supplies additional stability to the screw heads. Some recent research has shown that the filling of the oblong plate holes around the screw heads actually supplies the greatest portion of the increased stability contributed by luting [13]. This evolves from a phenomenon not unlike that seen in the orthodontic movement of teeth. The benefits gained by inserting certain screws in the DCP system in the load position to improve axial compression of the fracture may be lost postoperatively due to minimal movement of the screw head relative to the plate hole. By filling the oblong holes around the screw heads with PMMA, the plate and the screws are united much more solidly and such movement may be retarded.

14.3.2 Foals

As mentioned earlier, **in young foals with a transverse mid-diaphyseal fracture only one 10-hole broad DCP is usually applied**. This is achieved following fracture reduction and insertion of one to two cortex screws as lag screws across the fracture plane (Fig. X14C). The plate is contoured to fit the shape of the bone, and using the plate-screw technique the initial two to four screws are inserted in the load position, followed by the remaining screws in the neutral position. Care is taken to avoid placing screws across the physis, if at all possible. In some cases this cannot be avoided, especially if an oblique fracture occurs in the metaphysis. Should insertion of the screws in the epiphysis be necessary for stability, these screws should be removed after 2–3 weeks. Growth potential is hopefully only retarded for a relatively short period and may resume following screw removal.

A single 10-hole broad DCP provides adequate fixation of mid-diaphyseal fractures in young foals.

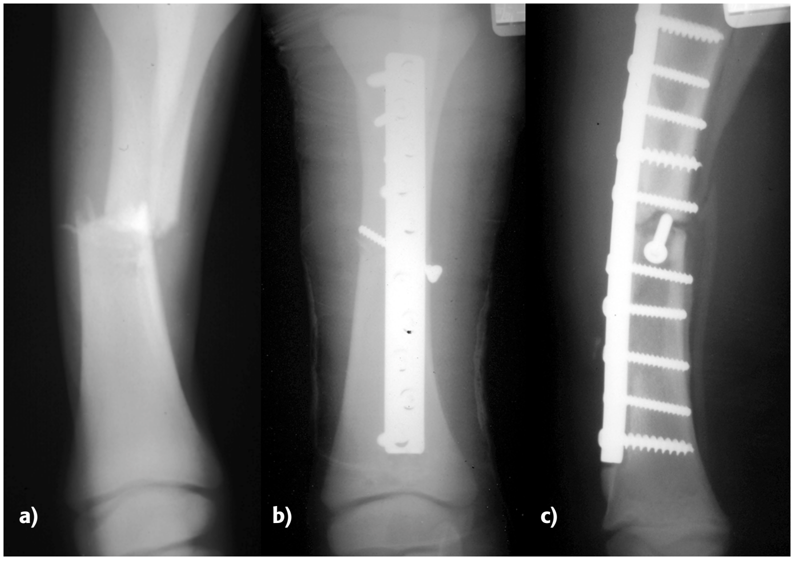


Fig. X14C: Craniocaudal radiographic view (a) of a mid-diaphyseal transverse radial fracture in a foal. This bone has a distinct tension side cranially, so a fracture can often be stabilized with a single plate applied in that location (b, c). Prior to plate application a 4.5 mm cortex screw was inserted in lag fashion across the fracture to maintain reduction.

If any "dead space" remains, insert a suction drain.

Bridging of the distal growth plate of the radius seems to lead to greater growth disturbances, possibly because of the greater growth potential in that region. Fractures confined to the true epiphysis often require bridging of the growth plate except in selected Salter type III or IV fractures. These latter types may be amenable to simple screw fixation alone. However, in Salter type III fractures a tension band applied by a cerclage wire in a figure-8 configuration or a small plate may be necessary to counteract the tensile forces mediated by the opposing collateral ligament.

In metaphyseal fractures, double plating is indicated, even in foals (**Fig. X14D**).

When the implants are in place, the surgical region is again thoroughly flushed and any remaining bleeding vessels are ligated. **A suction drain is indicated if any "dead space" remains** since minor hemorrhage may recur following recovery. The tubing exits the skin through an adjacent stab, separate from the primary incision(s). If enough tubing is available, it should exit at the most distal point on the fracture. Closure of the incision is performed in four to five layers. All layers except the skin are closed by using a simple continuous pattern of a monofilament resorbable suture material, size 2/0 (PDS, Maxon). The layers include the periosteum, where the two transected edges are adapted as close as possible over the two plates. The intermuscular septum, the antebrachial fascia, and the subcutaneous tissues are subsequently closed. One layer may be placed as a subcuticular suture. The skin is closed using a simple interrupted suture pattern of a monofilament nonresorbable suture material (e.g., nylon) or by means of metal skin staples. A tight pressure bandage is applied from foot to elbow over a nonadherent dressing at the incision site.

Fig. X14D: This oblique preoperative radiograph shows a transverse proximal metaphyseal fracture of the radius. The fracture was repaired with a butterfly plate applied craniomedially and a narrow DCP laterally. Note that both plates were applied distal to the proximal physis.

14.4 Postoperative treatment

In most cases a splint is not applied during the recovery phase, allowing the animal freedom of carpal movement. When the horse is standing, a splint may be applied over the bandage if deemed necessary [6]. In foals with a distal physeal or metaphyseal fracture where possibly only inadequate internal fixation could be applied, some type of external coaptation may be added. This may be possible even for the recovery period because these animals can be assisted when rising. However, splint application is not possible in proximal metaphyseal or physeal fractures due to the fact that the external coaptation would end at the level of the fracture, resulting in additional leverage forces and facilitation of fixation breakdown.

Fig. S14E: Postoperatively the foal bore almost full weight on the limb. A pressure bandage was applied to the surgery site to prevent seroma formation.

The animal is maintained in a box stall (**Fig. S14E**) and, barring any major complications during the immediate postoperative period, the bandage is changed for the first time 2–3 days postoperatively. Suction is maintained and the amount of fluid withdrawn is monitored and noted in the case record. Should fluid accumulation continue over a 3 day period without any significant decrease, instability may be present, possibly leading to fixation failure, or there may be an inflammation with impending infection. In the normal course of postoperative management, the drain may be removed at this time and a bandage of the same type reapplied. Some type of bandage is maintained over at least 2 weeks. After removal of the skin sutures or staples 10 days postoperatively, a minimal bandage may still be necessary. The horse may **begin exercise at a walk 4–6 weeks postoperatively**. Prior to pasture turnout, a radiographic evaluation should be performed, but not prior to 8 weeks postoperatively. Fracture healing usually occurs within 3–5 months.

The application of external fixation is not routine.

Hand walking exercise may begin 4–6 weeks postoperatively.

14.5 Complications

Three complications commonly encountered during radial fracture treatment are fixation breakdown (**Fig. X14E**), infection, or poor placement of an implant. A screw penetrating a joint can lead to arthrosis, pain, and decreased range of motion. In foals, crossing of the growth plate by implants may result in an angular deformity, or in shortening of the bone and possibly an abnormal gait. Physeal fractures usually result in considerable damage to the germinative layers of the physis. This, in itself, can produce some of the complications mentioned above. Additionally, care should be taken not to penetrate the ulna of a young foal with screws inserted from the cranial side. This disturbs the normal differential growth pattern between the ulna and the radius: the ulna is fixed to the radius which, with continued growth at the proximal aspect of the radius, results in subluxation and formation of elbow arthrosis [14–16]. Prolonged severe lameness with an inability to place weight on

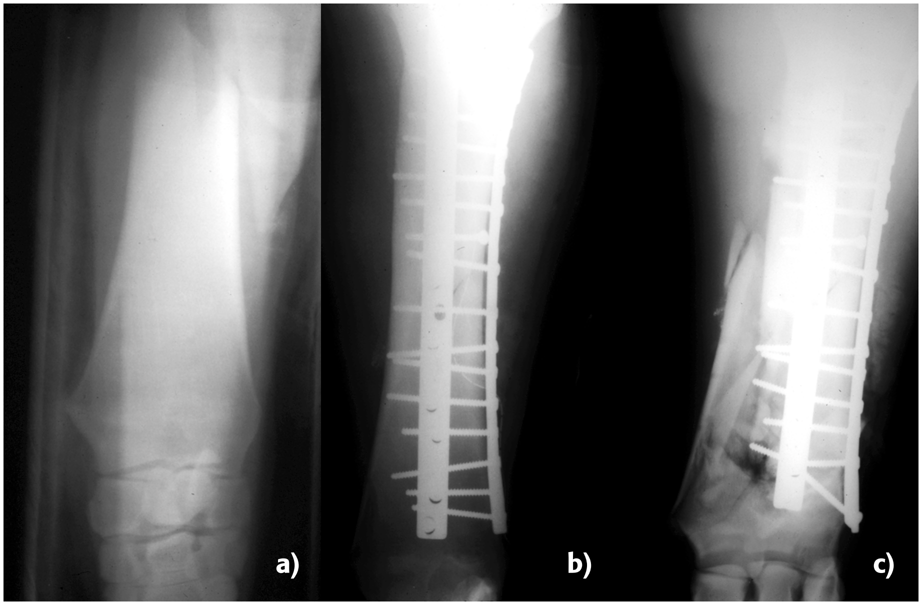


Fig. X14E: This craniocaudal radiographic view (a) shows a displaced fracture of the mid-diaphysis of the radius. The radiograph was taken with the transport splint in place to prevent additional damage to the surrounding tissues and the bone ends. The fracture was repaired with two broad DCPs (b), one placed cranially and the other laterally. Note that the screws in the distal aspect of the lateral plate are too short and do not engage the medial cortex. The mare initially placed good weight on the limb, supported externally by a splint, but the repair collapsed on the fifth postoperative day, necessitating humane destruction of the animal (c). Engaging the medial cortices with the distal screws in the lateral plate may have prevented this from occuring.

the limb may result in overload laminitis in the opposite front limb and/or in the rear limbs.

Implant failure, such as fracture of a plate may occur occasionally (Fig. X14F), especially in cases where poor anatomic reduction was achieved or if implants were reused.

The development of osteitis/osteomyelitis as a result of fracture treatment is of major concern. The vast majority of postoperative infections are iatrogenic in origin and result in fixation breakdown, followed by humane destruction of the animal. Therefore, during surgery meticulous attention has to be given to strict maintenance of asepsis and adherence to Halsted's principles of good surgical technique.

14.6 Results

Internal fixation of radial fractures is associated with various degrees of success. In foals with short oblique or transverse fractures of the mid-diaphyseal region, a relatively good prognosis can be given for future soundness and suitability for an athletic career [2]. **Involvement of an articular surface or the growth plate may jeopardize this prognosis**. Additionally, if a metaphyseal fracture is encountered, stabilization is not as ideal as it is in the mid-diaphyseal region and the outcome may vary accordingly [2].

Involvement of an articular surface or the growth plate worsens the prognosis.

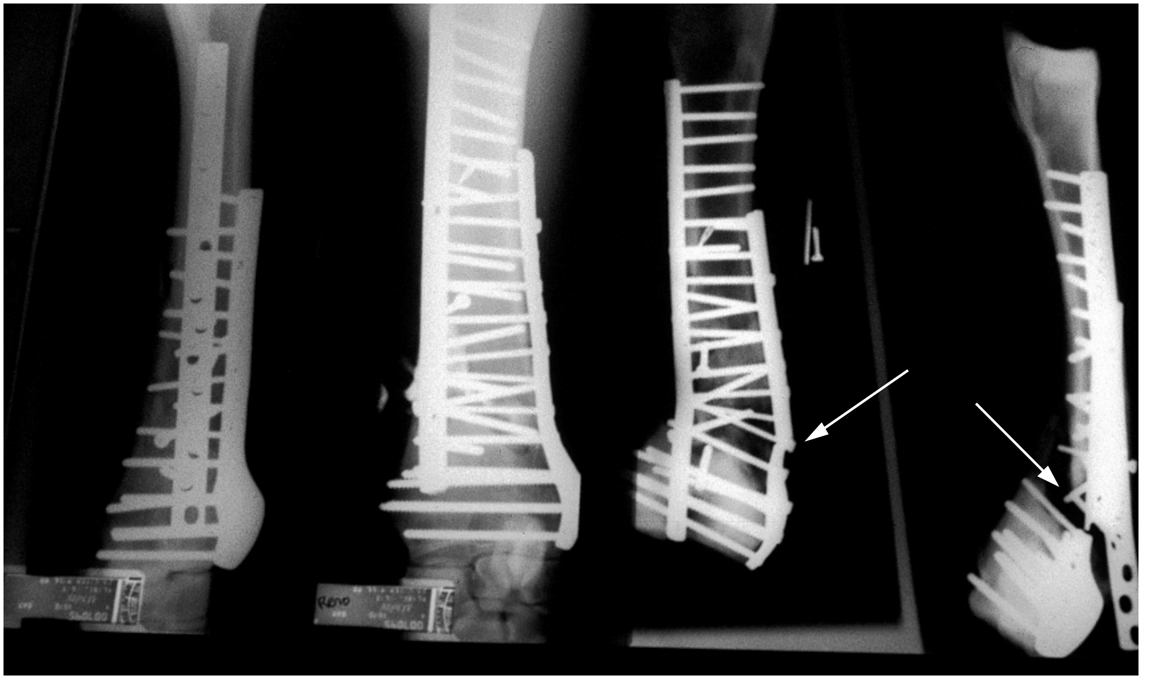


Fig. X14F: Even a heavy plate like the cobra plate can show fatigue failure (arrows) if it is cycled. Also, the contours of the cobra plate tend to fit the medial aspect of the radius better (compare Fig. X14B).

As with most equine fractures, the presence of infection preoperatively markedly worsens the prognosis. However, where adequate stability can be achieved and energetic perioperative antibiosis instituted, fracture healing can and will proceed to its natural conclusion (**Video X14A**, **Fig. S14F**). The biggest problem will always be the ability to achieve that degree of stability given the means at our disposal and the behavior of the species concerned.

In adult horses a tentative to poor prognosis for healing and future soundness has to be given [6]. It is reasonable to say that if an adult horse has to become an athlete following healing of a radial fracture, a poor prognosis is in order. One should be very careful to discuss these aspects with the owners preoperatively.

Fig. S14F: A 14-year-old Tennessee Walking Horse mare after healing of the radius fracture shown in **Video X14A**. Note the scar on the cranomedial aspect of the limb.

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14.7.1 Online references

See online references on the PEOS internet home page for this chapter:
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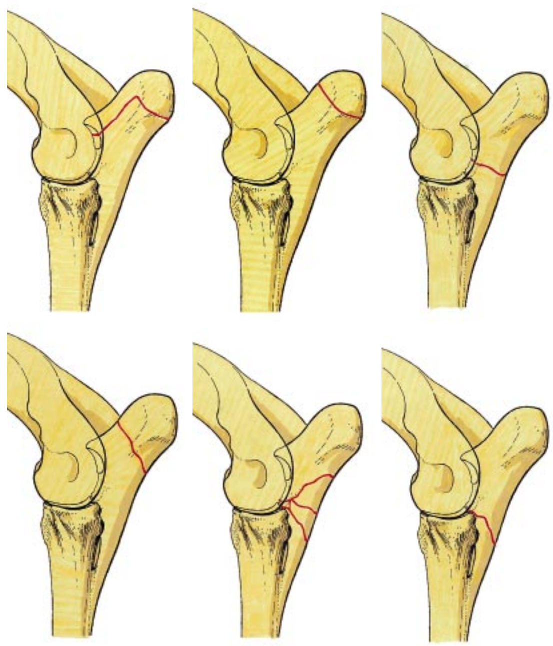
15 Ulna (olecranon): plate fixation

Gustave E. Fackelman

15.1 Description

Olecranon fractures (**Fig. S15A**) occur due to direct trauma to the elbow. As such they are more common in younger animals [**1**–**3**] and in breeds and locales practicing free-range management [**4**]. Various classifications have been employed by different groups of investigators [**5**–**8**]. **Basically they all comprise four or five types** and deal with: the two most common growth plate fractures (Salter I & II); whether or not the joint is affected; and, whether significant comminution exists (**Video F15A**). One scheme [**5**] includes a rather rare form of isolated fracture of the anconeal process.



Video F15A:
Fracture classification.

Olecranon fractures may be classified into five subgroups.

Fig. S15A: Unstable fractures of the olecranon eliminate the effectiveness of the "stay apparatus," and pain discourages use of the limb. The affected animal often adopts a "hopping" gait when advancing the limb.

Healing may occur without surgery, but there is usually a reduced range of motion.

In the discussion below we will deal with the Salter II fracture and an articular shaft fracture (Fig. X15A), as these two forms summarize the points essential to the repair by plating any of the fractures amenable to that form of fixation. Conservative treatment by coaptation has been tested over the years, and has met with widely varying results [4, 9, 10]. It appears to have its place, especially when economics play a role [6]. A somewhat analogous situation prevails in children, who are often treated initially by conservative means, with surgery as a fallback measure [11, 12]. **Even those who favor conservative therapy as definitive treatment state that a reduced range of motion following healing is the rule** [13]. As is the case with most fractures, their being open and contaminated makes treatment more difficult; and the prognosis for a return to full function becomes less favorable. However, most surgeons experienced in the method will opt for rigid internal fixation [14], and find a way to shorten convalescence, if meticulous attention is paid to technical detail [15].

Fractures involving only the apophysis of the olecranon process are usually managed by means other than plating [16–18], and will be described in chapter 16, Ulna (olecranon): tension band wiring. Treatment of those injuries in the horse [19] that mimic human Monteggia lesions [20] is more a matter of managing the radial component, and will be mentioned in connection with that bone.

It is interesting to note that the contours of the olecranon process of the equine ulna change significantly as the animal matures. In the young foal, the caudal aspect of the bone is almost straight (Fig. F15B), while in the adult it bears a definite concavity. Also, Salter type fractures may occur some time after radiographic and theoretical closure of the growth plate, a fact that also has a human counterpart [21].

Fig. X15A

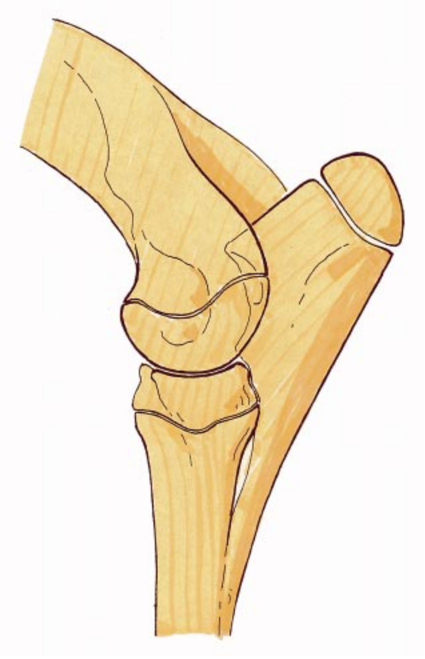


Fig. F15B

15.2 Preoperative considerations

A careful surgical plan should be sketched (**Fig. S15B**) using preoperative radiographs to ensure that all the necessary implants are available. The lengths of the screws required to gain adequate purchase will vary widely with the age and breed of the patient and the particular form of the fracture. In the growing foal, the plan should include avoidance of engagement of the **caudal radial cortex, as this type of bridging of the still active proximal radial physis can result in elbow dysplasia** [**5**, **18**, **22**, **23**] and/or radioulnar synostosis. Due consideration should be given to the sequence in which individual implants will be placed, so that important options are not eliminated. The patient should be positioned to allow those manipulations of the limb (usually passive elbow extension) necessary to effect reduction during surgery. Routine preparation of the skin is carried out, beginning at the coronary band and extending to the shoulder and the adjacent lateral thoracic wall. If there is comminution at the fracture site, the iliac crest should be prepared for the potential harvest of a bone graft. Provisions should be made for intraoperative radiography so that it may be performed efficiently and without any break in asepsis.

15.3 Surgical anatomy

The landmarks for the surgery are the olecranon process itself, and the division between the ulnaris lateralis and ulnar head of the deep digital flexor muscle. Due to swelling in the immediate area of the fracture, it may be necessary to identify this division further distally, and project it proximally. For fractures involving the more proximal reaches of the bone requiring access to the proximal ulna, the incision should begin 10 cm proximal to that structure and continue in something of a question mark shape along the shaft of the ulna. In more proximal fractures, especially those showing considerable separation, tearing may be noted in the origin of the deep digital flexor. Other anatomic points to be identified are the proximal radial growth

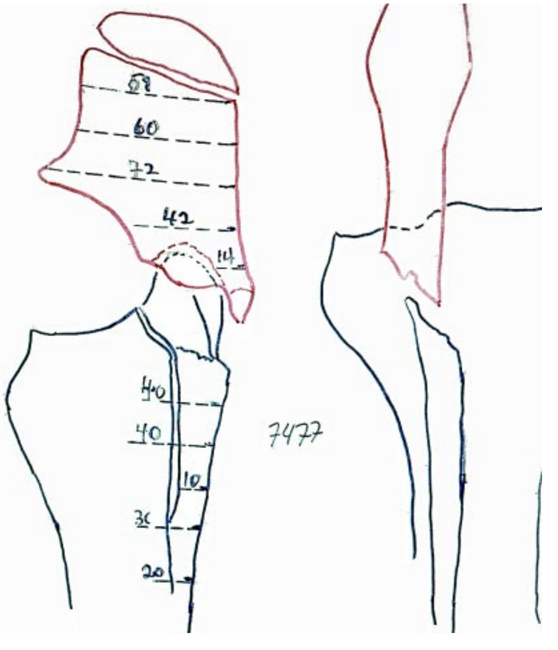


Fig. S15B

A careful preoperative plan is the key to a successful outcome.

Avoid engaging the caudal radial cortex with screws in the growing foal.

plate (if applicable), the interosseous foramen between the radius and the ulna, and the fracture itself. Study of a specimen prior to surgery will reveal the very thin nature of the olecranon process in the region of the anconeal process (Fig. F15C). This is occasioned by a **marked medial concavity, which must be borne in mind during drilling and tapping**.

Consider carefully the medial concavity of the olecranon process when placing lag screws.

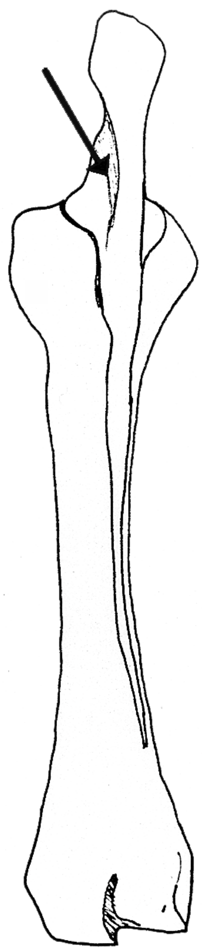


Fig. F15C: The marked medial concavity of the ulna at its junction with the olecranon process can make engagement of the anconeal process with lag screws difficult. The surgeon strives to drill parallel to the bone's lateral surface.

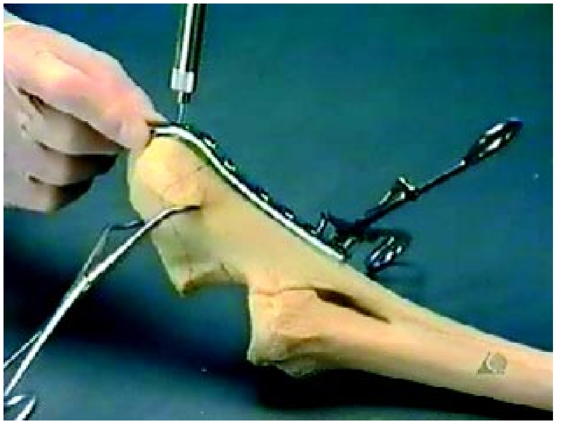
15.4 Surgical procedure

(Video 31026)

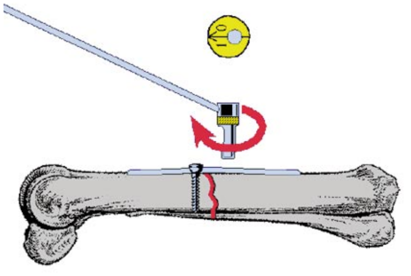
15.4.1 Salter II fracture of the proximal ulna

After loosely inserting the first screw, push the plate toward the fracture.

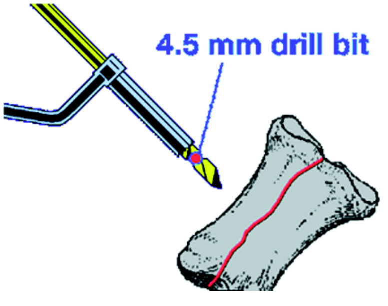
The fracture is identified, reduced, and temporarily held in place with bone holding forceps. A soft aluminum template corresponding to a 10-hole narrow dynamic compression plate is firmly pressed upon the bone surface reflecting the underlying contours. Using the bending press, the plate is contoured to correspond with the template. A short screw is inserted proximal to the fracture in the portion of the plate wrapped over the tuber olecrani, and only provisionally tightened. **The plate is aligned along the sharp caudal ridge of the more distal ulna, and slid toward the fracture site until the screw engages the upper margin of the elliptical hole.** The second hole is drilled in the distal part of the plate at a distance from the fracture, so as not to interfere with any screws to be later inserted in lag fashion. The yellow drill guide is used to place the screw in "load" position (Video PBASICSA). The length of this screw will depend upon its location (interosseous vessels), and the age of the patient (proximal radial growth plate). The two screws now in place are tightened alternately, creating tension in the plate and bringing the fracture plane under compression. Next, the lag screws (Video DBASICS) are placed through the appropriate plate holes, crossing the proximodistal portion of the fracture in the anconeal region. The local anatomy must be respected during drilling and tapping to prevent inadvertent premature penetration of the medial aspect (see



Video 31026: Type II ulnar fracture.



Video PBASICSA: Plate basics animation.



Video DBASICS: Drill basics animation.

above). Where possible, lag screws are placed crossing the horizontal portion of the apophyseal fracture, possibly necessitating the use of cancellous equipment for the most proximal implant. If interference with other implants can be avoided by slight angulation, the initial short screw may be replaced with a longer one.

The soft tissues are closed over the plate in routine fashion. If soft tissue trauma was extensive preoperatively, resulting in dead space and the probability of a postoperative hematoma, a suction drain is placed in the deepest portion of the wound and exiting proximally through a separate stab incision.

15.4.2 Articular fractures involving the shaft

The fracture is approached as described above, and identified. The degree of distraction and any comminution (usually of the lateral cortex) are noted. The soft tissues are separated from the bone to an extent appropriate to the placement of a 10-hole narrow dynamic compression plate (DCP) centered at the fracture site. A soft aluminum template is pressed firmly against the surface of the bone so that it conforms to its contours. The plate is then contoured to match, and secured to the bone by one screw proximal to the fracture site. Depending upon the degree of displacement, either the DCP principle (**Video PBASICSA**) is used alone, or **the tension device is applied to effect reduction** (**Fig. X15B**). If the latter option is employed, additional screws are inserted in the proximal fragment before the tension device is tightened. Any hole that might later accommodate lag screws is left empty for the time being. After

Use the tension device to effect reduction, if distraction is significant.

Institute physical therapy in the first postoperative week.

Fig. X15B: After anchoring the plate in the proximal fragment, it may be necessary to use the tension device to overcome the amount of distraction present due to triceps contracture.

Achieve axial compression first, then add lag screws.

reduction, the remaining screws are inserted in the plate assuring **axial compression.** If any screws are to be placed in lag fashion across the fracture site, these are inserted last. In young animals, or fractures of long standing, it may be necessary to employ cancellous equipment in the proximal fragment (**Fig. X15C**). Shorter screws are used in the area of the interosseous foramen (**Fig. X15D**). The soft tissues are closed over the implants. If significant dead space resulted from the injury, or from the surgical dissection, a suction drain is placed to abort the development of a postoperative hematoma.

15.5 Postoperative treatment

Usually, a protective roll of gauze is oversewn at the incision site (stent), and no further protection of the appendage is provided. If a drain was successfully placed, this is maintained for 48 to 72 hours, depending upon the amount of material conducted from the wound. The levels of prophylactic antibiotics established preoperatively are maintained until 24 hours after removal of the drain. **Passive flexion and extension are instituted 48 hours postoperatively, and hand walking is initiated 2 weeks later**. Given positive radiographic findings, the level of exercise may be gradually increased at 6 weeks postoperatively to include light riding if appropriate. No exercise at will at pasture is allowed until radiographic evidence of bony healing is present (± 12 weeks).

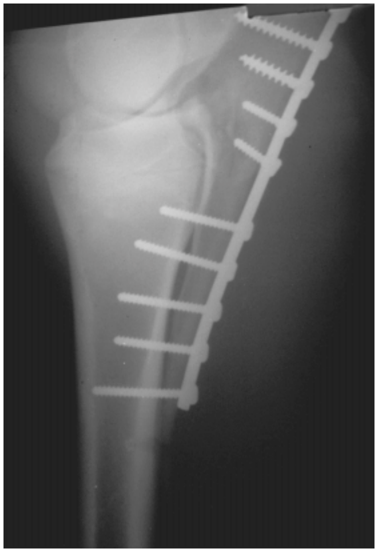


Fig. X15C

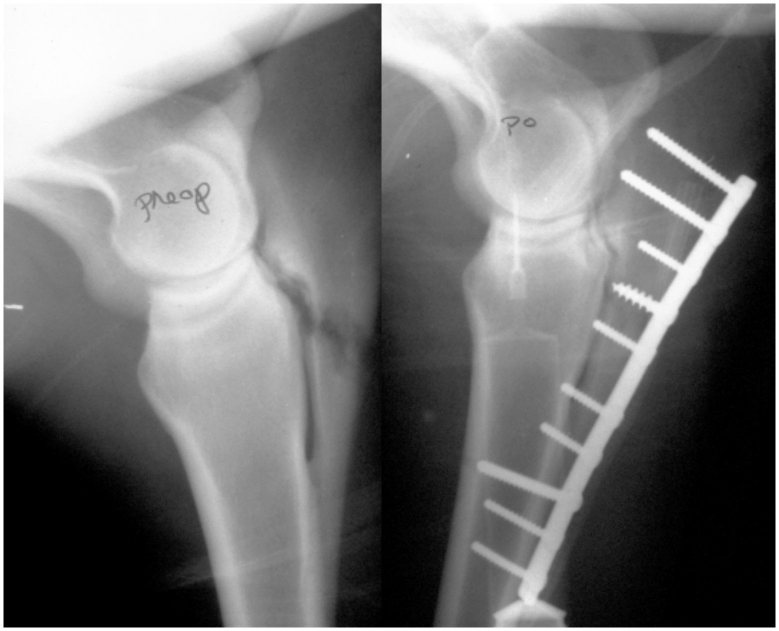


Fig. X15D

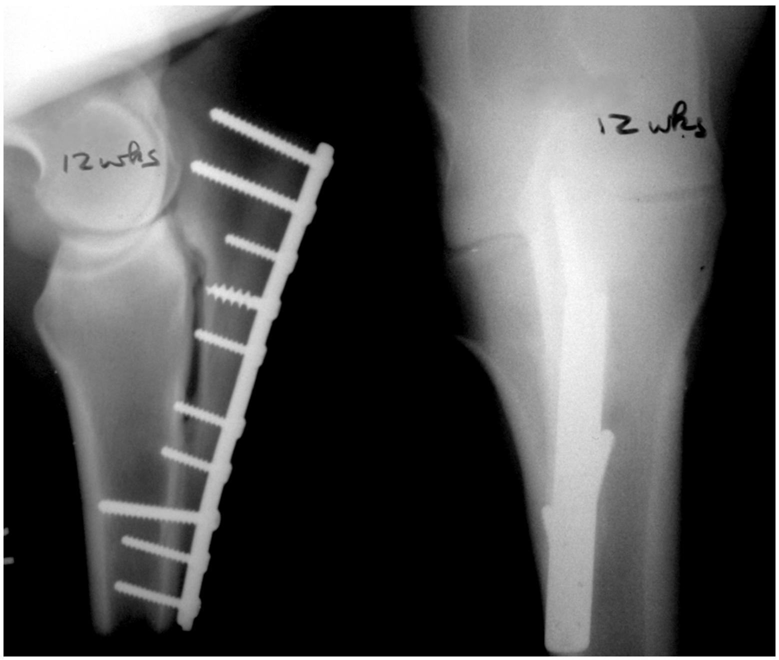


Fig. X15E: Follow-up radiographs taken 3 months after repair of the fracture in **Fig. X15D** show good healing without development of degenerative joint disease.

Counteracting distractive forces brings about healing of non-unions.

Fig. X15F: Older fractures such as this non-union may be healed by combining axial and interfragmentary compression.

15.6 Results

Following the techniques described above, healing is typically prompt and complete (**Fig. X15E**). The plate is under constant tension, with little or no tendency for cyclic bending. For this reason the relatively lighter caliber plate proves adequate. **Due to the small size of the implant in relation to the bone to which it has been applied, stress protection is not a problem and the implants are rarely removed**. Even in older cases with developed non-unions, healing can be expected when axial compression is applied (**Fig. X15F**).

Fig. X15G: A common complication seen following repair of olecranon fractures is demonstrated here. The most proximal screw exited the bone into the medial concavity of the ulna at its junction with the olecranon process. When the animal extended the limb postoperatively, the screw tip impinged upon the caudal aspect of the medial humeral epicondyle and was bent.

15.7 Complications

Complications specific to this surgery include:

- technical errors in the placement of the more proximal screws, resulting in impingement upon the humerus and bending (**Fig. X15G**);
- engagement of the caudal radial cortex distal to the radial growth plate, resulting in elbow dysplasia (**Fig. X15H**);
- damage to the vessels coursing through the interosseous foramen between the ulna and the radius (**Fig. X15H**);

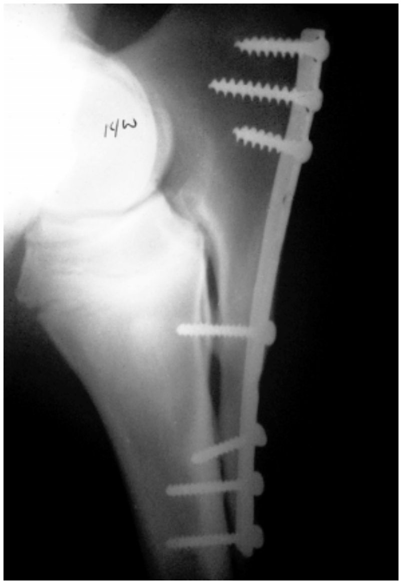


Fig. X15H: Lateromedial radiographic view of the elbow region of a young horse. An olecranon fracture was treated 14 weeks earlier with a long plate. Three cancellous bone screws were placed in the olecranon, and four screws fixed the ulna to the radius. The additional growth occurring at the proximal radius following fixation resulted in partial subluxation of the humerus because of the lack of passive adaptation of the ulna to such growth.

Following plating of olecranon fractures, the implants are rarely removed.

- loss of stability of short proximal fragments, especially with the use of "hook" plates (**Fig. X15I**); and,
- carpal contracture in the early post-operative period (**Fig. S15C**).

Fig. S15C: A common complication following repair of olecranon fractures, seen especially in ponies and foals, is postoperative carpal contracture. If the animal is observed to habitually adopt this position, a "tube cast" or splint should be applied.

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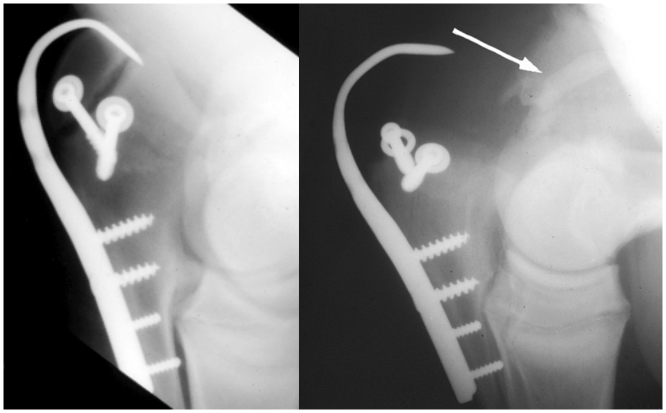

Fig. X15I: This comminuted fracture of the olecranon process, affecting the associated apophysis as well, was repaired with lateromedial lag screw fixation and a hook plate. Although considered "solid" at the conclusion of surgery, the plate straightened in the immediate postoperative period and allowed the fracture to displace (arrow).

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16 Ulna (olecranon): tension band wiring

Dean W. Richardson

16.1 Fracture description

Fractures of the olecranon process of the ulna are among the most common long bone fractures in horses. Most are due to direct trauma from either a kick or a fall. The fractures occur in horses of any age, although young horses are disproportionately affected. Clinical signs are usually quite dramatic with lameness, local pain and swelling over the fracture, and pain on flexion and manipulation of the elbow. If the fracture is displaced, loss of the triceps support may occur, and the horse stands with its elbow "dropped", its carpus flexed (Fig. S16A). **The specific configuration of an ulnar fracture can vary and is a critical consideration when selecting a repair technique.**

Fig. S16A: The horse afflicted with an olecranon fracture often stands with a "dropped elbow", resembling the position characteristic of radial nerve damage.

16.2 Preoperative considerations

A fracture of the equine ulna is an ideal candidate for the application of the tension band principle. **The pull exerted by the triceps muscle coupled with the absence of weight bearing forces on the vestigial distal ulna, results in an almost "pure" tensile stress environment along the caudal aspect of the bone**. This allows the use of wire, a material quite strong in tension but very weak in bending (Fig. X16A) [1–3]. Although there is no

The equine ulna exists in an almost purely tensile biomechanical environment.

Consider the configuration on the fracture when selecting a repair technique.

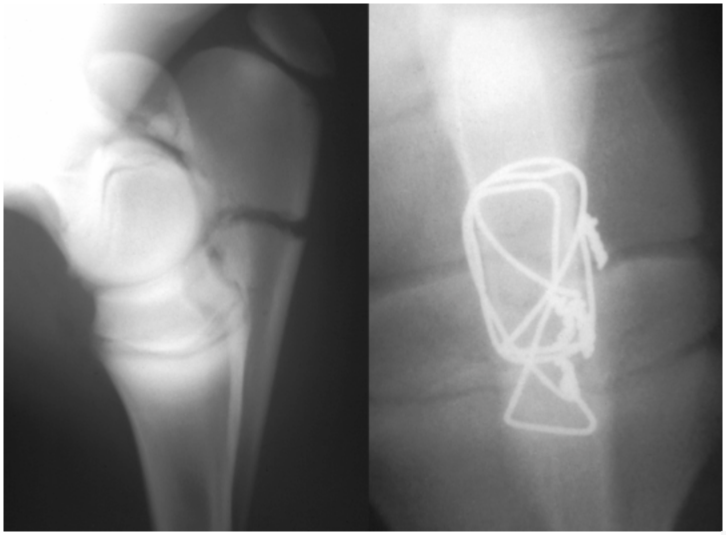

Fig. X16A: Wire alone can be used to stabilize many olecranon fractures, since it will be in an exclusively tensile stress environment.

There are occasions when plating is easier and more reliable.

Use tension band wiring for Salter-Harris type I fractures of the proximal olecranon.

absolute weight limit for the use of pins and wire to repair ulnar fractures, **there are distinct limitations for its use dictated by the configuration of the fracture and many occasions when plating is both easier and more reliable.** The primary indication for the wiring technique is in the young horse (< 6 months) where plating might interfere with growth [4]. **Tension band wiring is the technique of choice for Salter-Harris type I fractures of the proximal olecranon** (Fig. X16B) and is highly recommended for repair of simple, minimally displaced fractures at, or distal to, the level of the humeroradial articulation. The technique is not well suited to the repair of comminuted or intrinsically unstable fractures. It is usually not used in adult horses with fractures proximal to the joint level.

Fig. X16B: Tension band wiring is the treatment of choice for Salter-Harris type I fractures of the tuber olecrani. These fractures are difficult to repair with consistent success in another way.

16.3 Surgical anatomy

A straight incision is made over the caudolateral surface of the ulna, and a plane of dissection is developed between the ulnaris lateralis and the ulnar head of the deep digital flexor muscle. This tissue plane is readily identified at the level of the fracture hematoma. If the fracture involves the most proximal portion of the olecranon, the triceps insertion should be preserved. With simple wiring of the mid ulna, a very small incision is required (6–7 cm). If a pin and wire technique is necessary, the skin and fascial incisions are continued proximal to the olecranon tuber. All pins and wires can be placed in the proximal olecranon with minimal dissection of the triceps insertion.

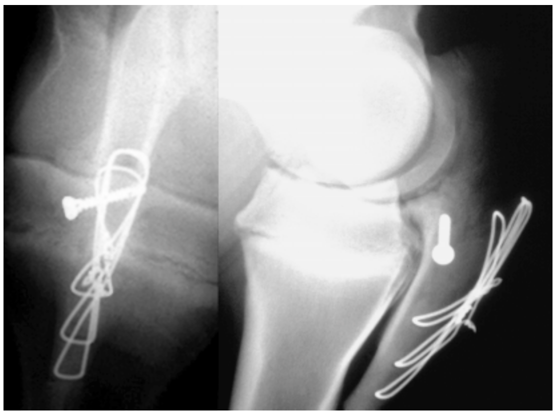

Fig. X16C: In oblique fractures, a lag screw may be used to maintain reduction during wiring and confer additional strength to the final fixation.

16.4 Surgical procedure

The fracture line is debrided with a small curette and/or a bone pick. **Reduction is facilitated by extension of the distal limb**. In oblique fractures, pointed reduction forceps are used for temporary reduction while one or two lag screws are placed. Either 3.5 mm or 4.5 mm equipment can be employed. Transverse fractures need to be manually reduced during pin placement and/or final wire tightening.

Extend the limb to help effect reduction.

16.4.1 Wire alone (for fractures at or below the humeroradial joint level)

The fracture is held in reduction manually, with forceps or with lag screws depending on its form (**Fig. X16C**). A 2.5–3.2 mm bit is used to drill holes transversely through the ulna at least 2–3 cm proximal to and distal to the fracture. Figure-8 loops of wire are passed through the holes and tightened with a wire tightener or pliers. **At least two strands of wire are used, even in small foals** (**Fig. X16D**). Three or four wires are typically used in yearling or adult horses (**Fig. X16E**). The wire should be at least 1.2 mm in diameter for foals, and 1.5 mm in larger horses. Prior to final tightening the surgeon should assure that the wire has been pulled straight, especially on the medial side of the bone. This is particularly important when using large gauge wire. It is optimal to tighten both the medial and lateral sides of the figure-8 but it is not usually necessary.

Use at least two strands of wire in each set of holes.

Allow room for the placement of two pins.

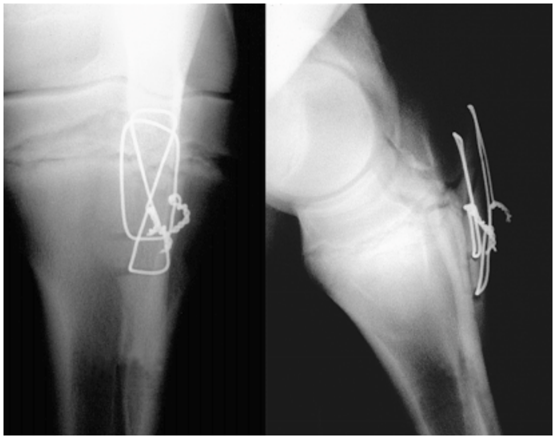

Fig. X16D: Even in small foals, two strands of wire are used. In this case, one wire was applied in figure-8 fashion, the other as a simple circle.

16.4.2 Pins and wire (for fractures proximal to the humeroradial joint)

After checking the specific shape and integrity of the proximal fragment (**Fig. X16F**), a trocar-tipped Steinmann pin held in a Jacob's chuck is inserted in a proximal-to-distal direction through the proximal fragment. **One should center the first pin but allow enough room for a second one next to it**. The pin diameter is dependent on body weight. In small foals, 3 mm pins are adequate, but in an adult horse a pin of up to 5 mm might be used. The two pins do not have to be the same size. The fragment is reduced through manipulation (elbow extension with varying amounts of rotation),

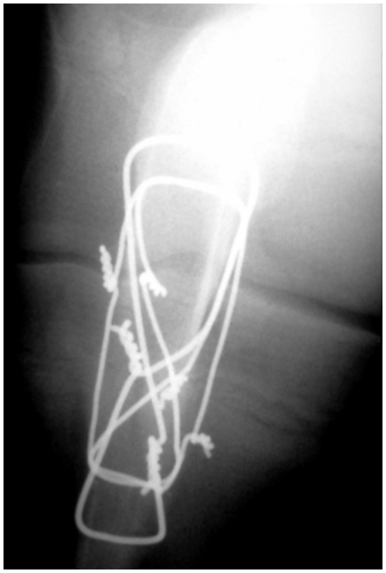

Fig. X16E: In yearlings and older horses, three or four strands of wire are used in the fixation.

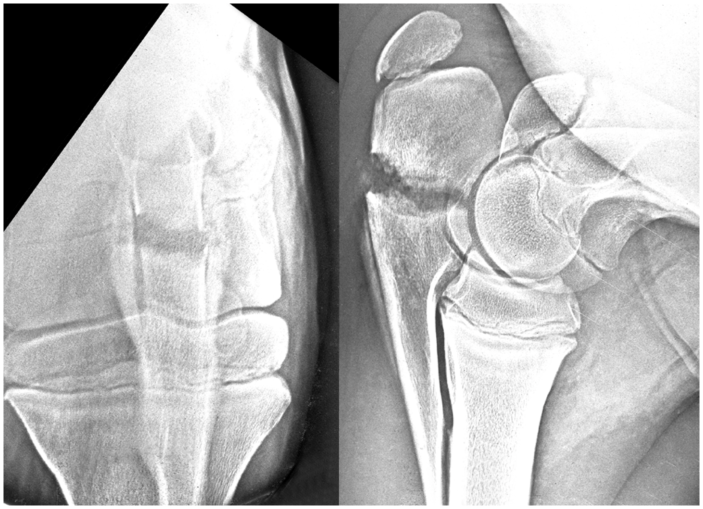

Fig. X16F: The shape and characteristics of the proximal fragment are carefully scruntinized prior to deciding on pin placement.

and the pins are passed into the distal portion of the bone. **Complete penetration of the distal cortex is not desirable; it should simply be engaged securely.** Complete penetration can lead to the implants migrating distally over the ensuing weeks or months. The second pin is inserted in a similar manner. One or two transverse 2.5–3.2 mm holes are drilled through the ulna approximately 3 cm distal to the fracture. A minimum of three wires (sized as above) are passed through the holes and around proximal ends of the pins. A 14 g 4.5–6.0 cm injection needle aids in wire passage. The wires are tightened alternately to help avoid any tendency to displace the fracture. The pins are cut and tapped down with a mallet and nail set, **allowing 6–8 mm to protrude above the bone's surface** (**Fig. X16G**). During cutting, it is especially important not to twist the cutters, which severely stresses the newly completed fixation. When the pin and wire technique is combined with lag screws, care must be taken to allow enough room for the pins in the medullary cavity. In larger horses, this does not pose as much of a problem because the screws can be placed away from the center of the bone.

An alternative to using a smooth pin as the longitudinal element in the repair is to use a screw. The primary advantage of a screw placed through the proximal fragment and down or out of the shaft of the ulna is that the power equipment can be used to facilitate insertion. The hole drilled in the proximal fragment should be a glide hole although the screw should not be tightened since the wire will serve to compress the fracture.

Do not penetrate the cortex of the distal portion of the bone.

Allow 6–8 mm to protrude above the bony surface.

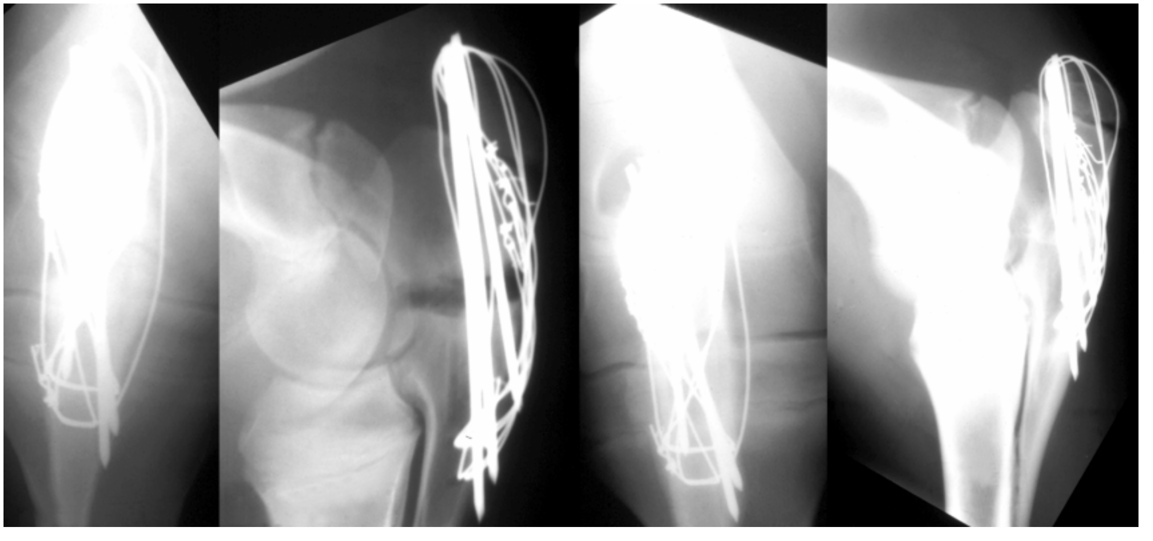

Fig. X16G: Radiographs taken immediately postoperatively and 13 weeks later demonstrate the elements of fixation used and the healing of the fracture.

16.5 Postoperative treatment

Closure of this incision is readily achieved and rarely requires tension sutures unless there was considerable muscle trauma. Drains are unnecessary unless there was marked soft tissue injury or contamination. Perioperative prophylactic antibiotics are continued for 1 day or until the drain can be removed. **Recovery from general anesthesia should be as smooth and gentle as possible using any available precautions (e.g., deep mats, small doses of xylazine in the recovery stall, and physical assistance)**. A fairly light, unsplinted bandage seems to maximize the patients' ability to position their limbs in a coordinated fashion. Recovery in foals is less risky since they can easily be physically lifted to their feet. The goal must be that initial loading of the repaired ulna be as close to normal as possible.

Recovery should be as smooth and gentle as possible, and should ideally be assisted.

16.6 Prognosis

Ulnar fractures, as a rule, have an excellent prognosis but comminution and involvement of the most proximal aspect of the ulna lessen the chances of a completely successful outcome [2]. Owing probably to the near perfect stability that can be achieved, open fractures of the ulna can be successfully managed with internal fixation, even when there is gross contamination. Athletic soundness is nearly always possible in simple fractures and breeding soundness is in any case achievable unless refractory infection develops. With specific reference to the pin and wiring technique, Martin et al. [5] recently reported the results in 22 horses treated with this method. Patient age ranged from 2 weeks to 12 years with a median age of 4 months. Body weight ranged from 68 to 477 kg (median 181 kg). Successful fracture healing was obtained in 18 out of 22 horses (82%). Of 17 horses with long-term follow-up, 13 were athletically sound.

16.7 Complications

The four unsuccessful cases in the above-mentioned series included one failure of fixation during a > 400 pound mare's recovery from anesthesia, and three postoperative infections.

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See online references on the PEOS internet home page for this chapter:
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17 Metacarpal (-tarsal) shaft

Jörg A. Auer

17.1 Description

Complete MC3/MT3 fractures are generally distinguished from incomplete fractures (so-called fatigue, stress, or saucer fractures). Complete fractures of MC3/MT3 are treated by means of internal fixation [1]. Incomplete fractures of the stress fracture type ("saucer" fractures) may be managed by placement of a position or compression screw in addition to several osteostixis holes around the screw [2]. In foals, transverse or short oblique fractures of the mid-diaphyseal region are those most frequently diagnosed [3]. Most of these injuries occur as a result of a kick. Adult horses most frequently acquire comminuted fractures of the diaphysis or the proximal or distal metaphysis. Rarely is the metacarpophalangeal joint involved, except if the shaft fracture began as a medial condylar fracture. Involvement of the carpometacarpal joint occurs more frequently. Occasionally, simple long or short oblique fractures are encountered in the adult horse. Again, the cause of the fracture is blunt trauma (kicks or falls). Because the bone is only covered by the periosteum, several tendons, subcutaneous tissue and skin, **type I or type II open fractures are frequent and bear a poor prognosis**. Expert preoperative management is essential to a successful osteosynthesis [4]. Place emphasis on preoperative immobilization of the fracture and expedient transport to a clinic equipped for internal fixation with a surgeon familiar with state-of-the-art fracture treatment[4].

In mid-diaphyseal fractures in foals younger than 4 months of age, one plate applied to the craniomedial or craniolateral aspect may prove sufficient [1]. **A prerequisite of success is solid bone-on-bone contact in the caudal cortex following reduction.** Short oblique metaphyseal fractures dictate the use of two plates, even in foals [3]. Shorter plates are used, taking care not to end both plates at the same level.

In adult horses, two plates are applied at a 90° angle to each other [1]. At least one long plate spanning the entire length of the bone, combined with a shorter plate centered over the fracture is the preferred constellation. Minimal contouring of the plates is required. Slight overbending at the fracture site increases the stability of the fixation.

Strive for accurate reduction of the caudal cortex.

Type I or type II open fractures bear a poor prognosis.

17.2 Conservative treatment

Occasionally, the costs of surgical treatment are prohibitive. In these cases conservative treatment consisting of cast application may be an option. However, the prognosis for future athletic soundness is unfavorable. This has to be discussed with the owners in depth. Also, the costs of multiple cast applications may be higher than initial plate application followed by uncomplicated fracture healing.

Comminuted fractures may respond to casting alone.

Comminuted fractures, which are very difficult to repair surgically, may lend themselves to cast treatment (Fig. X17A). Place the limb under traction during casting and apply a full limb cast. Despite the fact that intraoperative radiographs show good alignment of the fragments (Fig. X17B), some displacement may develop during recovery and the initial postoperative period. It is therefore prudent to

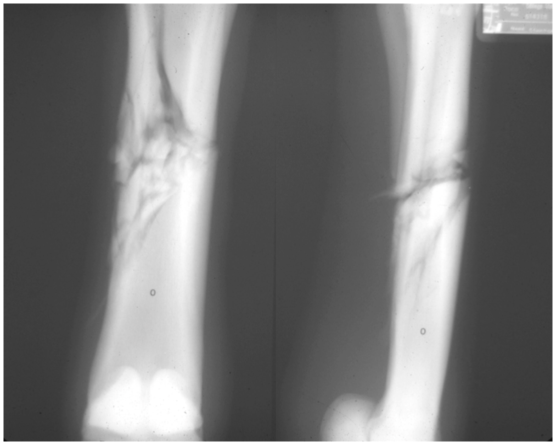

Fig. X17B: The fracture is reduced through traction under general anesthesia prior to cast application.

Fig. X17A: Dorsopalmar and lateromedial radiographic views of a comminuted closed fracture of the right MC3 in a 7-year-old Quarter Horse gelding. The carpometacarpal joint is involved.

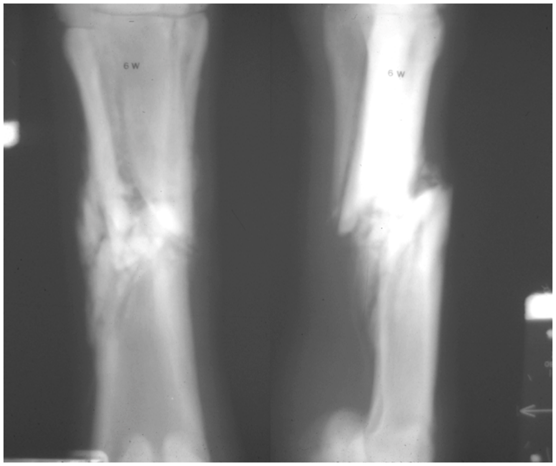

Fig. X17C: Weight bearing during the recovery phase and the immediate postoperative period caused some displacement as evidenced on the 6-week follow-up radiographs taken at the first cast change. Despite the fracture displacement, healing progressed satisfactorily.

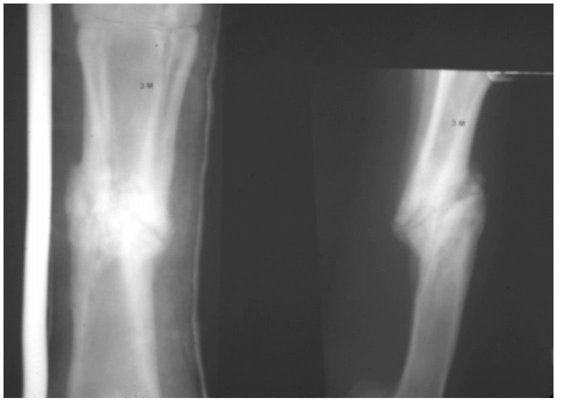

Fig. X17D: At 3 months the fracture healing was judged adequate to allow removal of the cast.

Fig. S17A: The fiberglass cast is removed at 3 months off the standing horse. A marked swelling is noted at the dorsal aspect of the midshaft of MC3.

take additional radiographs 2 days after surgery. Typically, **one to two cast changes are necessary during the approximate 3-month fracture healing period**. At each cast change take radiographs to document in progress, or lack of, fracture healing (Fig. X17C). Minor fragment displacement may remodel with time (Fig. X17D). Accomplish the final cast removal in a standing position (Fig. S17A) to prevent inadvertent refracture of the weakened bone during recovery from anesthesia.

Several cast changes may be necessary during the 3-month healing period.

17.3 Surgical treatment

17.3.1 Surgical anatomy

The metacarpus has an oval cross-section, while the metatarsus has a round one. The bone is approximately 25–35 cm long, and straight. MT3 is longer than MC3 [5]. In addition to the periosteum, the flexor tendons, the extensor tendons, the subcutaneous tissues, and the skin are the only structures that cover the bone. The approach to the bone is dependent upon the configuration of the fracture. **Ideally the incision is placed dorsolaterally, splitting the lateral digital extensor tendon** [6] (Fig. F17A). The proximal and distal ends of the incision are extended in a slight curve to provide better exposure. In displaced fractures, the sharp edges of the fragments are readily palpable and care must be taken not to penetrate the surgical gloves. Double gloving is recommended to protect the fingers, and to prevent contamination of the surgical site. In displaced fractures, the periosteum at the fracture site is always dis-

The approach incision splits the lateral digital extensor tendon.

Slow, steady traction brings about muscle relaxation.

rupted. Usually, a large hematoma evacuates during exposure. At the dorsolateral aspect the periosteum is transected along the entire length of the bone and elevated from the underlying bone (Fig. F17A). By applying this technique, excessive dissection associated with the danger of cavity formation is diminished. After adequately exposing the bone, reduction of the fracture is achieved either by specific manipulations, or by applying tension to the limb. **In severely displaced fractures, it is advisable to have an assistant, gloved and prepared for aseptic surgery, apply continuous tension to the limb**. In doing so, the contracted muscles slowly elongate against the continuously applied tension. Alternatively, a fragment distractor may be used, or tension may be exerted with the horse in dorsal recumbency and the limb connected to an overhead hoist. Tenting the two main fragments out of the incision, making contact between the congruent areas of the fracture, and slowly straightening the bone, may also reduce the fracture. This should not be attempted in a comminuted fracture.

Use the large pointed reduction forceps to maintain reduction.

Once the fracture is carefully aligned, its reduction is maintained using the large pointed reduction forceps (Fig. F17A).

17.4 Surgical procedure

17.4.1 Adult horses

A plate may be applied over countersink 3.5 mm screw heads.

Maintain reduction (Fig. X17E) by means of reduction forceps with or without tension and initially stabilize the fracture using cortex screws applied in lag fashion. The future locations of the plates are determined. Insert two to three

Fig. X17E: Dorsopalmar and lateromedial radiographic views of a short oblique midshaft fracture of MC3 after its reduction under anesthesia.

3.5 or 4.5 mm cortex screws across the fracture plane(s) using lag technique (Fig. F17B), and avoiding the plate locations. If this is not possible, incorporate the screw in the plate. Such substitution requires that bone alignment be precisely maintained. Another technique involves application of 3.5 mm cortex screws for the initial stabilization. **Because the cortex in the diaphysis is 7–9 mm thick, it is possible to countersink the 3.5 mm screw heads to such a depth that the entire screw head lies within the bone** (Fig. F17B). This allows application of a plate directly over the screw heads (Fig. F17C). In any case where interfragmentary screws are applied for preliminary fracture fixation, take care to avoid contact

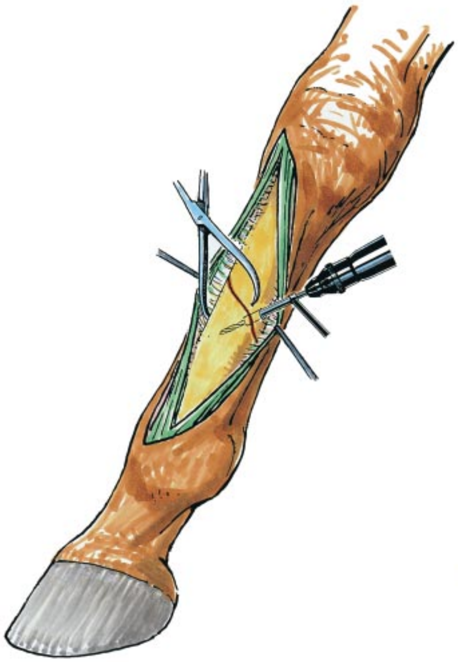

Fig. F17A: Carry out the skin incision whenever possible over the lateral digital extensor tendon. On either end extend the incision in a slight curve to increase exposure of the bone. Split the lateral digital extensor tendon longitudinally and carry the incision through the periosteum. Elevate the periosteum enough to allow application of up to two plates at 90° relative to each other. Reduce the fracture and temporarily maintain it in reduction with pointed reduction forceps.

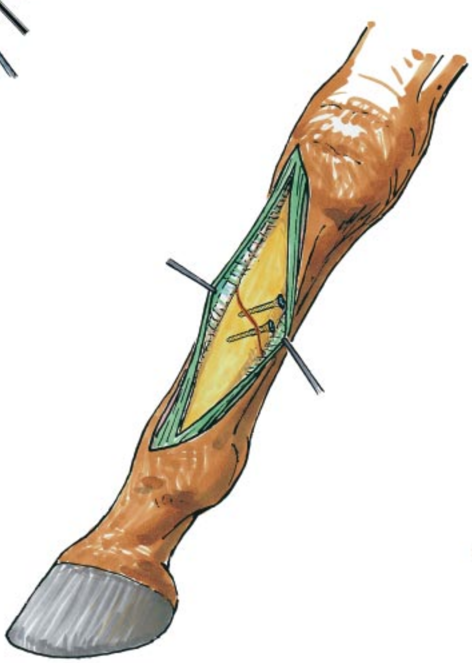

Fig. F17B: Apply two 3.5 or 4.5 mm cortex screws in lag fashion across the fracture to fix the fracture. The 3.5 mm screws can be countersunk completely allowing placement of the plate over the screw heads.

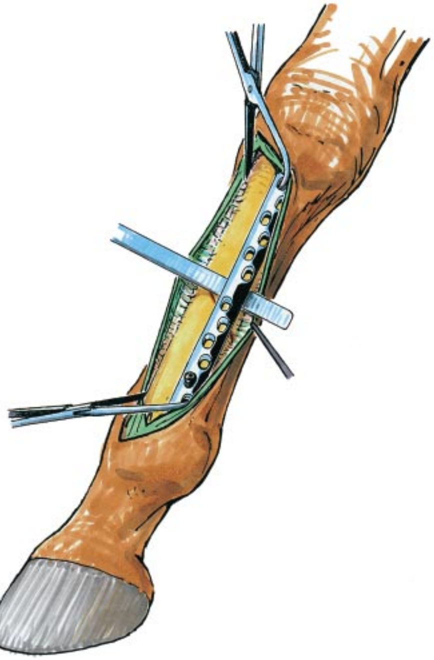

Fig. F17C: Contour the first plate to the bone. Overbend it at the fracture site, allowing slipping of the aluminum template under it. Apply the first screw near one end of the plate, but do not completely tighten it.

Fig. F17D: Displace the plate towards the fracture, insert the second screw under "load" conditions near the opposite end of the plate and tighten both screws.

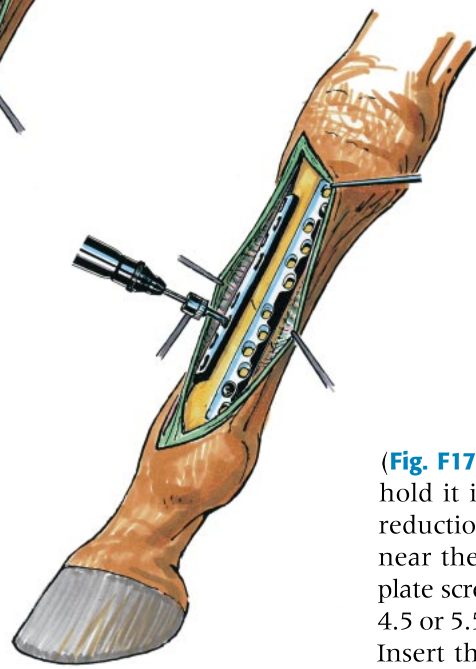

Fig. F17E: The second plate is contoured to the bone and positioned such that the screws fit between two adjacent screws of the other plate. The first screw is implanted.

Insert the first two screws through holes near the end of the plate.

between the plate screws and the lag screws. These interfragmentary screws are applied using the basic steps of screw insertion previously discussed. (See **chapter 2**, General techniques and biomechanics.)

Select the appropriate broad DCP, and contour it to the bone. Overbend the plate at the fracture site to allow even compression of the bone ends at both cis-cortices and trans-cortices (**Fig. F17C**). Apply the first plate and hold it in position with the pointed reduction forceps. Select a plate hole near the end of the plate and, using plate screw technique, loosely insert a 4.5 or 5.5 mm cortex screw (**Fig. F17C**). Insert the next screw near the other end of the plate. **Use of these plate holes for the initial screws prevents shifting of the plate relative to the bone.** This is especially important if long plates are being used (> 14 holes). Slide the plate toward the fracture plane, placing the first screw in "load" position. Check for correct placement of the plate and insert the second screw in "load" position. Next, firmly tighten the two screws, bringing the fracture under axial compression (**Fig. F17D**). Assure maintenance of close contact between plate and bone during

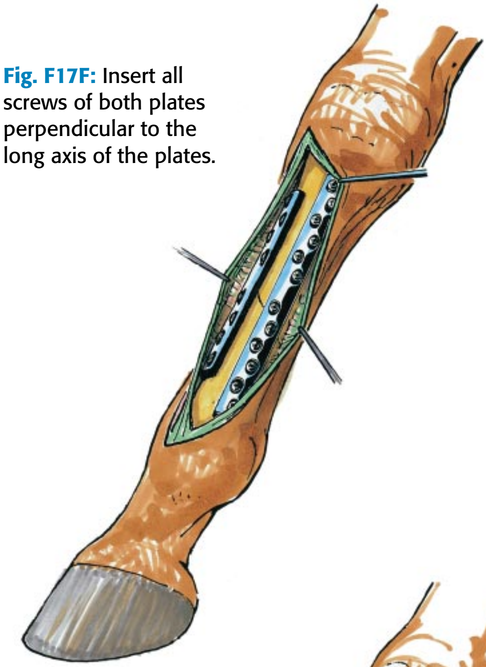

Fig. F17F: Insert all screws of both plates perpendicular to the long axis of the plates.

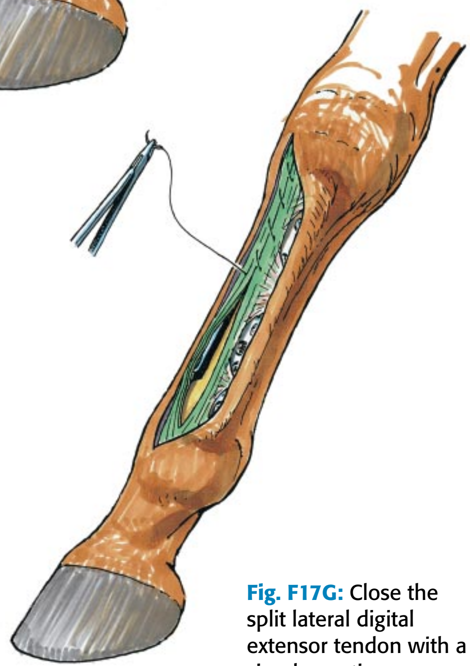

Fig. F17G: Close the split lateral digital extensor tendon with a simple continuous suture pattern.

these maneuvers. If necessary, one additional screw on either side of the fracture line can be inserted in "load" position. However, prior to completely tightening those screws, the previously placed screw on the same side of the fracture has to be loosened to allow the additional compression to take place. Placement of an additional screw near either side of the fracture plane is encouraged. Once maximal compression has been achieved, remove the reduction forceps. At this time it is advisable to apply the second plate (**Fig. F17E**). **In foals possibly one, in adults two screws are inserted in "load" position, the rest in "neutral".**

Insert only one or two screws in "load" position.

Insert plate screws perpendicular to the long axis of the bone. Position the second plate such that its holes interdigitate with the holes of the first plate (**Fig. F17E**). Interference amongst the plate screws is thereby eliminated [7]. Inadvertently contacting a screw with the drill bit or tap may result in the instrument's breakage. This is particularly common if several oblique lag screws were inserted.

Insert the remaining screws (**Fig. F17F**). **Apply each screw crossing a fracture plane in lag fashion**. After all the screws have been inserted, perform final tightening alternately in both plates and take postoperative radiographs (**Fig. X17F**).

All screws crossing the fracture plane are inserted in lag fashion.

Metaphyseal fractures are more difficult to treat, because the smaller fragment provides so little space for the insertion of the number of screws needed for rigid fixation (**Fig. X17G**). In all such cases, including those involving foals, double plating is indicated. Double plating, using regular broad DCPs (dynamic compression plate) may be successful, but the use of a dynamic condylar screw (DCS) implant is probably superior [8]. The width of the DCS is the same as that of the broad DCP, but it is 1 mm thicker).

The DCS provides more secure fixation of short metaphyseal fragments.

The two distal-most holes in the DCS plate will accept cancellous bone screws.

The DCS is especially suited for metaphyseal fractures with one very short fragment. The DCS system is "user-friendly". (See chapter 14, Radius.)

In comparison with the broad DCP, the DCS plate is an ideal fixation device for large animals, partly due to its superior strength [8]. The DCS plate is applied to the lateral (Fig. X17H) or medial aspect, because the thickness of the proximal and distal aspect of the bone in a sagittal plane may be insufficient to accept the smallest available length of DCS, measuring 55 mm. Therefore, that part of the plate needs to be applied in the frontal plane. All the instruments and implants needed for insertion of the DCS plate contain a 2.5 mm diameter canal in the center, to accept the threaded guide wire of that diameter.

The two distal-most plate holes are round, preventing application of axial compression, but accepting cancellous bone screws. If needed, axial compression may be provided by applying one or two of the remaining 4.5 or 5.5 mm cortex screws in the "load" position. Additionally, interfragmentary compression may be applied by inserting any screw crossing a fracture plane in lag fashion. **If only one DCS**

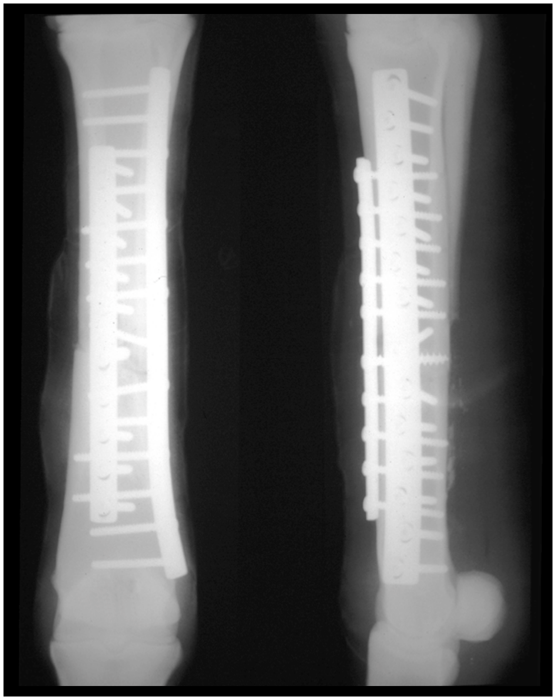

Fig. X17F: A 14-hole broad DCP was applied to the lateral aspect and a 10-hole broad DCP to the dorsal aspect of the bone. The plates were staggered and the screws inserted perpendicular relative to the long axis of the plates.

Fig. X17G: Dorsopalmar radiographic view of an oblique distal metaphyseal fracture of MC3 in a Quarter Horse stallion. The fracture was open for less than 3 hours. (Courtesy JP Watkins, Texas A & M University.)

implant is used, external coaptation with a cast is indicated for at least 4 weeks (Fig. X17I). The second plate, if deemed necessary, is applied and all remaining screws are inserted into both plates and alternately tightened. Take care to stagger the two plates slightly. One plate should span the entire length of the bone (in metaphyseal fractures). In diaphyseal and oblique fractures both plates together (additive) should span the entire length.

Plate luting has been advocated to increase the strength of internal fixation[9]. It is performed by applying the plates to the bone using standard technique. After the plates are fixed, the screws are loosened, the plates elevated away from the bone, and the contact area between the plates and the bone covered with methylmethacrylate. Subsequently, the screws are reinserted and securely tightened. Because the methylmethacrylate is still soft, tightening of the screws results in a perfect contact interface between bone, methylmethacrylate, and the plate. **Penetration of the fracture plane by methylmethacrylate should be avoided, because it prevents fracture healing in that area of contact**. However, invasion of

If only one DCS plate is used, augment the fixation with a cast.

Avoid introduction of methylmethacrylate into the plane of the fracture.

Plate luting may be used to strengthen the fixation.

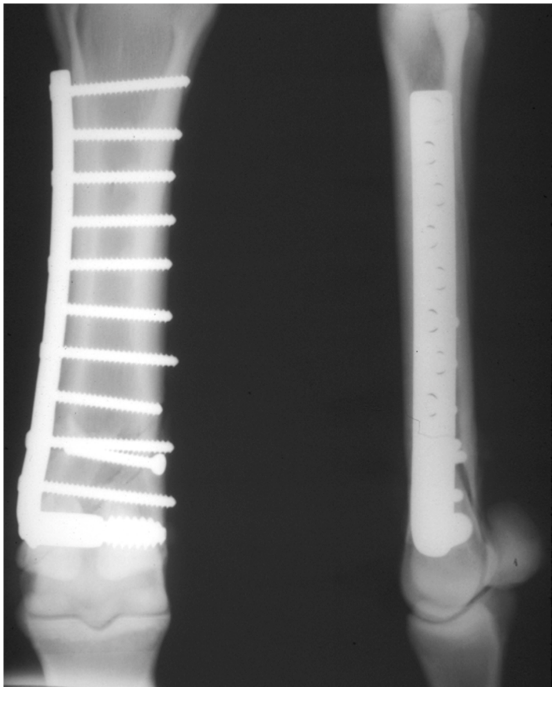

Fig. X17H: The fracture in Fig. X17G was repaired with an interfragmentary cortex screw applied in lag fashion and a 10-hole DCS laterally. A fiberglass cast was applied for the first 4 weeks postoperatively. (Courtesy JP Watkins, Texas A & M University.)

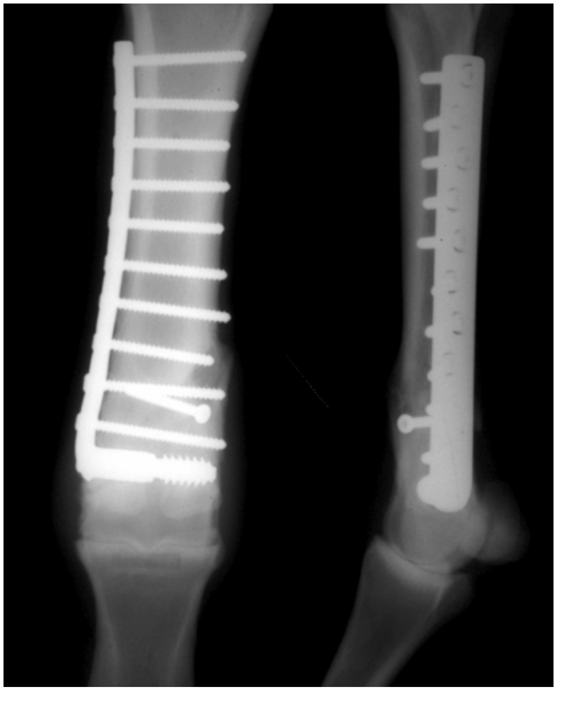

Fig. X17I: Fracture healing progressed without development of osteitis/osteomyelitis with a good cosmetic and functional result. (Courtesy JP Watkins, Texas A & M University.)

Whenever possible, avoid bridging the growth plate.

the oblong plate holes by methylmethacrylate is desirable because it increases the stability of the screw heads. Recent research shows that, in actual fact, the filling of the oblong plate holes around the screw heads provides the greatest proportion of the increased stability contributed by luting the loaded plate [10]. The benefit of the DCP system facilitating axial compression of the fracture by the insertion of selected screws in the "load" position, is lost postoperatively because movement of the screw head relative to the plate hole is possible. By filling the oblong plate holes around the screw head with methylmethacrylate, the plate and the screws are united much more solidly, providing additional strength.

17.4.2 Foals

Young foals with a transverse or short oblique mid-diaphyseal fracture (**Fig. X17J**) may be treated with only one broad 10-hole DCP (**Fig. X17K**, **Fig. S17B**). Reduce the fracture, and if the angle permits, insert a cortex screw in lag fashion across the fracture plane. Contour the plate to fit the shape of the bone and insert the initial two to four screws in "load" position. Insert the remaining screws in "neutral" position. **Take care to avoid placing screws across the physis, if at all possible**. With adequate fixation, healing is uncomplicated with a good cosmetic result (**Fig. S17C**) and implant removal at 4–5 months postoperatively (**Fig. X17L**). If

Fig. X17J: Radiographic views of an oblique distal metaphyseal fracture of MT3 in a foal. Note that the transportation cast is too short, allowing excessive movement and displacement of the fragments.

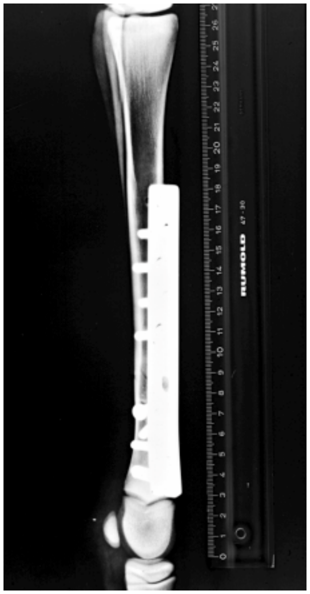

Fig. X17K: A 9-hole broad DCP was applied to the dorsolateral aspect of the bone. Note that the plate does not span the entire bone. No implants were inserted into the physis.

Fig. S17B: Immediate postoperative view of the repaired MT3, depicting anatomic reduction and a straight bone.

Fig. S17C: The foal at 4 months postoperatively at the time of implant removal. A good cosmetic result is presented.

Fig. X17L: The plate was removed 4 months postoperatively after healing of the fracture had occurred.

growth plate bridging is necessary, e.g., in an oblique fracture in the metaphysis, remove the epiphyseal screws after 2–3 weeks. In doing so, the growth potential should be minimally impaired. **Bridging of the distal growth plate through insertion of additional implants may lead to greater growth disturbances than with the proximal physis, because of the greater contribution to longitudinal growth in that region.**

Epiphyseal fractures (Fig. X17M) frequently require bridging of the growth plate if internal fixation is attempted, except in selected Salter–Harris type III or IV fractures, which may be amenable to simple screw fixation or application of a short narrow plate associated with external coaptation for a few weeks (Fig. X17N). However, in Salter–Harris type III fractures a tension band consisting of a cerclage wire in a

Fig. X17M: Salter–Harris type II fracture of the distal MC3 in a foal, exhibiting some displacement in the transportation cast.

Avoid bridging the growth plate whenever possible.

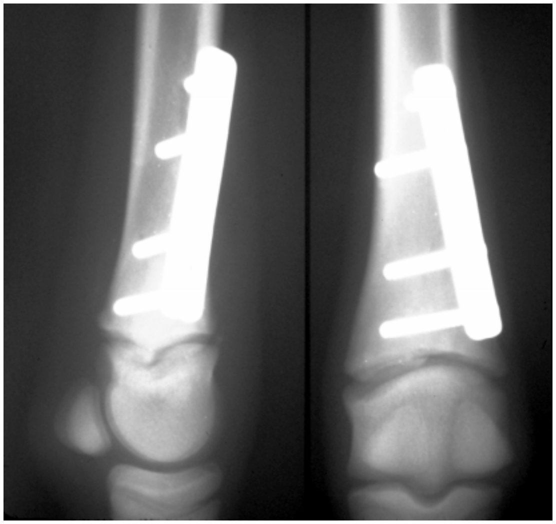

Fig. X17N: The fracture was reduced and a 4-hole narrow DCP applied to the metaphysis. No implants were inserted into the physis. A fiberglass cast was applied for the initial 4 weeks.

Adaptation of the split tendon relieves tension on the thin subcutaneous tissues and the skin.

figure-8 configuration, or a small plate may be necessary to counteract the tension created by the collateral ligament.

In long bone fractures (oblique or spiral) involving part of the growth plate, avoid crossing of the physis with implants (plate, screw, wire) if at all possible. Should this not be possible, use only a minimal number of implants and remove them early.

When all the implants are in place, flush the surgical region again and ligate any bleeding vessels. Insert a suction drain if bleeding continues. Do this immediately prior to closure of the tissues. Locate the exit portal in the skin separate from the original skin incision(s). If enough tubing is available, it should exit distal to the distal most aspect of the surgical site. Close the incision in three to four layers. Close all layers except the skin using a simple continuous pattern of 2/0 monofilament resorbable suture material (PDS, Maxon®). The layers include the periosteum, where the two transected edges are adapted as closely as possible over the two plates. **Adaptation of the longitudinally split tendon allows application of a considerable amount of tension without damaging the thin subcutaneous tissues** (**Fig. F17G**). If needed, one layer may be placed as a subcuticular suture. Close the skin using a simple interrupted suture pattern of monofilament nonresorbable suture material (e.g., Supramid®, Nylon) or skin staples. It may be necessary to create some longitudinal relief incisions at a distance from the implants. After closure, a tight pressure bandage is applied over a nonadhering dressing (e.g., Telfa®).

17.5 Postoperative treatment

After recovery from anesthesia, a splint may be applied over the bandage, if deemed necessary. Some type of external coaptation is indicated in foals with a distal physeal or metaphyseal fracture where only one plate or inadequate internal fixation may be applied. This may be possible even for the recovery period, because these animals can be assisted in rising.

Maintain the animal in a box stall and barring any major complications during the immediate postoperative treatment, change the bandage for the first time 2–3 days postoperatively. Maintain suction drainage and document the amount of fluid withdrawn per unit time in the case record. Should fluid accumulation continue over a 3-day period without a significant decrease, instability or an inflammatory process with impending infection (or both) may be present. Routinely, the drain is removed at the time of the first bandage change. Maintain some type of bandaging for at least 3 weeks. After removal of the skin sutures or staples 10 days postoperatively, a minimal bandage is still indicated. Start to exercise at a walk 4–6 weeks postoperatively. Carry out radiographic evaluation prior to turning the animal out to pasture approximately 8 weeks after surgery. Complete fracture healing typically takes 3–5 months.

17.6 Complications

Complications are: fixation breakdown, infection, or poor placement of an implant, such as a screw penetrating a joint leading to arthritis with pain and decreased range of motion. In foals, bridging the growth plate by implants may lead to the development of an angular deformity or to shortening of the bone with attendant gait abnormality. Physeal fractures usually result in considerable damage to the germinative layers of the physis. This alone may lead to the complications mentioned above. Additionally, care should be taken not to penetrate the vestigial metacarpal or metatarsal bones located on the opposite side. This could lead to postoperative fracture of the involved splint bone, especially in its distal aspect. Prolonged severe lameness may afflict the overloaded opposite, or “support” limb. Foals that protect the injured limb for a prolonged period of time may also develop an angular limb deformity due to overload.

Finally, development of osteitis/osteomyelitis as a result of fracture treatment is of major concern. The vast majority of postoperative infections are iatrogenic in nature and result in fixation breakdown, followed by humane destruction of the animal. Therefore, pay meticulous care to strict maintenance of asepsis and the application of Halsted’s principles during surgery. Even with impeccable technique, **perioperative administration of broad-spectrum antibiotics is advisable.** Open fractures (**Fig. X17O**) treated by means of internal fixation (**Fig. X17P**) may lead to osteitis/osteomyelitis (**Fig. X17Q**). Despite such an infection, fracture healing can proceed with good adjunctive management including flushing of the surgery site, incorporation of antibiotic impregnated PMMA, external coaptation, and judicial application of anti-inflammatory drugs (**Fig. X17R**). Persisting draining tracts are present (**Fig. S17D**) and disappear only after implant removal (**Fig. S17E**, **Fig. S17F**, **Fig. X17S**).

Administration of perioperative antibiotics is routine.

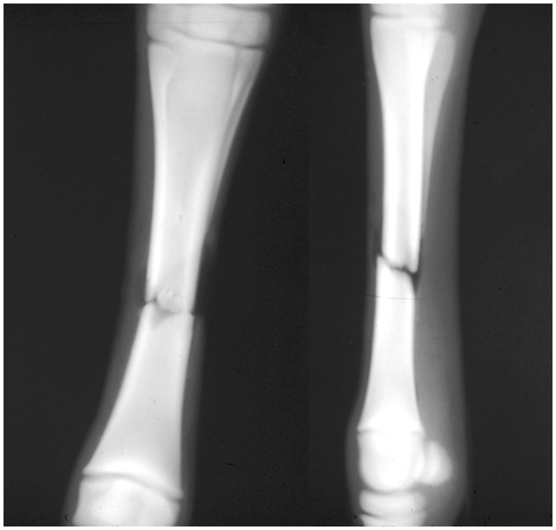

Fig. X17O: Dorsopalmar and lateromedial radiographic views of an open transverse midshaft fracture of MC3 in a 2-month-old foal.

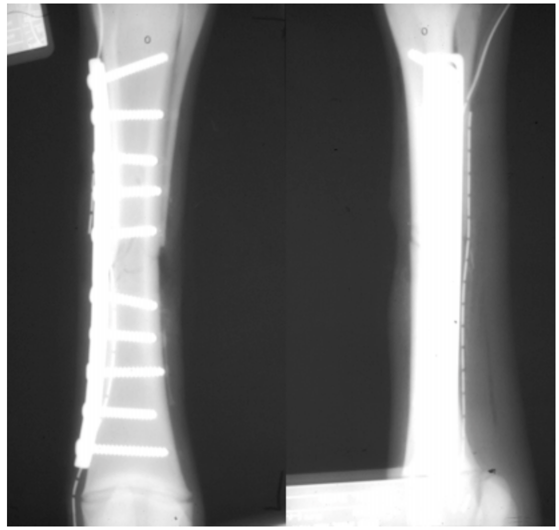

Fig. X17P: A broad 10-hole DCP was applied to the lateral aspect of the bone. An ingress/egress catheter was installed for postoperative flushing and local antibiotic management.

Fracture healing can occur in the presence of infection, if stability can be maintained.

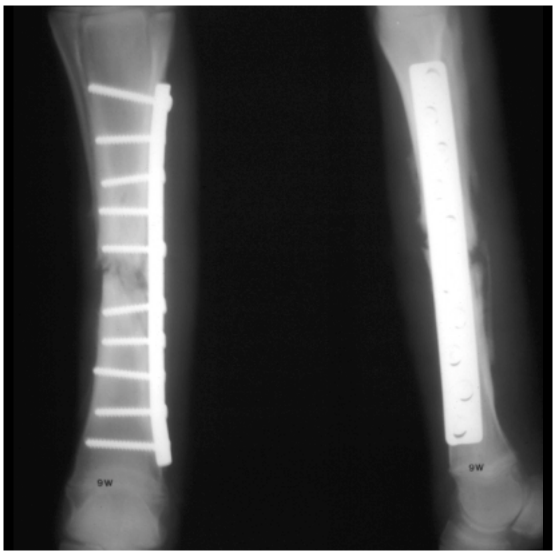

Fig. X17Q: Despite aggressive management, a considerable amount of lysis developed at the surgery site at 7 weeks postoperatively. External coaptation was applied to reduce loading of the implants and support weight bearing.

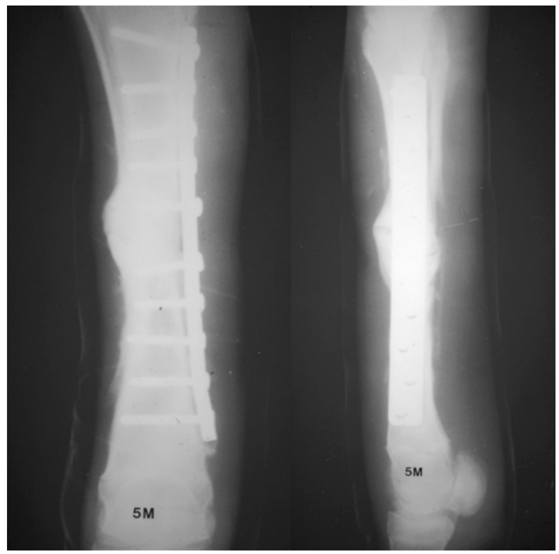

Fig. X17R: At 5 months postoperatively the fracture had healed in the presence of a persistent draining tract and considerable callus formation.

Fig. X17S: The implants were removed 6 months postoperatively, which resulted in the remission of drainage.

Usually, implants must be removed to bring about final resolution of drainage.

Fig. S17D: The limb is enlarged with a persistent draining tract present. The foal was willing to bear weight on the limb.

Fig. S17E: The plate is approached during implant removal showing the excessive soft tissue proliferation as a reaction to the persistent infection. Most of the screws were loose.

Fig. S17F: After plate removal, the underlying bone and surrounding soft tissues were curetted leaving only healthy tissue near the former implant bed.

There is wide variation in outcome following surgical stabilization of fractures of the shaft of the third metacarpal/ metatarsal bone.

17.7 Results

The success of internal fixation of MC3/ MT3 shaft fractures varies widely. In foals with closed short oblique or transverse fractures of the mid-diaphyseal region, a favorable prognosis can be given for future soundness and an athletic career [3]. Involvement of an articular surface or the growth plate may place this prognosis in jeopardy. In metaphyseal fractures, stabilization may not be as complete as in the middiaphyseal region, and the outcome will vary accordingly [3].

Give a guarded prognosis for healing and future soundness in adult horses [3]. It is reasonable to say that the prognosis for an adult horse becoming an athlete is guarded to poor. These aspects have to be discussed with the owners in depth prior to performing surgery.

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18 Femur

Larry R. Bramlage & Gustave E. Fackelman

Femur fractures in adult horses are generally not treated. Therefore this chapter deals exclusively with femur fractures in foals. There are three common types of femur fractures seen in the foal: the proximal femoral physeal fracture, the diaphyseal spiral fracture, and the distal physeal fracture (usually Salter type II) fracture. As the age group advances, further complex distal fractures may be seen [1].

18.1 Proximal femoral physeal fracture

18.1.1 Description

The proximal femoral physeal fracture can be difficult to diagnose. Often it is associated with a history of the foal having flipped over backwards, or "spread eagled" on ice. **It is most common in foals 6 months to 1 year of age** [2]. The fracture is intra-articular and occasionally will have a fragment of metaphysis attached to the epiphysis. The most important preoperative consideration is early diagnosis, as motion of the fracture plane quickly eburnates the interdigitations of the proximal femoral physis and makes subsequent maintenance of reduction much more difficult.

18.1.2 Preoperative considerations

No immobilization of the limb is necessary with this type of fracture. In fact, the level of pain seems so low that the foal must be prevented from using the limb in most instances.

18.1.3 Surgical anatomy

The femur is difficult to extract from the acetabulum as the accessory ligament remains attached to the metaphyseal portion of the bone. Therefore, reduction of the fracture is monitored by palpation alone. In addition, it must be borne in mind that **the femoral head does not directly appose the flat spot on the lateral aspect of the femur**. The femoral head is positioned dorsomedial to the femoral shaft and the flat lateral aspect of the bone (anteversion). Implants passed straight medially, perpendicular to the plane of the lateral cortex, will exit the bone caudal to the femoral head.

> The plane of the femoral head is not parallel to the lateral surface of the bone.

> Suspect proximal femoral physeal fracture, when lameness follows a fall in a foal 6 to 12 months of age.

18.1.4 Surgical procedure

Surgical approach is through a trochanteric osteotomy to disengage the middle gluteal muscle and allow access to the acetabular area. Extensive dissection of the pelvis is not possible due to the large muscle mass, and because the sciatic nerve cannot be mobilized and lies immediately caudal to the acetabulum. The surgical approach is dorsal to the palpable greater trochanter, making a 20–30 cm incision starting cranial, half the distance between the greater trochanter and the wing of the ilium. It then extends caudally, dorsal to the greater trochanter, and curves distally along the plane of the biceps femoris muscle. The subcutaneous tissue and skin are incised and elevated, preserving the tough dorsal fascia of the area with the skin until the greater trochanter is encountered. The superficial gluteal tendon is transected from its attachment to the third trochanter, and is retracted from the field. Sufficient tendon remains attached to the third trochanter to provide for its being sutured back into position. The middle gluteal attachment to the greater trochanter is isolated by passing a finger beneath it and dissecting from cranial to caudal, around the trochanter, which extends proximal to the femoral head.

Palpate the drill bit as it passes through the metaphysis. This ensures correct location in the epiphysis.

One implant can be predrilled prior to transecting the greater trochanter. However, this may prove fruitless since implants for stabilization of the fracture will pass through the same area. Predrilling attachment sites is theoretically better, but practically often results in an unusable hole. In addition, it may prove difficult to find the site of the predrilled hole in the greater trochanter due to the thickness of the tendon of insertion of the middle gluteal muscle. The greater trochanter is transected transversely and often slightly obliquely from distal lateral to proximal medial. **This removes the middle gluteal attachment with sufficient bone attached to the tendon to facilitate internal fixation of the osteotomy.** The middle gluteal muscle is then retracted medially to expose the dorsum of the femur and the femoral head.

Remove enough bone during osteotomy to facilitate rigid internal fixation of the greater trochanter after fracture fixation.

The joint capsule will most often be torn; however, if it is not, it can be incised to allow an approach to the coxofemoral joint. The femur is usually luxated craniodorsal and must be retracted and replaced in the acetabulum over the area of the femoral epiphysis. Reduction of the femur is greatly facilitated by a large bone clamp placed across the proximal femur in the area of the femoral neck, which can be used to retract the femur abaxially out of the acetabulum to ascertain both the cranial to caudal and the rotational manoeuvers necessary to reduce the femoral head.

Before the femoral head is reduced, a finger is inserted in the fracture to identify the ideal location for the implant to pass through the metaphysis and into the epiphysis. **The best way to determine the ideal site is to drill the hole with one finger in the fracture plane until the drill bit is palpated just as it begins to exit the metaphysis**. The capital epiphysis of the foal is small, and as much purchase as possible is necessary. The consideration of implants would include pins or screws. Due to the anatomy and position of the femoral epiphysis, pins can be used, as loading tends to impact the physis upon the femoral neck. The 6.5 mm cancellous bone screw with 16 mm thread is the author's (LRB) preference, though the 7.0 mm cannulated screw as used in cattle [3] would also be a possibility.

A 3.2 mm drill bit is used to drill the thread hole through the lateral femur up the femoral neck and into the midportion of the femoral metaphysis. The fracture is then reduced and the epiphysis drilled. A finger is used to identify the pending penetration of the articular cartilage. A depth gauge is used to ascertain the appropriate length screw, and the 4.0 mm drill bit is then used to enlarge the hole in the cortical bone of the femur into a glide hole for the shaft of the 6.5 mm cancellous bone screw. It is not necessary to enlarge this hole through the entire metaphysis. The cancellous bone tap will not easily pass through the lateral femoral cortex, but will subsequently follow the path of the 3.2 mm drill hole. The hole depth is determined with the millimeter gradations on the tap to anticipate when the articular surface is being approached as well as to determine the length of screw that is necessary. The cancellous bone tap is used to tap the hole within the epiphysis until it nears the surface of the articular cartilage. The 6.5 mm cancellous bone screw is only available in gradations in length of 5 mm, **thus a screw length a few millimeters short of the joint surface is used**.

The most difficult manoeuver is drilling and tapping the initial 3.2 mm hole from the femoral neck into the physis without distracting the fracture or without loss of reduction of the fracture as the hole is being drilled across the fracture plane. Loss of reduction makes it difficult to reposition and relocate the 3.2 mm hole. If the reduction has been difficult, the following procedure is ideal: drilling of the first hole with a 3.2 mm drill bit, leaving the bit in place, and then inserting the "second" cancellous bone screw first, in the prescribed method, through a second 3.2 mm hole. Subsequent removal of the initial drill bit and replacement with a 6.5 mm cancellous bone screw, as described, allows the best method for creation of fixation without risking loss of reduction. Two or three screws can be inserted. Two is enough to maintain reduction and fixation if the fracture has not been badly damaged, and the interdigitations of the physis have not been extensively eburnated.

When fixation has been accomplished, a suction drain is placed deep within the site and the greater trochanter is reattached to the proximal femur using lag screws and tension band wires. The wires are passed through the trochanter and the lateral aspect of the femur. The wire will be drilled through the third trochanter, or in some situations it can be passed around one of the screws used for fixation of the proximal epiphyseal fragment, if available.

Replacement of the trochanter with the lag screws and tension band wire is followed by attachment of the superficial gluteal tendon to the third trochanter. The subcutaneous tissue and skin are then closed and the foal is assisted in standing upon recovery from general anesthesia.

18.1.5 Postoperative treatment

Appropriate antibiotic, analgesic, and anti-inflammatory therapy is undertaken and continues according to postoperative evaluation of soft tissue healing and use of the limb. External support is neither necessary nor appropriate.

18.1.6 Complications

The most common complications include:

- loss of fixation in the proximal fragment,
- postoperative infection, and
- degenerative arthritis of the hip joint, due to damage to the articulation, and possibly to necrosis of the epiphysis (caput femoris).

If adequate fixation is achieved, the results are rewarding and the foals will begin to use their limbs immediately. If instability ensues, degenerative arthritis is inevitable and a useful life for the foal becomes a matter of serious doubt. Other methods of fixation using dynamic hip screw (DHS) plates present interesting alternatives [2].

Replace the trochanter with lag screws and a tension band wire.

Use a screw a few millimeters "short" to avoid damage to the articular surface.

In this area, loss of growth potential is less important than loss of stability.

Left untreated, most foals develop femoral head necrosis and debilitating lameness.

Femoral diaphyseal fractures occur during a fall with the limb in adduction.

However, the associated screw is very large in relation to the size of the foal's physis. In most instances, it is difficult to apply well because the femoral neck does not appose the flat-sided lateral aspect of the proximal femur. The lag screws add an additional dimension to fracture fixation compared with pins, and **loss of growth potential in the proximal physis is of less significance than loss of stability.**

18.1.7 Results

Limited case reports are available, but in general the prognosis is related to the amount of damage done to the hip joint prior to surgery, the accuracy of reduction and fixation, and the avoidance of other complications such as postoperative fixation. With minimal preoperative damage and early accurate repair, athletic use is conceivable, but in most instances not attainable. Salvage as a breeding animal or as an individual of limited use are reasonable expectations. This contrasts with those animals left untreated. **Most of them suffer necrosis of the femoral head, presumably due to: an interruption of the blood supply as a result of trauma ± surgery, seen also in dogs [4]; pseudoarthrosis, and chronic debilitating lameness.** Few are sound, even as breeding stock.

18.2 Diaphyseal and distal metaphyseal fractures

18.2.1 Description

One quarter of the foals with long bone fractures have diaphyseal fractures of the femur [1]. Femoral fractures also occur in adult horses; however, because of their size and the fact that the majority of these fractures are severely comminuted, this discussion will be limited to femoral fractures in the young.

18.2.2 Preoperative considerations

Clinical signs of diaphyseal and distal physeal fractures include edema and swelling in the thigh region, proportional to the amount of displacement. A non-weight bearing lameness is usually present, and in displaced diaphyseal fractures there is rotational instability. Crepitation is usually noted upon manipulation of the limb.

Definitive diagnosis is made radiographically. The foal is placed in lateral recumbency with the affected limb down. The radiographic cassette is placed under the affected limb and the beam is directed from medial to lateral with the opposite limb abducted.

The most common diaphyseal fracture configuration is comminuted with a large spiralling component; however, short oblique and transverse fractures can occur. **The causative traumatic event, when witnessed, seems to be a fall with the limb in adduction.** The primary force is probably torsional and any comminution is the result of the high energy dissipated at the time of bony failure. Open fractures are uncommon because of the extensive surrounding musculature.

18.2.3 Surgical procedure

Horses are placed in lateral recumbency with the affected limb uppermost. The hair is removed, starting at the middle of the back and including the tuber coxae, to approximately 10 cm below the stifle. The skin is shaved over the lateral aspect of the femur. This area is prepared for aseptic surgery.

A linear incision is made in the skin from the greater trochanter to the lateral aspect of the stifle. The fascia lata is incised. The vastus lateralis and biceps femoris muscles are bluntly separated, exposing the tendinous insertion of the superficial gluteal muscle on the third trochanter. This tendon is transected to provide adequate exposure of the proximal femur; sufficient tendon should be left attached to the bone for reapproximation at closure. The insertion of the biceps femoris muscle on the lateral patellar ligament is partially incised to provide the necessary exposure in more distal fractures.

The fracture hematoma and any devitalized tissue should be removed. Fracture reduction is accomplished by manual traction and temporary bone clamp fixation after tenting and interdigitating ("toggling and angulating") the fragments through the incision. Fracture reduction is maintained by self-retaining bone holding forceps and lag screws. **The screws should be positioned so as not to interfere with subsequent plate placement.** A broad dynamic compression plate (DCP), cobra head plate [5], angle blade plate, or DCS [6] (dynamic condylar screw) plate is positioned on the lateral surface of the femur from the greater trochanter to the supracondylar fossa or lateral epicondyle. This lateral plate is fixed with 4.5 or 5.5 mm cortex screws, applying dynamic compression as indicated. Screws are placed in all of the plate holes, and lag screws should be used when crossing the fracture plane to create interfragmentary compression. **In diaphyseal fractures a broad DCP should also be placed 90° to the lateral plate on the cranial surface under the rectus femoris**. The cranial plate is applied in compression, but serves mainly as neutralization, and again lag screws are used across the fracture whenever possible. The application of plates at 90° angles provides maximum stability and neutralizes the bending forces at the fracture site (Fig. S18A). Implant selection is an important aspect in successful management of femoral fractures. The pull-out strength of 5.5 mm cortex screws seems significantly greater than that of 4.5 mm screws in foal diaphyseal bone. **Therefore, the use of 5.5 mm cortex screws is beneficial when the need for additional stability is anticipated**.

Increased distal exposure to provide adequate reduction of distal metaphyseal or physeal fractures is accomplished by partially transecting the biceps femoris insertion from the lateral patellar ligament. If extensive articular reconstruction is necessary, placing the horse in dorsal recumbency (Fig. S18B), and "taking down" the lateral and medial patellar ligaments may also be helpful (Fig. S18C). In distal physeal fractures where an angle blade plate, DCS plate, condylar buttress plate, or a cobra head plate is used, only one lateral plate may be necessary. In yearlings or older patients [5], double plating should still be practiced (Fig. X18A) for the most dependable results (Fig. S18D).

> Place a second plate at 90° to the lateral plate.

> Use 5.5 mm cortex screws for added stability.

> Lag screws used as temporary fixation should not interfere with the definitive repair.

Fig. S18A: Exposure of the shaft of the femur for double plating requires separation of the vastus lateralis and the biceps femoris, transection of the tendon of the superficial gluteal, and possibly incision of the insertion of the biceps femoris.

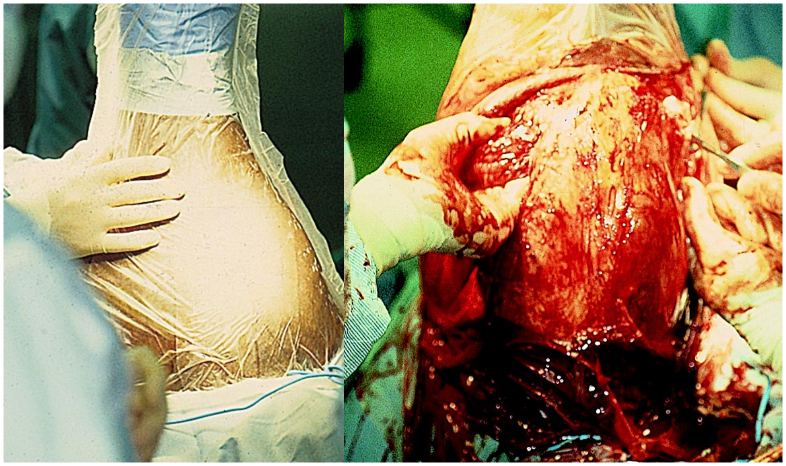

Fig. S18B: The horse has been positioned in dorsal recumbency, and the stifle was prepared for aseptic surgery (left). Dorsal recumbency, and a position near the edge or corner of the table provides easy access for two teams of surgeons (right).

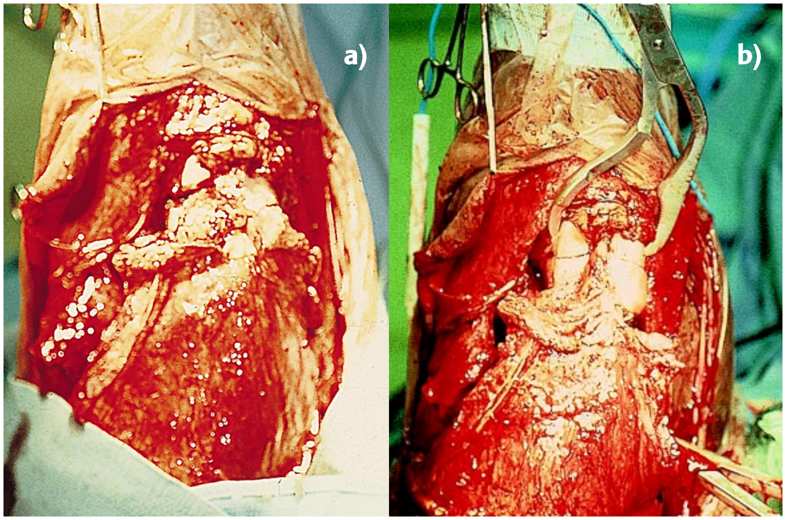

Fig. S18C: a) Reflection of the lateral and medial patellar ligaments permits access to the distal femur, badly comminuted in this case. b) The wide exposure allows careful reconstruction of the distal joint surface of the femur, and temporary fixation with large self-retaining forceps.

Fig. X18A: The treatment of this comminuted distal femoral fracture in a yearling Arabian with a cobra head plate medially and a straight DCP laterally results in good healing at 2.5 months postoperatively.

Fig. S18D: At 3 months postoperatively the Arabian filly in **Fig. X18A** was exercising freely, with a good range of motion. The left hind limb was operated.

The use of a cancellous bone graft is rarely necessary because fracture repair is limited to young stock, the fracture usually involves a portion of the metaphysis, and the rich blood supply favors rapid healing.

A continuous suction drain should be placed deep in the incision and exited through a separate portal, either proximal or distal to the incision. **Suction drains can also be placed in the more superficial tissue planes in an attempt to prevent seroma formation;** however, seroma formation is much more common in the deeper layers. The drain is sutured in position and maintained postoperatively until drainage is substantially decreased, usually after 3 to 4 days. Transected superficial gluteal tendinous insertions are apposed and sutured. The intermuscular septum between the vastus lateralis muscles and the biceps femoris, the incision in the fascia lata, the subcutaneous tissue (**Fig. S18E**), and the skin are closed in routine fashion. A stent bandage should be sutured over the incision to prevent postoperative contamination.

A suction drain is usually placed, since seroma formation is common.

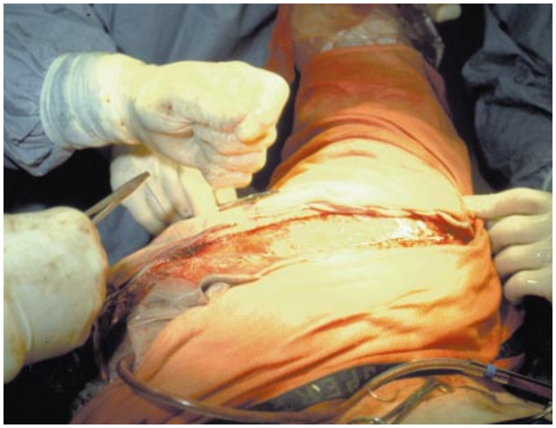

Fig. S18E: The deeper layers of the incision are closed individually after installation of a suction drain, concluding with the closure of the fascia lata.

Fig. S18F: Despite postoperative suction drainage and good soft tissue healing, a seroma may form in the early convalescent period. It should be evacuated by sterile aspiration. Left: cranial view. Right: caudal view.

Heavy soft tissue cover provides protection, and a good parosteal blood supply.

18.2.4 Postoperative treatment

Patients should receive perioperative broad spectrum antibiotics and tetanus prophylaxis. If surgery time exceeds 2 hours, it may be necessary to administer additional systemic antibiotics during surgery. As a rule, antibiotics are continued in the postoperative period for at least 24 hours after the removal of the suction drain. All foals are given a non-steroidal anti-inflammatory drug for control of pain and inflammation at the fracture site.

18.2.5 Complications

The most frequently encountered complication with surgical repair of femoral fractures is the development of a seroma (**Fig. S18F**). Seroma formation frequently adds to the difficulty of maintaining the intact skin and deep incisions. If the closure is compromised, this directly adds to the likelihood of infection. Infection is the most common complication related to failure. Implant loosening can also be observed, especially with distal physeal fractures.

Although anatomic reconstruction is necessary to facilitate the bone's ability to support the weight of the horse without pain, minor instability can be overcome in femoral diaphyseal fractures in foals due to their capacity to form callus readily. The large muscle cover and callus formation can aid in stabilizing the fracture repair. **The soft tissue provides both protection and a superior blood flow to the healing fracture.** However, infection or major instability will often prevent healing, despite these advantages. The traumatized tissues are quite prone to colonization by micro-organisms, and due to the nature of the bone and the animals, the implants may be exposed to forces close to the limits of their tolerance.

18.2.6 Results

Conservative management of diaphyseal fractures by stall confinement can result in fracture healing [7]; however, **the affected limb is usually shorter, rotationally deformed, and nearly useless.** It is also important to realize that most of these foals will develop varus angular limb deformities in the opposite limb because of the prolonged non-weight lameness in the fractured limb. Conservative management of minimal displacement and stable distal physeal fractures, however, can result in a satisfactory outcome. These foals should receive stall rest for 3 months, followed by restricted exercise in a confined area. The use of non-steroidal anti-inflammatory drugs to control inflammation and pain should be included.

Approximately 50% of the foals with diaphyseal fractures repaired by internal fixation (Fig. X18B) with double plating will enjoy satisfactory healing (Fig. S18G). Radiographically, there is usually extensive periosteal and endosteal callus present in all cases at approximately 5 weeks after surgery. This callus formation is most prominent on the caudal cortex at the site of the muscle insertions on the femur (Fig. X18C). Three months after surgery, the fracture line is typically no longer discernible radiographically. With adequate fracture healing, 80% of the animals will have no long-term infirmity and will be fit for their intended use. **Surgical removal of the implants is rarely required, and as the horse matures the implants will become engulfed by the bone.** If the implants become infected or if the implant crosses the physis,

Conservative management leads to shortening and rotational deformity.

Removal of implants is rarely necessary.

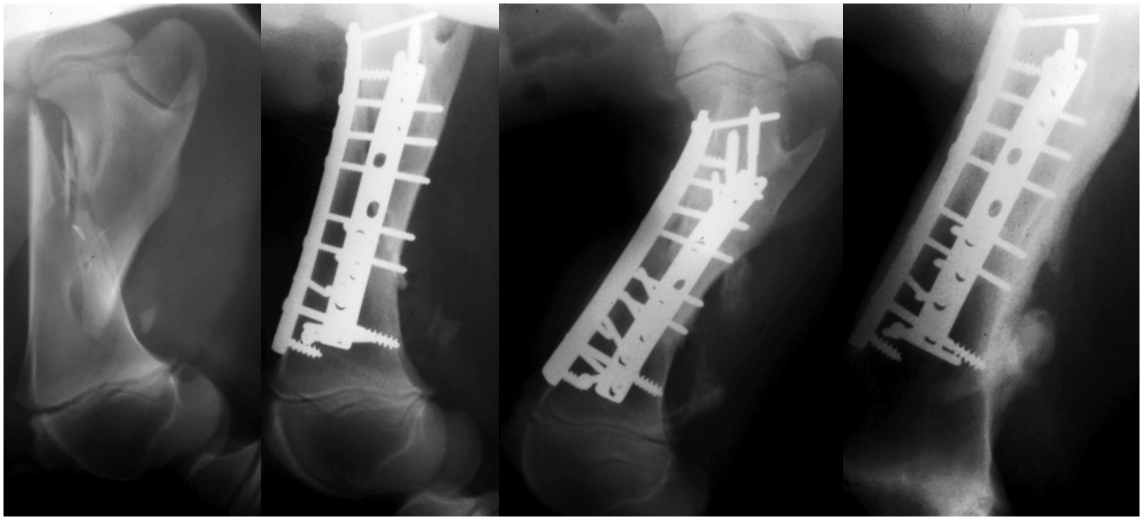

Fig. X18B: The healing of a long oblique fracture of the femoral shaft is seen following repair with two broad DCPs. Whenever the fracture plane was crossed, screws were inserted in lag fashion.

Fig. S18G:
The case in **Fig. X18B** in the perioperative period is seen later at maturity with no ill effects from the original injury.

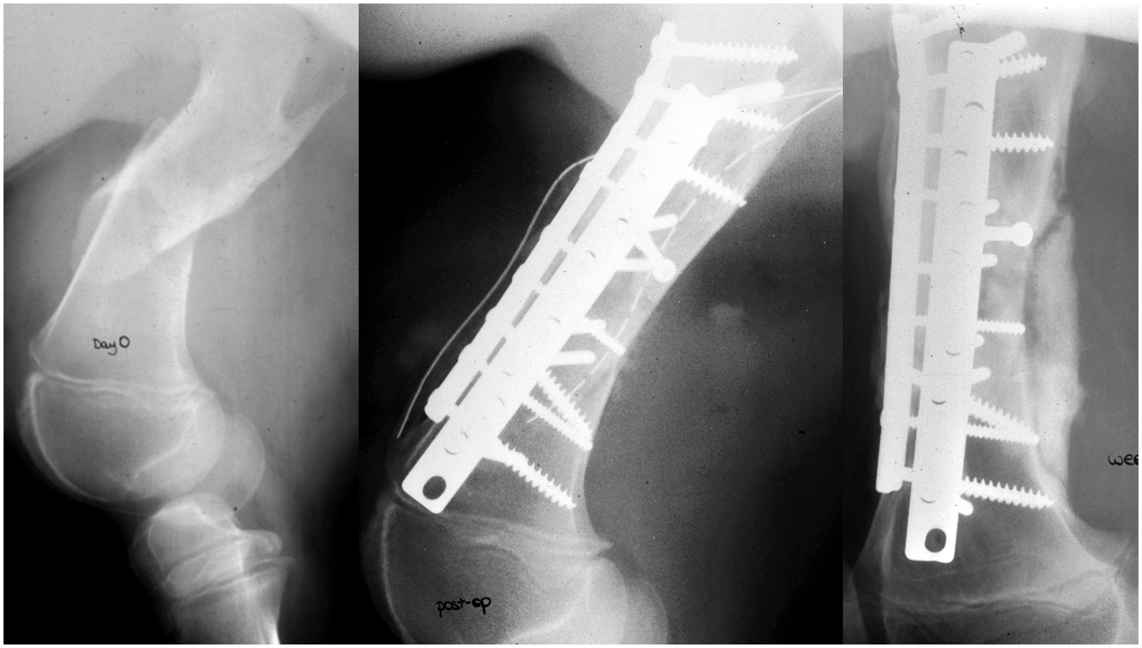

Fig. X18C:
The development of exuberant callus on the posterior aspect of the femur is common despite rigid internal fixation.

removal of the implant may be necessary to resolve the infection or preserve any residual longitudinal growth.

Successful treatment of diaphyseal fractures is related to age and size. The majority of foals with successful outcomes are less than 3 months of age. In foals over 3 months of age, use of a DCS or cobra plates, more rigid forms of fixation, should be considered. Success also depends on the integrity of the caudal cortex, a bone deficit of any size resulting in a loss of the buttress effect and predisposing to implant failure.

The prognosis for distal physeal fractures is not as good as those in foals with diaphyseal fractures because of the limited bone available on the distal fragment for implant purchase. Implant failure and loss of fracture reduction is not an uncommon sequel; however, with **the more recently available implants such as the condylar buttress plate, the cobra head plate, and the DCS plate, which all allow for increased holding power in the distal fragment**, the problem of limited stability can be overcome. The advantages of using the condylar buttress plate or the cobra head plate is that neither require the use of instrumentation other than the standard AO bone plating equipment; however, because of their rather large distal flaring, they limit the flexibility of positioning and screw placement. The DCS system, on the other hand, requires the use of specific instrumentation but affords increased flexibility for positioning. The DCS plate is also 5.8 mm thick compared with 5.0 mm of the condylar buttress plate and, therefore, is a more rigid implant. The cobra head plate has a thickness of 6.0 mm so that its preset contours are difficult to alter. It must be applied to the lateral cortex, whose contours it more closely approximates.

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19 Tibia

Larry R. Bramlage & Gustave E. Fackelman

Excluding distal fragmentation [1], stress type failure managed conservatively [2, 3], and the tibial crest fractures usually treated by tension band plating [4], the common types of fractures of the tibia in the horse are localized in the proximal physeal and diaphyseal region.

19.1 Proximal physeal fracture

The most common fracture in the foal is the Salter–Harris type II proximal tibial physeal fracture, with the metaphyseal piece left attached at the lateral aspect. The fracture occurs when the foal is kicked from that side of the limb while bearing full weight. The soft tissue of the medial proximal tibial physis ruptures in tension due to the bending moment applied laterally. The fracture propagates across the tibial growth plate from medial to lateral approximately two thirds the width of the bone. Then the medial bending force on the distal limb supervenes to distract the physis. Tensile forces are created across a vertical plane within the metaphysis and the fracture orientation shifts abruptly to proximodistal. This splits the lateral metaphysis, leaving part of it attached to the true epiphysis. In contradistinction to the damage seen medially, the soft tissue on the lateral aspect remains unscathed. Occasionally, complete disruption of the soft tissue surrounding the physeal plate will occur, in which case the fracture becomes grossly unstable.

19.1.1 Preoperative considerations

The biomechanical force that created the fracture was a tension force across the medial aspect of the growth plate. Therefore, the **fracture instability is most easily neutralized by re-establishing the tension support on the medial aspect of the limb**. Any technique which will hold the proximal tibial physis in position atop the metaphysis without disruption of the surrounding soft tissue has the potential to stabilize this fracture well enough to allow healing [5]. (These fractures heal very rapidly.) Bridging of the fracture is normally accomplished in 3–4 weeks since normal bone formation, as part of bone growth, is already well underway at the time of injury. Development of a support system for fracture healing is unnecessary. The most stable fixation involves creation of a medial tension band, replacing the function served by the soft tissue of the physis prior to the fracture. If the lateral soft tissue is intact, stability is relatively easy to obtain. If the epiphysis is completely disrupted from the metaphysis, a more extensive form of fixation is required.

Achieve stability by neutralizing distractive forces medially.

Approach the medial aspect of the proximal tibia along the caudal edge of the bone.

19.1.2 Surgical anatomy

The approach to the proximal aspect of the tibia from the medial side is along the caudal edge of the bone. This allows the soft tissue to be elevated cranially and the plate to be placed, without the incision being directly over it. The proximity of the tibia to the skin surface in this area can present a difficult situation for wound healing, especially if the metal plate lies immediately beneath the skin.

Damage to the growth plate is directly proportional to the time elapsed since injury.

19.1.3 Surgical procedure

Surgical positioning can be either in dorsal or lateral recumbency. It is the authors' preference to place the horse in lateral recumbency with the injured limb "down". This facilitates putting pressure on the proximal tibial physis while elevating the distal limb to obtain reduction. The opposite hind limb is flexed, abducted, and tied back to prevent its interfering with surgery.

The incision is started caudomedially and extended somewhat obliquely across the proximal medial aspect of the tibia, anticipating the position of the implant and creating the distal portion of the incision caudal to the future implant site. The thin proximal tibial physis presents the most difficult skeletal anatomy. The screws must be inserted within the proximal tibial physis sufficiently proximal to the growth plate to allow purchase within the bone but not so proximal as to endanger the stifle joint. **Placement of long needles along the plane of the proximal tibial physis to provide orientation helps with accurate placement of the screws.**

Maintain reduction by the placement of a screw and wire tension band medially.

Long needles placed along the proximal tibial growth plate aid in orientation.

19.1.4 Reduction

Reduction is accomplished by gentle traction of the physis to separate the fracture plane and to allow debridement of any interposed blood clots. Removal of debris allows the physis to be brought into close apposition to the proximal tibial metaphysis. Any damage done to the growth cartilage of the physis is usually at the point at which the fracture changes from transverse to vertical. The metaphysis seems to abrade in particular the center of the physis. Evaluation of the amount of damage provides a prognosis for survival of a functional proximal tibial growth plate. **The degree of damage depends mainly upon the delay between injury and surgery, and on the adequacy of preoperative immobilization.**

Following debridement and accurate reduction, the surrounding soft tissue is reflected along the medial aspect. If this soft tissue is not elevated, it tends to become entrapped between the metaphysis and the physis preventing complete reduction. The reduction is accomplished by exerting pressure on the medial aspect of the metaphysis, while simultaneously elevating the distal limb, and keeping the soft tissue on the medial side out of the fracture plane.

When achieved, reduction can be maintained by the placement of a screw and wire tension band similar to that used in growth plate retardation (**chapter 26**, Metacarpal [-tarsal] deviations) on the somewhat more cranial aspect of the limb. The wire is tightened and secures the bone allowing subsequent placement of the definitive implants. The soft tissue dissection should be carried to the bone surface on the metaphyseal side of the fracture, but the paraphyseal tissue on the epiphyseal side should not be disturbed. A 4-hole T-plate is used with the two transverse holes positioned in the epiphysis nearer to the posterior aspect of the proximal tibia and halfway between the stifle joint surface and the growth plate. The two proximal screws are inserted using needles within the physeal plane to direct their orientation. The proximal screws can be inserted across the entire width of the epiphysis improving their holding power. **Use of 5.5 mm cortex screws is ideal because they represent the smallest diameter implant with the greatest holding power.** After placement of the two proximal screws, the implant is depressed to the bone surface and the four distal holes within the T-plate are inserted into the metaphysis using the tension device or offset placement of the screws in order to produce the desired amount of compression. Once the implant is positioned, it is possible to put a second screw and wire cranial or caudal to the T-plate in large foals. **Any screw crossing the vertical fracture plane is placed in lag fashion**. When the fixation is complete, the soft tissues are apposed in an attempt to accurately close the subcutaneous tissue and then the skin. Suction drainage can be applied if soft tissue damage or dead space warrants it. A stent bandage may be sutured over the incision as a means of reducing the tension on the incision line and protecting it postoperatively. The area is difficult to bandage, but some compression of the soft tissue to reduce hematoma can be obtained if elastic tape is used in combination with ether to increase the holding power of the tape to the skin.

19.1.5 Postoperative treatment

Postoperatively, no external fixation is applied. The foal is helped to its feet during recovery from anesthesia, and appropriate broad spectrum antibiotic therapy along with anti-inflammatory treatment is continued until all swelling has subsided (± 1 week). The health and condition of the soft tissue postoperatively will determine the exact duration of antibiotic treatment. Typically, foals are confined to a stall for a period of 4 weeks, at which time postoperative radiographs are taken. Radiographs are taken earlier if any indication of postoperative complication should appear. The foal should be bearing weight within 1–2 days and should begin walking soundly within the first 7–10 days. Unsoundness indicates some type of complication.

> Screws 5.5 mm in diameter have better holding power in the soft epiphyseal bone.

19.1.6 Complications

Three major complications may be encountered in the repair of this fracture.

- Postoperative sepsis.
- Failure of the fixation in the form of loss of holding power within the epiphysis.
- Seldom, implant failure in the metaphysis.

  The weakest link remains the attachment of the implants to the epiphysis of the proximal tibia.

> Any screw crossing the fracture plane is placed in lag fashion.

> The weakest portion of the fixation remains the attachment to the epiphysis.

To minimize growth disturbance, remove the epiphyseal screws after 3–4 weeks.

A complication which is related indirectly to sepsis is the dehiscence of the wound, as the skin and subcutaneous tissue on the medial aspect of the limb are frequently traumatized from within by the initial injury. If the delay between fracture and definitive treatment is prolonged or if first aid is less than ideal, disruption of the skin on the medial aspect of the limb is a common sequel. Sepsis is a serious complication but does not necessarily mean failure if the case is appropriately managed. Drainage, antibiotic medications, and the maintenance of cleanliness facilitate healing. Closure of the proximal tibial physis is a potential complication, but seems to be of no significance. **If stability is sufficient, remove the epiphyseal screws at 3–4 weeks postoperatively** to prevent this (**Video X19A**).

19.1.7 Results

Considering local anatomy, and ease of reduction, the lateral approach is preferred.

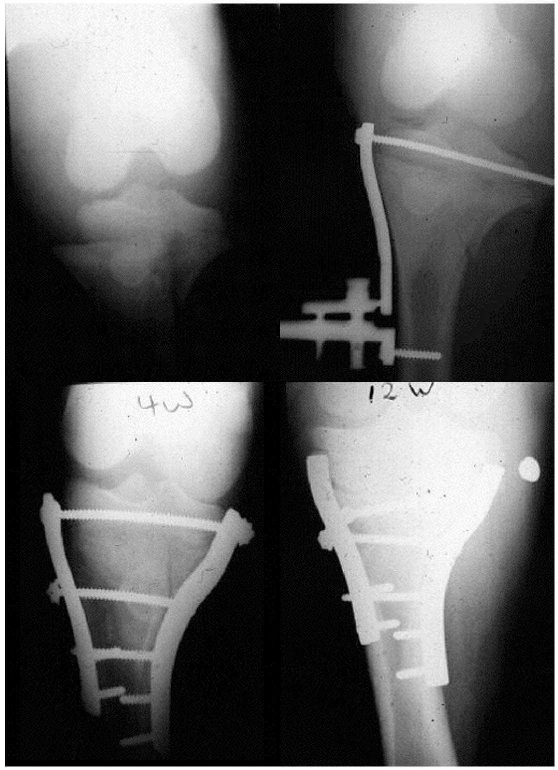
The results of surgical fixation are good, especially in smaller foals. The preoperative condition of the soft tissue [6], the amount of instability at the lateral aspect of the limb, the adequacy of reduction implants, and the holding power of the proximal epiphyseal implants are components of the equation that governs the results (**Fig. X19B**). A favorable response permitting athletic activity in approximately 50% of cases can be expected. Closure of the proximal tibial physis will occasionally occur. Contrary to the situation in humans [7], this does not seem to be a major complication. In spite of considerable damage, the equine proximal tibial physis does not seem as prone to premature closure as the physis of other animals or humans (**Fig. X19C**).

19.2 Diaphyseal fractures

Diaphyseal fractures of the tibia are almost always spiral in nature, and are usually comminuted. Loading of the tibia results in torque, presumably due to the angulation of both the stifle and tarsocrural joints. This angulation allows some abduction of the stifle upon flexion, preventing the limb from impacting upon the ventral abdomen during exercise. Since the fractures are quite unstable, appropriate first aid therapy is essential to minimizing soft tissue damage. Although other techniques have been described, especially for more distal fractures [8, 9, 10], the authors prefer double plating for the fracture types under consideration here.

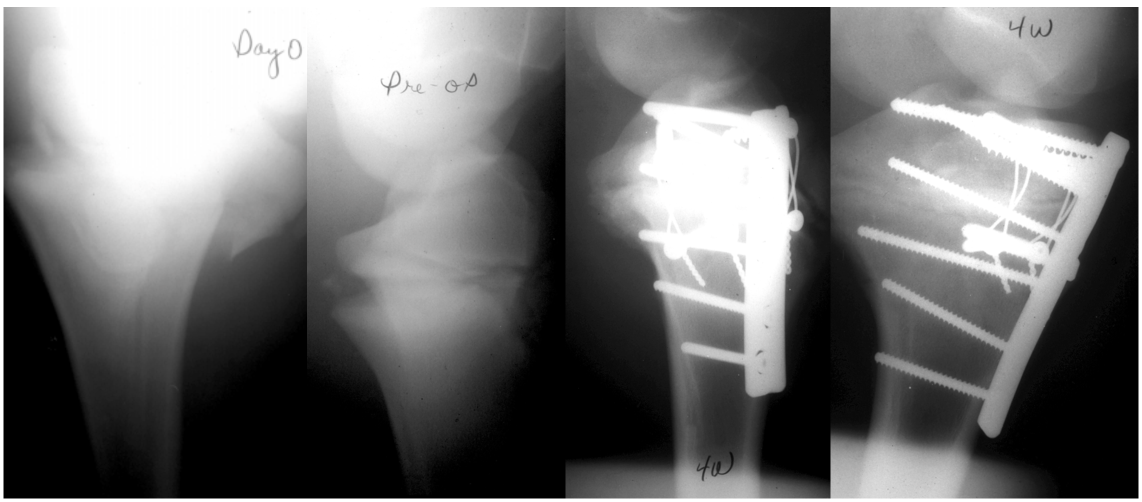
19.2.1 Preoperative considerations

Preoperative considerations include positioning of the horse on the table for surgical intervention. Traction on the distal limb does not help in reducing a tibial fracture. In fact, such efforts may actually cause overriding due to tension built up in the reciprocal apparatus. Placing the injured tibia “down” impedes surgical manipulation and requires that the approach be made from the medial aspect of the limb where little soft tissue cover is available. Therefore, **in most instances, the horse is positioned in lateral recumbency with the injured tibia uppermost.** The surgical approach must take into consideration the cranial tibial artery on the cranial lateral aspect of the tibia. The lateral outpouching of the stifle joint, which extends distally from the stifle surrounding the long digital extensor tendon, is present on the proximal lateral aspect of the tibia. The tenuous soft tissue on the medial aspect of the tibia and the closely apposed extensor tendons distally must be circumvented as the incision nears the tarsocrural joint.



Video X19A: Tibia fracture prog ressives.

Fig. X19B: Salter—Harris type I I fractures of the proximal tibia require lag screw and plate fixation to maintain their position. T he goal is to create a usable weight bearing axis as soon as possible.



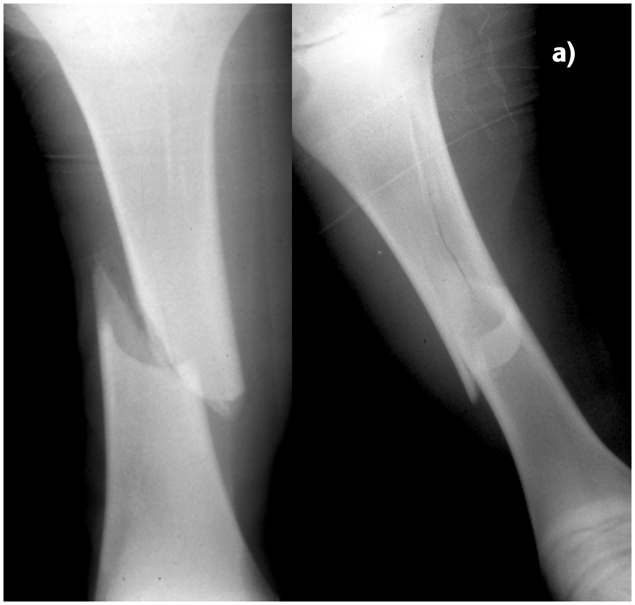
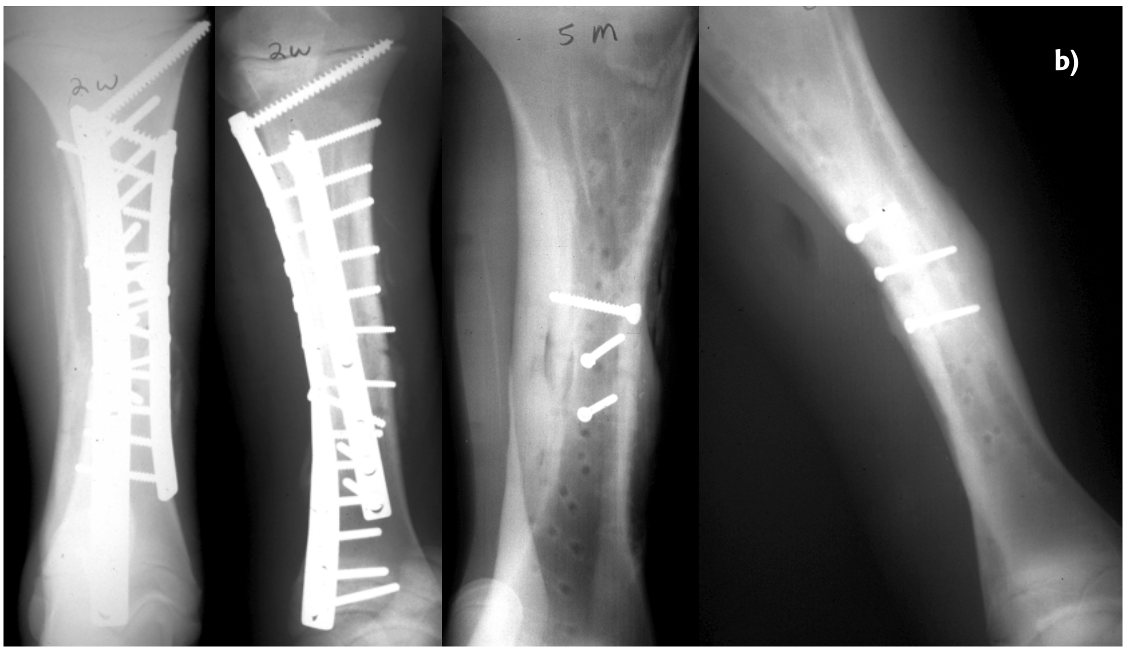


Fig. X19C: a) Oblique shaft fractures in the young heal well when plated according to the principles presented in this chapter . b) If the animal is destined to be an athlete, these implants are usually removed.



Three main surgical approaches are available:

- the medial approach directly over the tibia where no muscle cover intervenes;
- the lateral approach between the long digital extensor and the cranial tibial muscle;
- the cranial approach where the incision is made over the cranial tibial muscle.

The cranial approach over the muscle is most useful. The deep dissection is extended slightly medially, and the periosteum is incised allowing the muscle and the periosteum to be retracted as one unit laterally. **This provides a cranial approach to the proximal tibial shaft. The biomechanics of weight bearing of the tibia dictate that one plate be placed craniolaterally, spiraling around to cranial as it passes distally.** This serves to neutralize torque during loading as well as to place the major implant on the tension surface of the bone. Normally this implant is placed first. The cranial approach eliminates the necessity of dealing with any vasculature as the latter is moved out of the surgical field by elevating the periosteum with the cranial tibial muscle. Implants on the medial and lateral aspect of the bone can be placed through one incision eliminating the need for an additional incision. Such additional trauma is unavoidable when placing two implants by the medial or the lateral approach.

19.2.2 Surgical procedure

The incision is initiated craniolaterally along the lateral patellar ligament, extending to the tibial crest, and then passed directly cranial over the muscle belly of the cranial tibial muscle to the distal aspect of the limb. It then curves slightly to the medial aspect of the limb as the tarsocrural joint is approached. The incision is carried through the skin and subcutaneous fascia until the cranial tibial muscle is encountered. The cranial tibial muscle is elevated laterally, the periosteum is incised, and a subperiosteal dissection plane is established from cranial to lateral exposing the lateral surface of the bone. If the fracture involves the mid to proximal portion of the bone, the implant will have to be placed as proximal as possible. It will be necessary to enter the stifle joint at its distal out-pouching which surrounds the origin of the long digital extensor muscle. Normally one can avoid the long digital extensor and cranial tibial attachments by separating them through the proximal incision so that the implant can be placed near the most proximal aspect of the bone in the area of the physis or physeal scar. Working on both sides of the cranial tibial muscle allows placement of the plate without unduly damaging the muscle.

Fracture reduction is accomplished by traction on the distal aspect of the tibia and appropriate reconstruction of the tibia. The repair begins by reattaching any comminution to the parent bone with lag screws to create a two part fracture. When this has been achieved, the plate is bent and twisted to reflect the curve of the bone from craniolateral to cranial. **The screws are inserted in the order dictated by the prevailing fracture configuration**. Any screw

> From proximal to distal, the plate is contoured to spiral from craniolateral to cranial.

> The sequence in which screws are inserted is determined by the form of the fracture, which varies from case to case.

Plate luting is more useful in simpler fractures.

The craniomedial plate is placed in a soft tissue envelope created by subperiosteal dissection.

Postoperatively, casts do more harm than good.

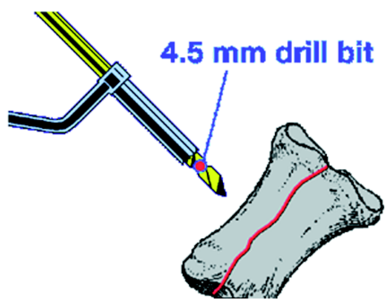
crossing the fracture plane is applied in lag fashion (Video DBASICS). The lag screws, in combination with the plate, create interfragmentary as well as axial compression for the most stable fixation.

Once the craniolateral plate has been applied and screws have been inserted in all of its holes, the craniomedial plate is positioned. Normally it must be twisted from craniomedial to medial as it is placed in a pocket of skin and subcutaneous tissue. **This "soft tissue envelope" was created by elevation of the periosteum from the craniomedial aspect of the tibia analogous to the approach employed earlier for the lateral plate**. It is occasionally necessary to flex and abduct the limb to permit access to the medial aspect of the tibia for drilling. The stability conferred by the lateral plate already in place facilitates this manipulation. The medial plate is placed avoiding the screws from the lateral plate, again utilizing lag screw fixation whenever a fracture plane is crossed. Interfragmentary and axial compression are then created as needed. Both plates are loaded in tension, distributing axial compression over the entire fracture plane. Luting the plates has been described and found to strengthen the overall fixation [11]. **It is probably more useful in simpler fractures, where the potential for intrusion of methylmethacrylate into multiple fracture planes is less likely.**

After placement of the plates, a suction drain is inserted exiting proximolaterally, to be attached to a reservoir at some position on the horse's back. Closure includes the layers of the fascia of the cranial tibial muscle, subcutaneous tissue, and the skin. Release incisions can be made in the skin over the cranial tibial muscle belly to relieve tension on the closure if preoperative swelling and operative manipulation has increased the diameter of the limb. Leaving the stab incisions over the muscle minimizes the possibility of contamination of the implants. Reduced tension on the primary incision enhances the healing of the skin margins.

Postoperatively, no cast is used as this only serves to increase the load upon the implants. Equine anatomy dictates that the cast cannot extend above the stifle, which effectively defeats its purpose and may even be dangerous [12].

Stent bandages are sewn over the incisions and additional bandaging is used for protection during the postoperative period. Often the horse is allowed to recover from anesthesia unimpeded, further wound dressings being placed after the animal regains its feet. The horse is always assisted in recovery in an attempt to help it to smoothly regain a standing position. Struggling greatly increases the likelihood of postoperative failure of implants and/or bone.



Video DBASICS: Animation of drill basics.

19.2.3 Postoperative treatment

Antibiotics and nonsteroidal anti-inflammatory drugs (NSAIDs) are normally continued for a prolonged period of time (10–19 days), as tibia fractures are generally accompanied by considerable soft tissue damage. The health of the soft tissues and the postoperative use of the limb by the patient will dictate the exact required duration of antibiotic and NSAID therapy. Stall rest is maintained with no exercise allowed for 6–8 weeks depending on the age of the horse. Foals are often radiographed at 6 weeks; adults at 8 weeks, to ascertain whether bridging of the fracture has occurred. Postoperative use of the limb is the most accurate criterion used to adjudge the degree of stability. If willingness to use the limb is never really attained or steadily diminishes, radiographs are taken sooner. The most common complication associated with the repair of tibial fractures is breakdown of the reduction and fixation. Usually it is the bone that fails. Failure may follow areas of comminution or extend along the multiple drill holes. If recovery from anesthesia is uneventful, and the use of the limb is good, then complications would also include postoperative sepsis due to primary infection or breakdown of the incision. With

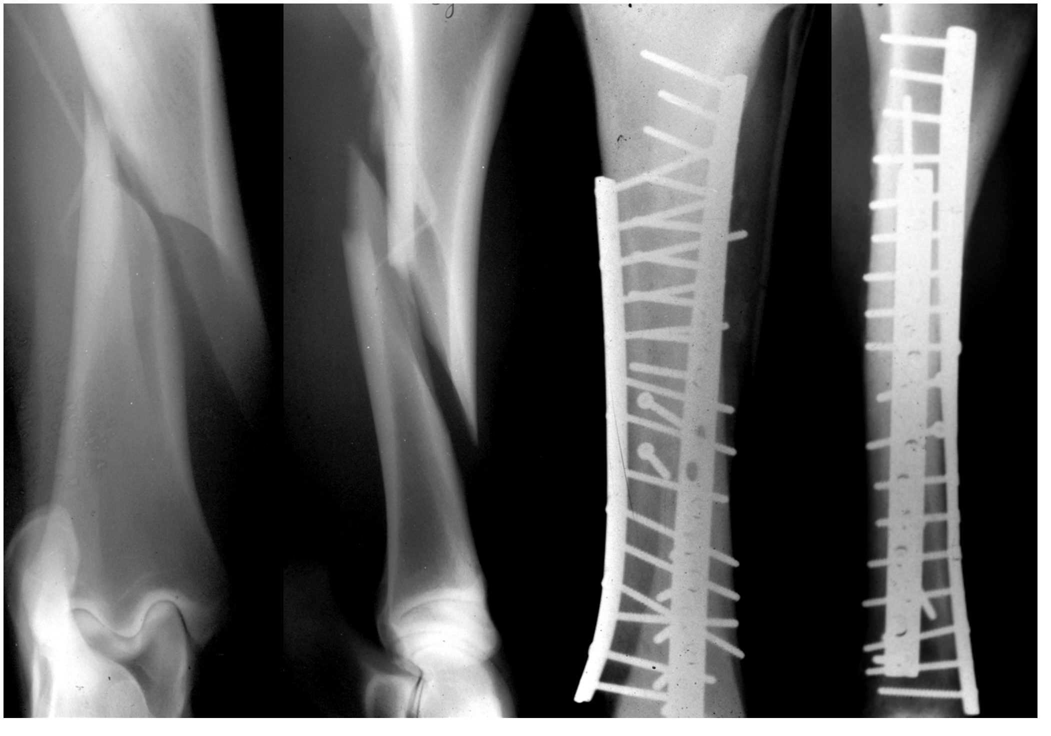


Fig. X19D: Tibial fractures in adults are more difficult, and often complicated by the presence of additional fissures. W hen straightforward, they may be successfully repaired using the principles described.

Fig. S19A:
The patient in **Fig. X19D** showed good weight bearing shor tly after surgery, and went on to an uncomplicated

any major long bone fracture, failure of the implants may occur with repeated cyclic loading. A single acute overload early in the postoperative period, generally causes the bone to fail.

19.2.4 Results

Fixation of tibial fractures in the adult (**Fig. X19D**) is difficult because the fracture tends to be comminuted. Simple fractures in adults can be fixed and do heal successfully (**Fig. S19A**) [**13**]. This, however, remains the exception to the rule since comminution and soft tissue damage is typically severe. Therefore, the prognosis for tibial fractures remains unfavorable in the adult. In the foal, the implants usually protect the bone well enough to allow healing. The prognosis is still guarded, but in the authors' experience 60% success in the healing of the fracture and dismissal of the horse postoperatively is attainable. Athletic activity is virtually assured if surgery and stabilization proceed without complications.

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19.3.1 Online references

See online references on the PEOS internet home page for this chapter:
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20 Proximal interphalangeal arthrodesis: screw fixation

Jörg A. Auer

20.1 Description

Indications for arthrodesis of the proximal interphalangeal joint include degenerative joint disease (high ringbone) [1] (Fig. X20A), luxations or subluxations, and selected fractures [2, 3]. In this chapter arthrodesis using lag screws only will be discussed. A study comparing three semi parallel screws across the articular surface with two oblique cross screws showed the three screws' technique to be stronger [4].

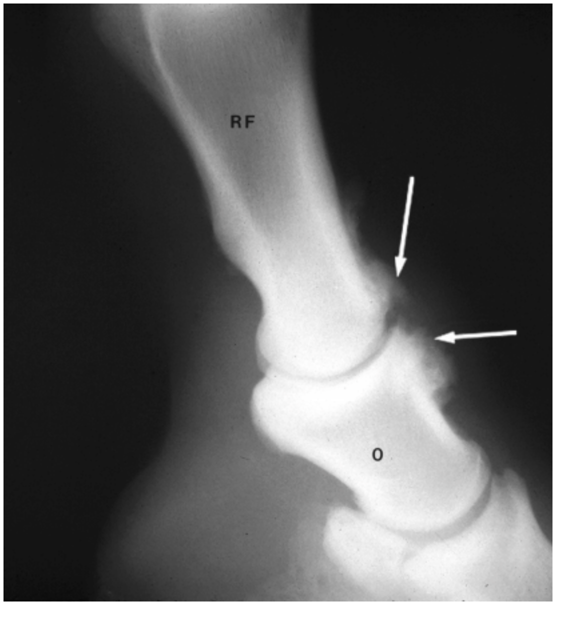


Fig. X20A: Lateromedial radiograph of the phalangeal region of a horse suffering from arthrosis of the proximal interphalangeal joint. The arrows point to the periosteal new bone formation surrounding the joint.

20.2 Surgical anatomy

Application of a tourniquet in the midmetacarpal/-metatarsal region during the surgery to facilitate visibility is optional. Drape the foot circumferentially from the coronary band distally, using impervious, disposable materials. Proximal to the metacarpophalangeal joint the drapes are also applied circumferentially, allowing access to the entire phalangeal region (Fig. S20A).

Fig. S20A: The phalangeal region is draped for aseptic surgery after previous preparation of the skin.

Fig. S20B: Perform an inverted "T" incision through the skin with the horizontal incision placed 1.5 mm proximal and parallel to the coronary band. The vertical incision is centered axially on the horizontal incision and extends to the proximal third of the proximal phalanx.

20.3 Surgical procedure

(**Video P1_P2ART**, **Video 31021**)

Approach the joint through an inverted "T" skin incision. The horizontal incision is parallel to the coronary band at a distance of 1.5 cm and extends 5 cm on either side of the midline. The vertical incision is centered on the horizontal incision, and carried proximally to the proximal third of the proximal phalanx (**Fig. S20B**) [**3**]. The common digital extensor tendon is transected in an inverted "V" incision distal to the insertion of the extensor branches of the suspensory ligament. Dissect the two parts of the common digital extensor tendon from the underlying tissues and reflect them distally and proximally, respectively.

Do not use a drill bit to remove articular cartilage.

This will transect the joint capsule horizontally and open the joint. Isolate and transect the collateral ligaments and the suspensory ligaments of the distal sesamoid (navicular) bone to allow more complete exposure of the joint surface [**5**] (**Fig. S20C**).

Remove all articular cartilage with a curette to allow solid bone-on-bone contact (**Fig. S20D**). **The use of a drill bit to remove articular cartilage through drilling-type motions is discouraged.** This can result in an uneven

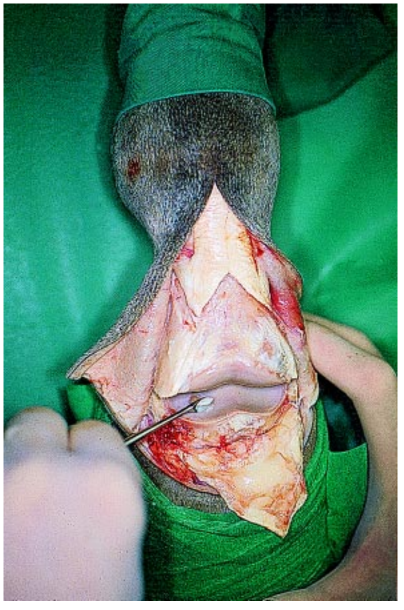


Fig. S20C: After you transect the common digital extensor tendon in an inverted "T," dissect the stumps and transect the suspensory ligament of the navicular bone along with the collateral ligaments, allowing complete opening of the joint.

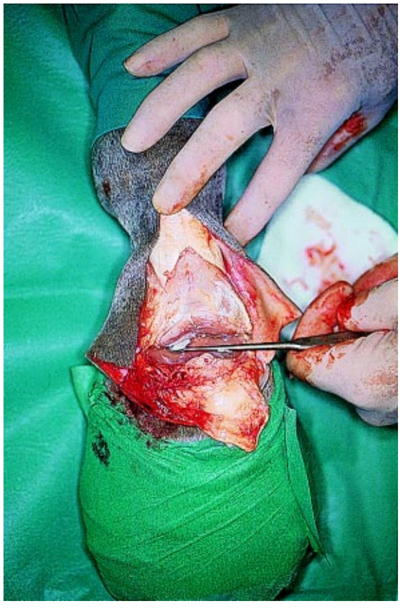
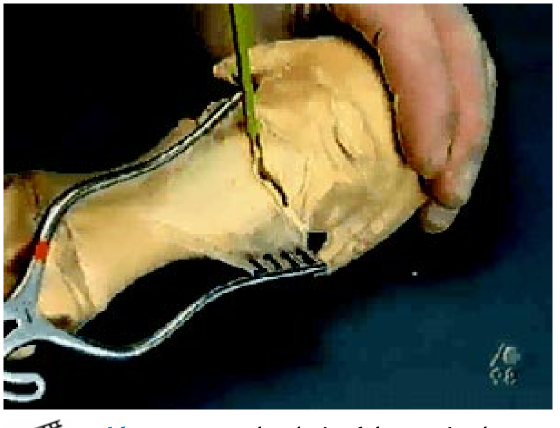
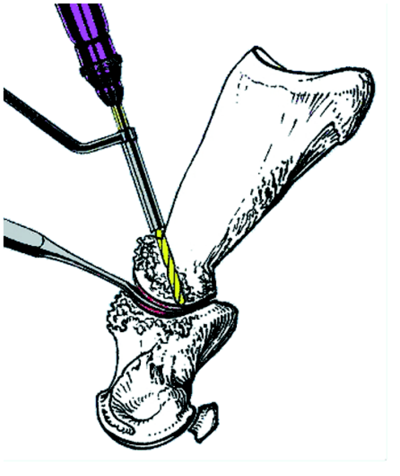


Fig. S20D: Remove all the articular cartilage with the help of a curette. This facilitates bone-to-bone contact.



Video 31021: Arthrodesis of the proximal interphalangeal joint.



Video P1_P2ART: Animation P1/P2 arthrodesis.

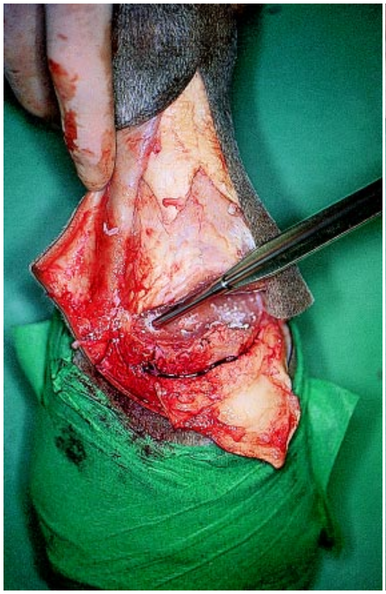


Fig. S20E: Perform osteostixis across the subchondral bone plates of the two opposing bones to facilitate ingrowth of vessels into the previous joint space.

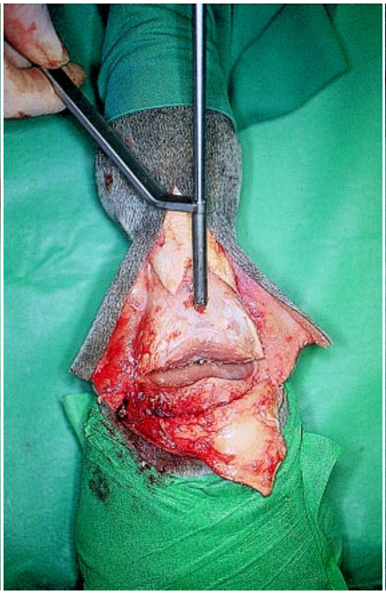


Fig. S20F: Prepare the central glide hole with a 5.5 mm drill bit . Open the joint to recognize when the drill penetrates the joint.

Fig. S20G: Prepare the adjacent glide hole on either side of the central glide hole.

surface with poor bone-on-bone contact and less stability. Cyclic strain exerted upon the screws is increased, leading to a greater probability of implant failure.

Osteostixis is performed by drilling two to three holes penetrating the subchondral bone plates of the proximal and middle phalanges (**Fig. S20E**). Remove all loose cartilaginous remnants and flush the joint. Remove also any periarticular proliferative bone with an osteotome or a chisel.

Earlier [5], a shelf was cut into the dorsal cortex of the proximal phalanx parallel to the joint to facilitate screw insertion. This is no longer recommended. Using the 5.5 mm drill through the 5.5 mm drill guide, drill the central glide hole in the midsagittal plane across the proximal phalanx (**Fig. S20F**). It is advisable to separate the proximal and the middle phalanx to facilitate the perception of complete penetration of the 4.5 mm drill bit. Alternatively, retrograde drilling of the central hole proximally from the articular surface may be employed [2]. However, a greater amount of soft tissue dissection is necessary. Next, prepare the two adjacent glide holes, diverging slightly in the frontal plane, and in a palmar/plantar direction (**Fig. S20G**). All three glide holes must penetrate the middle phalangeal joint completely to ensure a lag effect.

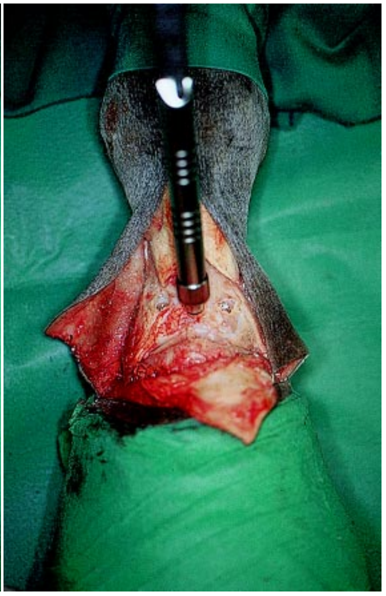


Fig. S20H: The joint is reduced through dorsal pressure at the tip of the hoof, and the thread hole is prepared through the 4.0 mm drill sleeve placed into the central glide hole. Excessive penetration of the palmar cortex is avoided to prevent damage to the navicular bone or neighboring soft tissue structures.

Fig. S20I: With the countersink a depression is created to accommodate the screw head.

Fig. S20J: Screw length is determined with the depth gauge.

Reduce the joint and apply pressure to the tip of the toe in a dorsal direction. This aligns the phalangeal axis. Using the 4.0 mm drill bit through the 4.0 mm end of the double drill sleeve (5.5/4.0 mm), inserted through the central glide hole (Fig. S20H), prepare the thread hole in the palmar/plantar aspect of the middle phalanx. **Take care not to advance the drill too far after penetrating the palmar/plantar cortex.** This prevents inadvertent trauma to the navicular bone and its associated soft tissue structures.

Flush the hole and, turning the countersink in a clockwise direction, create a depression for the screw head in the glide hole (Fig. S20I). This is an extremely important step ensuring even distribution of forces between the screw head and the bone. With the help of the depth gauge, determine the length of the screw to be used (Fig S20J). The hook at the end of the depth gauge should engage the proximal edge of the hole and 2 mm should be added to the reading thus obtained. This assures complete engagement of the distal cortex, improving the holding power of the screw. Cut the threads in the thread hole with the 5.5 mm tap, introduced into the glide hole through the 5.5 mm

Create an adequate countersink depression for the screw head.

Advance the drill bit carefully when penetrating the palmar cortex. This prevents damage to the navicular bone and associated soft tissue structures.

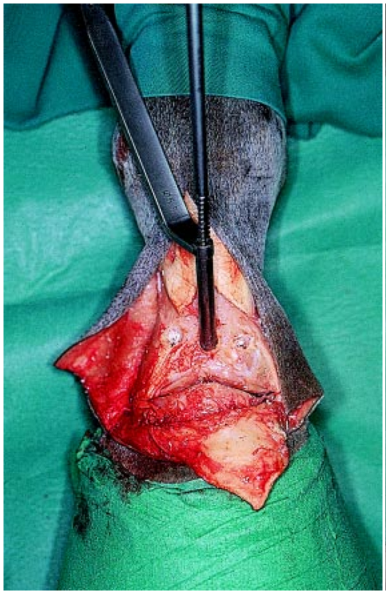


Fig. S20K: With the 5.5 mm tap placed through the 5.5 mm tap sleeve the threads are prepared in the thread hole.

Fig. S20L: The central 5.5 mm cortex or shaft screw of predetermined length is inserted and securely tightened.

Fig. S20M: The remaining two screw holes are prepared; the screws are inserted and tightened.

Shaft screws increase the stability of the fixation.

tap sleeve (**Fig. S20K**). After additional flushing, insert the 5.5 mm screw of predetermined length into the hole and tighten it securely (**Fig. S20L**). The dorsal pressure on the distal phalanx can now be relaxed. Insert the other two screws using an identical technique (**Fig. S20M**). Recently [**6**], **the use of shaft screws has been advocated to increase stability of the transarticular fixation**. When all three screws are in place and solidly tightened, flush the surgical site once more and close the soft tissues. It is advisable to add a cancellous bone graft to the dorsal aspect of the former joint surface to facilitate bony union. Take intraoperative radiographs to assure correct placement and correct length of the screws, and make any necessary replacement(s) (**Fig. X20B**). Repair the common digital extensor tendon using 2/0 or 3/0 monofilament resorbable suture material in a simple continuous pattern (**Fig. S20N**). If a tourniquet was used, release it at this point, and ligate or cauterize any bleeding vessels. Close the subcutaneous tissues with a simple continuous pattern of 2/0 monofilament resorbable suture material, and the skin with simple interrupted or vertical mattress sutures of 0 monofilament non-resorbable suture material (**Fig. S20O**). Skin staples are not recommended because they open slightly as a result of the tension, and therefore do not ensure tight closure.

Fig. S20N: The two stumps of the common digital extensor tendon are united with simple continuous suture of 2/0 monofilament resorbable suture material (Maxon).

Fig. S20O: The skin edges are apposed with simple interrupted sutures.

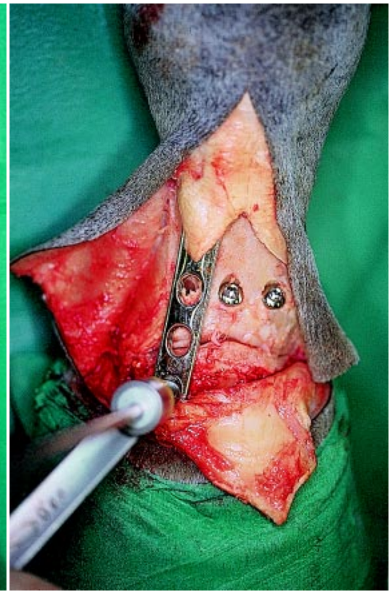


Fig. S20P: The narrow 5-hole DCP is contoured to the dorsolateral aspect of the proximal and middle phalanx and the most distal screw implanted using plate screw technique.

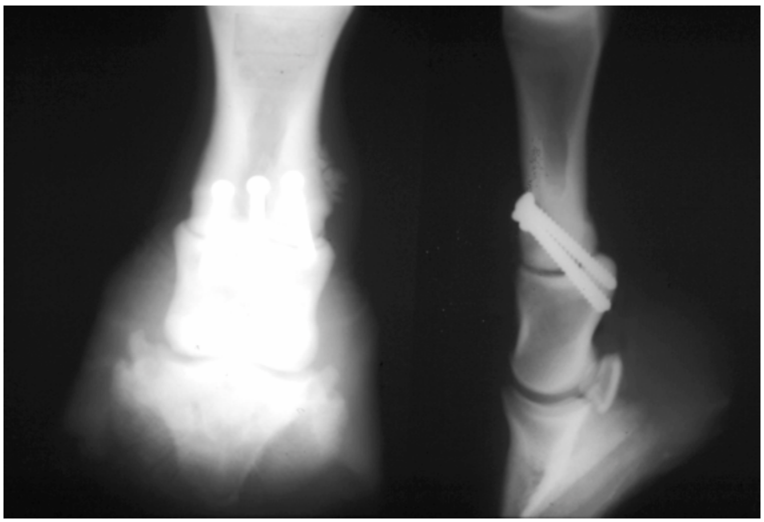


Fig. X20B: Dorsopalmar (left) and lateromedial (right) radiographs show the completed surgery. The screws diverge slightly, lending greater stability to the fixation.

Fig. S20Q: The plate is displaced proximally placing the screw into "load" position, and the second most proximal screw hole is prepared in the proximal phalanx and the screw inserted.

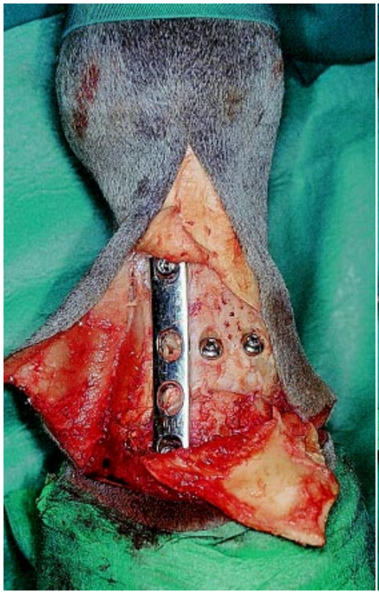


Fig. S20R: The two screws are tightened securely.

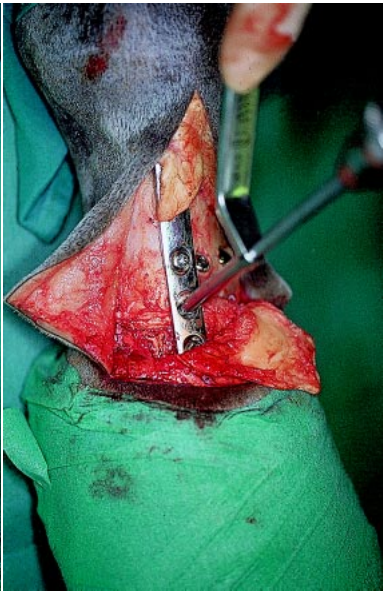


Fig. S20S: After implantation of the two additional screws into the proximal phalanx, the last screw hole across the joint is prepared using lag technique.

An alternative, stonger fixation involves the placement of a DCP anterolaterally.

Place a non-adhering dressing over the skin incision and apply a cast.

An **alternative, more stable technique** [7] **involves application of a 5-hole narrow DCP on the dorsolateral aspect of the phalanges.** A screw is fully inserted into the middle phalanx through the most distal hole in the plate (**Fig. S20P**). The second most proximal plate hole is prepared in "load" configuration and the screw inserted (**Fig. S20Q**). Tightening the screws places the joint under considerable compression (**Fig. S20R**). Insert the remaining two screws into the proximal phalanx. Finally, through the plate hole centered over the joint prepare a hole for application of lag technique across the joint using a shaft or cortex screw (**Fig. S20S**, **Fig. S20T**). Place two more screws (5.5 mm cortex, or shaft screws) transarticularly as with the three-screw technique. By placing the plate abaxially, avoids the extensor process is avoided during maximal movement of the distal interphalangeal joint (**Fig. X20C**).

Fig. S20T: The cortex or shaft screw is inserted and securely tightened.

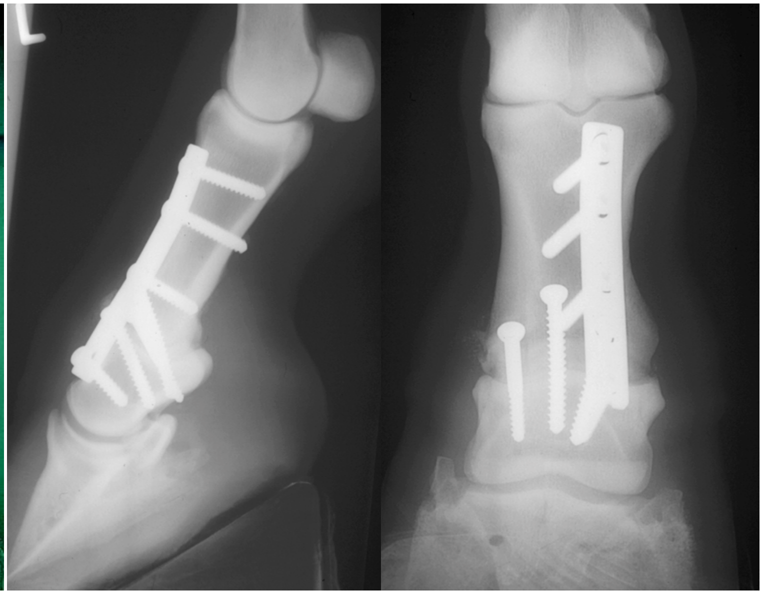


Fig. X20C: Dorsopalmar and lateromedial radiographs of an arthrodesis of the proximal interphalangeal joint using an abaxial 5-hole plate and two transarticular screws (one cortex [middle] and one shaft [lateral] screw).

20.4 Postoperative treatment

Continue perioperative broad-spectrum antibiotics for 5 days. The cast should stay in place for 10 days, after which period it is changed and the skin sutures removed. The new cast should stay in place for an additional 3–4 weeks. Six weeks postoperatively, hand-walking exercise may commence. Take radiographs at 2 months postoperatively to evaluate progress. Union of the two articular surfaces occurs within 3–5 months, by which time lameness should have disappeared.

20.5 Complications

Complications leading to failure of the arthrodesis [2] include infection, cast ulcer, bone or implant failure, implant loosening, and laminitis. An instable fixation may result in a prolonged lameness and lead to excessive new bone formation at the surgery site (**Fig. X20D**).

Fig. X20D: Lateromedial radiograph of a joint fused with three cortex screws. There is marked bony proliferation at the former joint level, possibly caused by initial instability of the fixation.

20.6 Results

One study [8] reported a 76% success rate in the forelimb and an 81% success rate in the rear limb. Another more recent study [2] claimed a success rate of 46% in the forelimbs and 83% in the rear limb. Animals successfully treated [3] have been used for racing, show jumping, endurance racing, etc.

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20.7.1 Online references

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21 Proximal interphalangeal arthrodesis: plate fixation

Gustave E. Fackelman

21.1 Description

In some cases, it may be desirable to use a plate as the main implant to effect fusion of the proximal interphalangeal joint. The individual surgeon's preference may play a role in this decision, as may the size of the patient, or associated fractures of the proximal or middle phalanges.

encroach distally upon the extensor process of the distal phalanx. Bone grafting, as practiced often in humans [1–3] and previously described in the horse [4] has proven unnecessary, hence no second surgical (donor) site need be prepared.

21.2 Preoperative considerations

The kind or shape of the plate to be used is determined by the pathology presented by any particular case. Although a centrally placed straight DCP is the strongest alternative, a T-plate may be useful in a smaller patient with an especially short middle phalanx (**Fig. F21A**). Similarly, left or right directed L-plates may be preferred to avoid fracture lines in the proximal phalanx, while still obtaining a firm anchorage in the middle phalanx (**Fig. X21A**). In each case, **the plate should be compared with preoperative radiographs to ensure the appropriateness of its geometry**, and to ensure that it does not

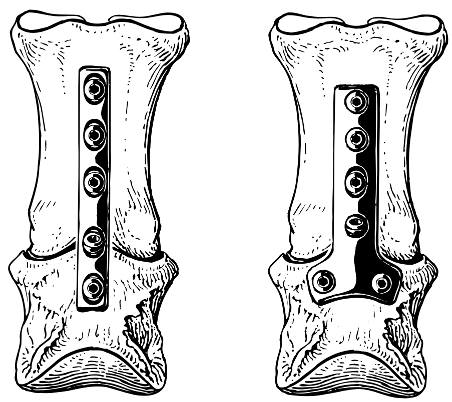


Fig. F21A: Either a 5-hole narrow DCP or a T-plate may be used for proximal interphalangeal arthrodesis. The T-plate may be placed even further proximally, and still provide firm anchorage in the middle phalanx.

To insure appropriate geometric relationships, compare the plate with preoperative radiographs.

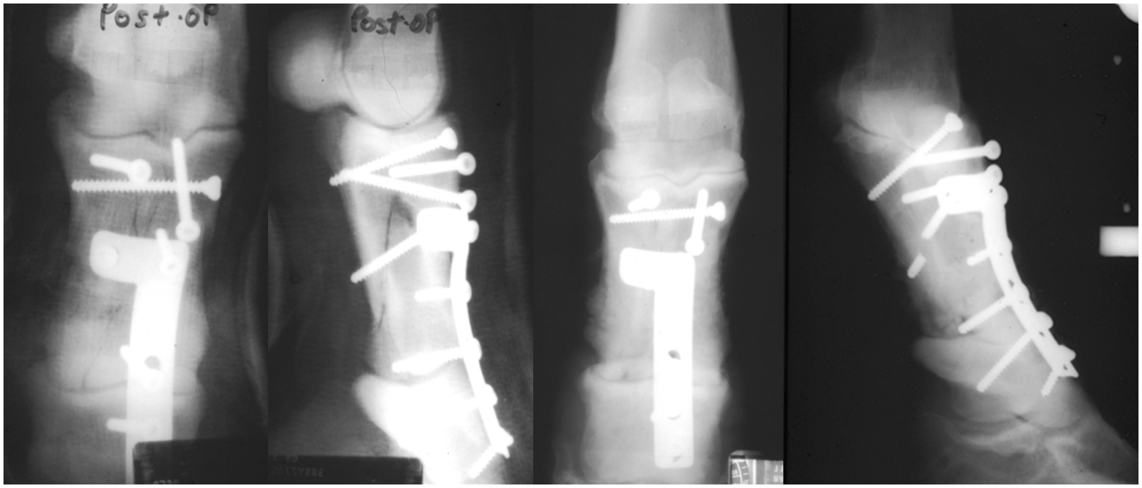


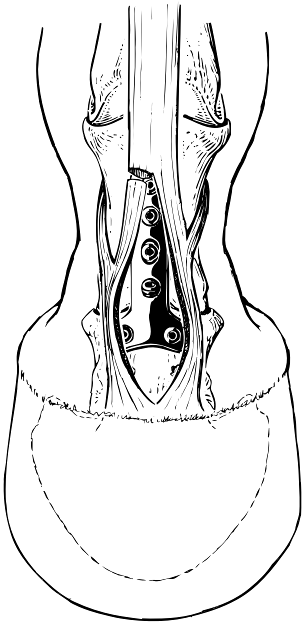
Fig. X21A: When primary arthrodesis of the proximal interphalangeal joint is performed in association with repair of comminuted fractures of the proximal phalanx, a neutralization plate is often used. At times, an L-plate may best fit a particular fracture/implant configuration.

21.3 Surgical anatomy

Relating to the arthrodesis itself, the basic surgical anatomy for this procedure is identical to that described for lag screw fixation of the joint (**chapter 20**, Proximal interphalangeal arthrodesis: screw fixation). If additional pathology is present in the proximal phalanx, the exposure will have to be greater, and resemble that described for the reduction and repair of comminuted fractures of the proximal phalanx (**chapter 11**, Proximal phalanx: comminuted). The pathologic anatomy becomes the major factor in deciding upon implant placement and orientation. If additional exposure is required for inserting the screws through the plate, the tenotomy may be slightly extended (**Fig. F21B**). Two separate stab incisions in the distal portion of the extensor tendon can facilitate the placement of the screws in the crossbar of a T-plate.

21.4 Surgical procedure

When the DCP is used in combination with two lag screws for a simple arthrodesis, the procedure is identical to that demonstrated in the accompanying video (**Video 31021**, Arthrodesis of the proximal interphalangeal joint, p. **223**). When it is applied to reinforce a multifragment fracture of the proximal phalanx, the repair of this bone is carried out first, followed by that of the plate bridging the joint. During placement of the individual lag screws in the proximal phalanx, **consideration can usually be given to the subsequent placement of the plate, to avoid interference between the two sets of implants**. Removal of articular cartilage is practiced, but osteostixis of the distal end of the proximal phalanx may be difficult due to the proximity of the most distal lag screw used in fracture repair (**Fig. X21B**). The plate is placed


a)

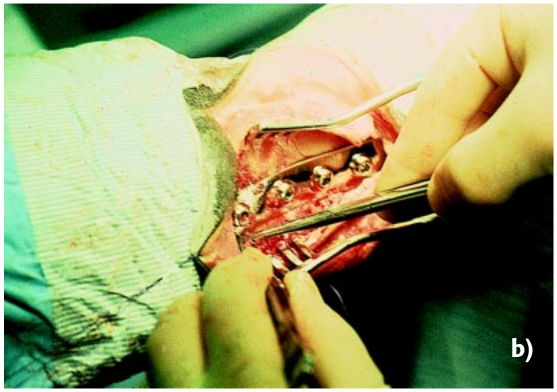


Fig. F21B: a) If sufficient retraction of the borders of the longitudinal tendon incision is impossible without excessive trauma, the tenotomy may be extended transversely on one side. b) The distal screws in a T-plate may be more easily inserted through separate stab incisions.

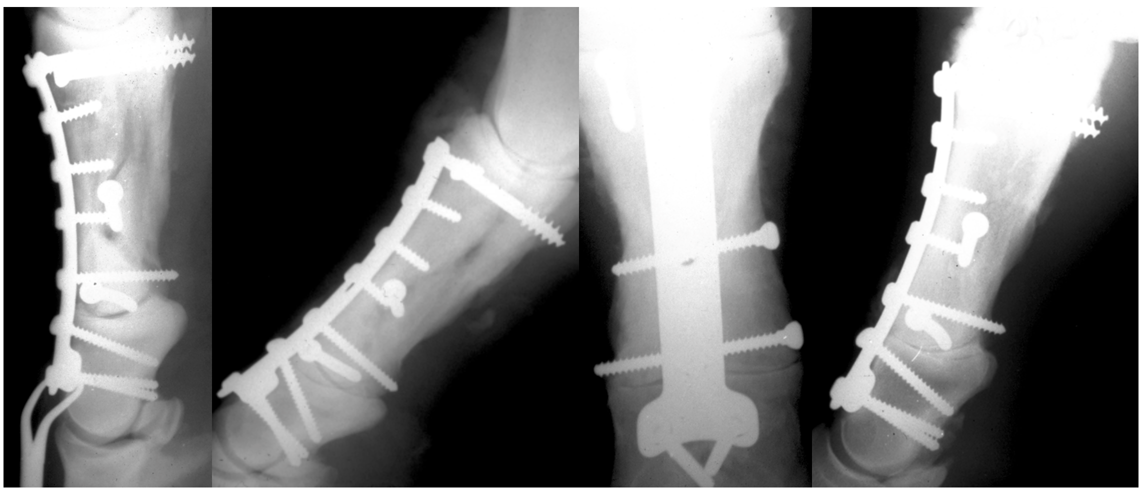


Fig. X21B: When using a buttressing T-plate for primary arthrodesis, the more distal implants in P1 may interfere with osteostixis. Debridement of articular cartilage appears to adequately stimulate fusion.

Consider possible plate placement during insertion of individual lag screws.

in tension utilizing the characteristics of its own particular configuration, which brings the articular surfaces under compression. Closure is routine, as already described in the above-mentioned chapters.

21.5 Postoperative treatment

In all but simple arthrodesis cases, a cast is used for 6–12 weeks postoperatively to reinforce stability. The animal receives perioperative antibiosis, and follow-up radiographs are performed at cast changes and monthly thereafter. The rapidity of fusion will be determined by the amount of pathology, and the degree of stability attained. In straightforward cases, hand-walking exercise may begin at about 6 weeks postoperatively. In more complicated ones, this is usually postponed an additional 6 weeks.

21.6 Complications

The major complication specific to this procedure is breakdown of the fixation due to instability. Typically, there was either a lack of adequate bone-on-bone contact, or the implant(s) selected were too small for the demands placed upon them (**Fig. X21C**). Given a reasonable biomechanical situation, healing results in a stable limb, serviceable soundness, and a good cosmetic appearance (**Fig. X21D**, **Fig. S21A**).

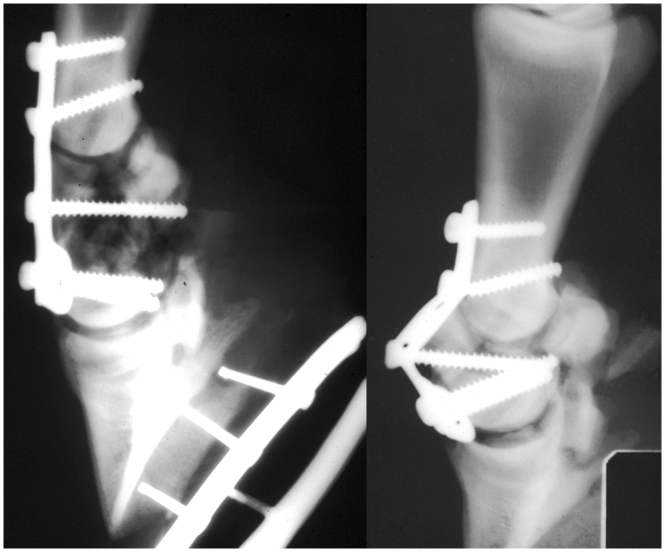


Fig. X21C: Inadequate bone-on-bone contact through a T-plate made this a very unstable fixation, with predictable results despite protection in a cast.

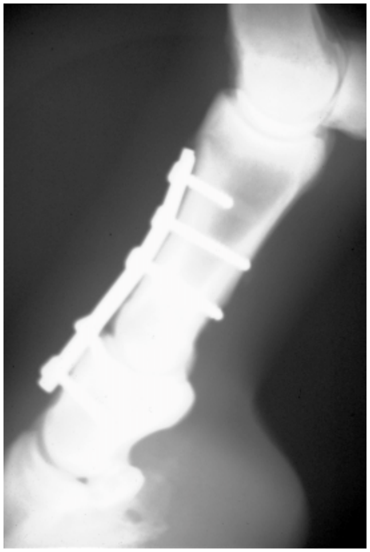


Fig. X21D: Radiographic healing is progressing, and the limb has a cosmetic appearance at 8 weeks postoperatively. The indication for surgery was lameness due to chronic luxation.

21.7 Results

When performed for its classic indication [5], that is to alleviate the symptoms of arthritis or chronic luxation (Fig. X21E), this procedure enjoys a high success rate, similar to reported results [6] cited in an earlier chapter (chapter 20, Proximal interphalangeal arthrodesis: screw fixation). In cases of more extensive pathology, the surgery is usually viewed as a salvage procedure, preserving axis and limb length adequate for pasture soundness (Fig. X21F, Fig. S21B).

21.8 References

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Fig. S21A: External appearance of the limb of the arthrodesis shown in Fig. X21D.

Fig. S21B: External appearance of the limb of the horse shown in Fig. X21F after cast removal.

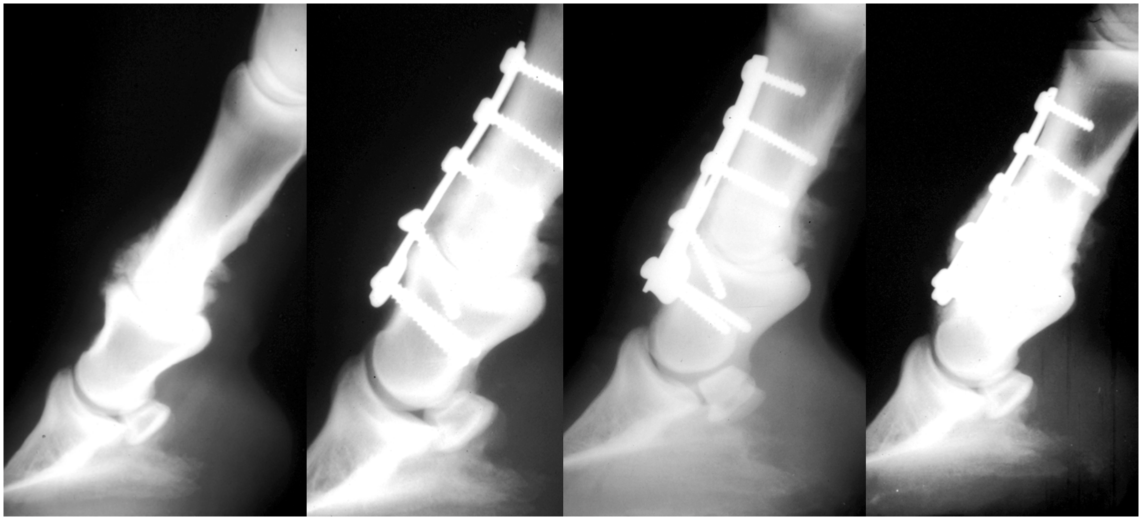

Fig. X21E: Fusion of arthritic joints bears a favorable prognosis. These radiographs show progression through 6 weeks and 6 months postoperatively. The fixation would have been strengthened by the addition of lag screws.

Fig. X21F: Arthrodesis was performed for comminuted fracture and luxation. After 12 weeks of cast fixation, the axis and length of the limb are acceptable.

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22 Metacarpophalangeal arthrodesis

Jörg A. Auer & Gustave E. Fackelman

22.1 Description

Arthrodesis of the metacarpophalangeal joint is performed to alleviate the pain of chronic arthritic conditions, to correct flexural deformities of the joint caused by extensor paralysis, or to eliminate the need for the suspensory apparatus in cases of the latter's disruption by rupture (**Fig. S22A**, **Fig. X22A**) or fracture (**Fig. X22B**). It is also advocated in the management of some severely comminuted fractures of the proximal phalanx. **Steady refinement of the technique throughout the last decade [1–5] has resulted in a reasonable degree of dependability.** Solid fixation is assured if the tension band provided by the suspensory apparatus is intact (e.g., in chronic debilitating degenerative joint disease), and is even achievable in animals with avulsion of both suspensory branches. These cases of total breakdown of the suspensory apparatus or multifragment fractures of both proximal sesamoid bones present special challenges (see below) and the resultant biomechanics test the limits of the implants' endurance.

Fig. S22A: Side view of a 14-year-old Peruvian Paso Fino stallion with disruption of the suspensory apparatus in both rear limbs.

Fig. X22A: Lateromedial radiograph of a 6-year-old Peruvian Paso Fino mare with avulsion of the insertions of both suspensory branches. Note the dropped fetlock, almost touching the ground, and the marked swelling in the surrounding tissues.

There has been steady refinement of the technique during the last decade.

Fig. X22B: Lateromedial radiograph of a horse with multifragment fractures of both proximal sesamoid bones, resulting in complete disruption of the suspensory apparatus. Note that the limb is held in extension to avoid distraction of the fragments.

22.2 Preoperative considerations

In cases of rupture of the suspensory apparatus, preoperative considerations pertain to the blood supply to the distal limb.

Fixation should be taken down every few hours to prevent venous pooling.

Other than economics, the **main preoperative considerations pertain to the blood supply to the distal limb, especially in cases of rupture of the suspensory apparatus** [6]. Due to the juxtaposition of the palmar/plantar digital vessels to the proximal sesamoid bones, vascular constriction or actual rupture may have occurred. The quality of first aid will play a major role in preventing serious soft tissue compromise. Application of a so-called "board splint" [7] or any of a number of other devices designed to maintain the fetlock in an attitude of physiologic flexion (see also **chapter 11**, Proximal phalanx: comminuted) are indicated. **The fixation should be taken down every few hours to prevent venous pooling**. The administration of intravenous dimethylsulfoxide (DMSO) to keep soft tissue swelling to a minimum should be considered. If surgery is a possibility, initiate perioperative antibiotics.

22.3 Surgical procedure—DCP

Two surgical procedures will be described in detail: application of a 14-hole broad dynamic compression plate (DCP) (**Fig. F22A**) and the palmarolateral application of a dynamic hip screw (DHS) implant system (**Fig. F22B**) [8].

Make the approach through a straight incision to the bone, preferably in one motion, over the lateral digital extensor tendon through the skin, subcutaneous tissues, extensor tendon, and periosteum. Extend the incision across the meta-

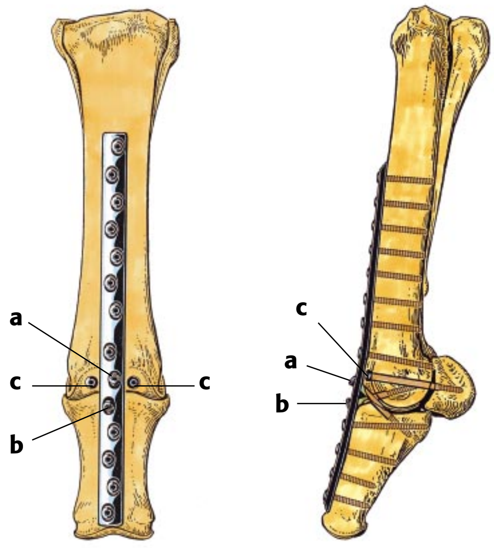


Fig. F22A: Dorsopalmar (left) and lateromedial drawing of metacarpophalangeal arthrodesis with a dorsally applied 14-hole DCP. Screws (a, b) are applied transarticularly and screws (c) are applied in lag fashion across MC3 to secure the proximal sesamoid bones. Note that the drawing depicts shaft screws. Instead of these more expensive screws, regular cortex screws may be used.

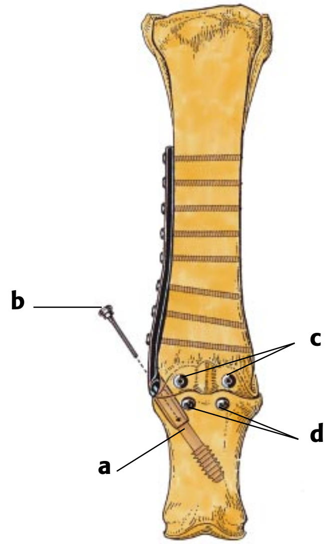


Fig. F22B: Dorsopalmar drawing of metacarpophalangeal arthrodesis with an 8-hole dynamic hip screw (DHS) implant system. The DHS (a) is implanted into the proximal phalanx, and the compression screw (b) is then inserted into the DHS screw shaft. Two screws (c) are inserted across MC3 in lag fashion to secure the proximal sesamoids, and two additional cortex or shaft screws (d) are inserted into MC3 transarticularly from the proximal phalanx.

carpophalangeal joint to the distal aspect of the proximal phalanx. **The capsular attachments and the collateral ligaments are transected and the joint is disarticulated to allow complete removal of all articular cartilage** (**Fig. S22B**). Osteostixis may be advantageous in facilitating osseous union.

With an osteotome and a mallet, modify the contours of the dorsal aspect of the proximal phalanx and the sagittal ridge of the distal MC3 to achieve a greater plate-to-bone contact area and to reduce the amount of plate bending required. The 12- or 14-hole plate should be

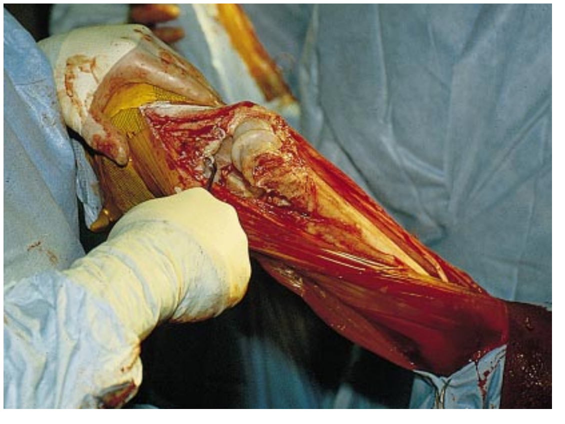


Fig. S22B: The joint is disarticulated, allowing complete access to all articular surfaces for cartilage removal. The animal is positioned in dorsal recumbency.

Transect the capsular attachments and the collateral ligaments and disarticulate the joint to allow complete removal of all articular cartilage.

The plate should have an angle of about 10° (170° joint angle).

contoured so that the four holes in the distal part of the plate lie on the proximal phalanx and **an angle of 10° is achieved at the joint** (**Video 31025**). Fix the plate temporarily with bone holding or large pointed reduction forceps, and insert the distal four screws (4.5 or 5.5 mm) as usual (**Video PBASICSB**). After placing the first screw, the correct orientation of the plate along the dorsal aspect of MC3 should be critically re-evaluated. The limb is extended and a 4.5 or 5.5 mm cortex screw is inserted through the distal MC3 into the proximal sesamoid bone in lag fashion (**Fig. S22C**). The glide hole penetrates MC3 fully but does not enter the proximal sesamoid bone. The difficulty of this part of the procedure consists in correctly choosing the location of the glide hole to assure placement of the thread hole in the centre of the proximal sesamoid bone. Insert one such screw in each proximal sesamoid bone.

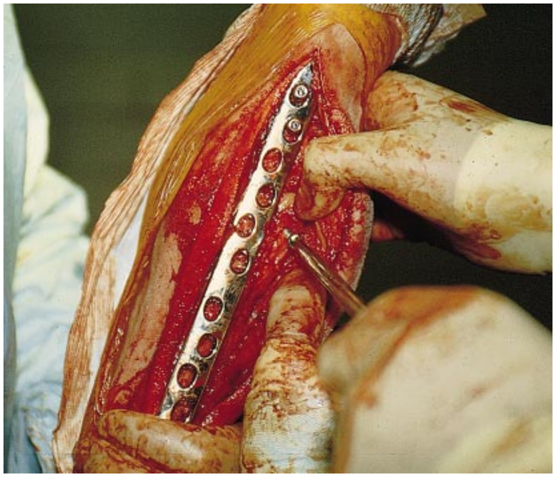
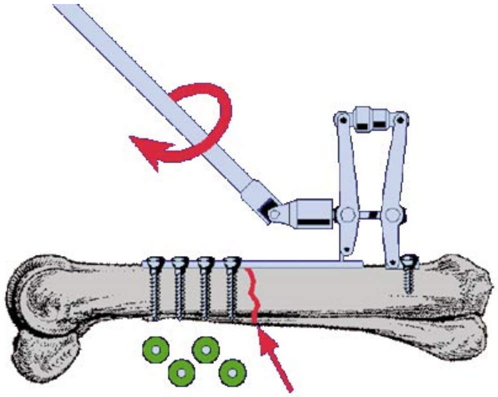


Fig. S22C: The plate has been contoured to the joint region and the distal four screws have been inserted. A lag screw is presently inserted from the dorsal aspect of the distal MC3 into a proximal sesamoid bone. The animal is positioned in dorsal recumbency.

Video 31025: Arthrodesis of the metacarpophalangeal joint.



Video PBASICSB: Plate basics animation (with tension device).

Lag screw insertion would be ineffective (and may even be impossible) in total disruption of the distal sesamoidean ligaments or multi-fragmentary fracture of both sesamoid bones (Fig. X22B). **In such cases a cerclage wire in figure-8 fashion should be installed between the palmar aspect of the proximal phalanx and MC3 to serve the purpose of a tension band**. For insertion, drill a 3.2 mm hole parallel to the articular surfaces of P1 and MC3 in the frontal plane about 3 cm distal and proximal to the joint, respectively. Thread two cerclage wires of 1.5 mm diameter through the holes in figure-8 fashion and tighten them with the fetlock in flexion.

Place the limb in its intended final position, apply the plate to MC3 and temporarily secure it there with forceps. Attach the tension device to the bone proximal to the plate with a 20 mm cortex screw. Tightening the device brings the distal sesamoidean ligaments (or the cerclage wires, if employed) under tensile load. This adds to the stability of the fixation, despite the plate being applied to the compression side of the limb. Remove the tension device after inserting the first screw in MC3 (Fig. S22D). Insert and tighten all the remaining screws except screws five and six from the bottom. **Each of these last two screws crosses the joint in lag fashion, in such a plane that it interferes neither with its counterpart nor with the screws lagging the proximal sesamoid bones to MC3** (Fig. F22A). Additional lag screws may be placed from the dorsal and proximal aspect of the proximal phalanx flanking the plate (Fig. S22E, Fig. X22C).

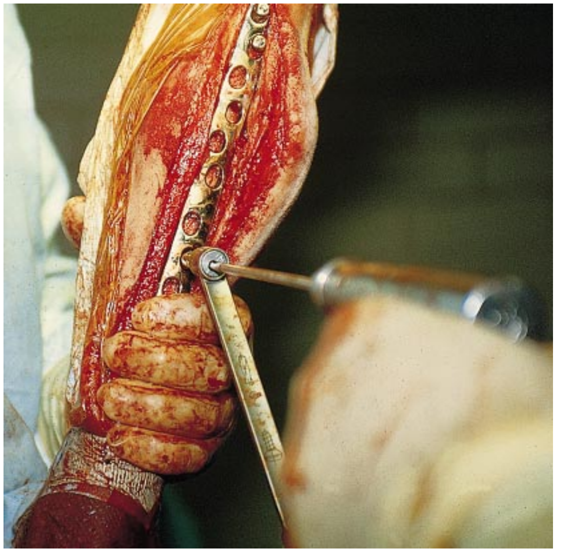


Fig. S22D: The tension device is tightened and a screw is implanted into MC3. The animal is positioned in dorsal recumbency.

When the distal sesamoidean ligaments are ruptured, replace them with a tension band wire.

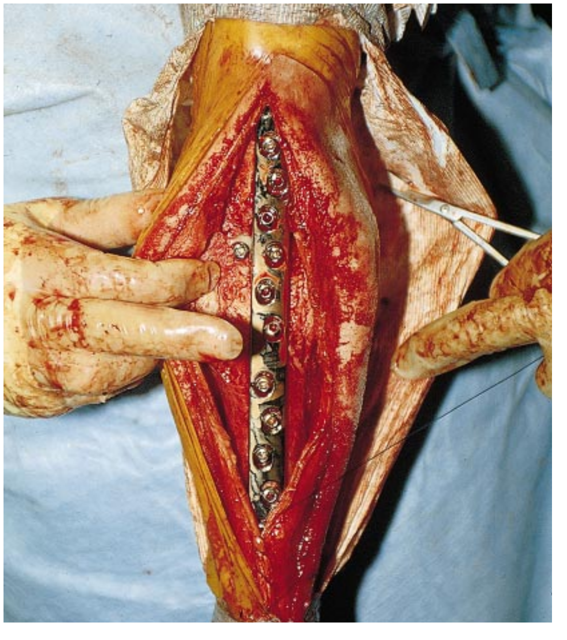


Fig. S22E: All the implants are in place and the soft tissues are about to be closed. The animal is positioned in dorsal recumbency.

Insert screws five and six in lag fashion across the articulation.

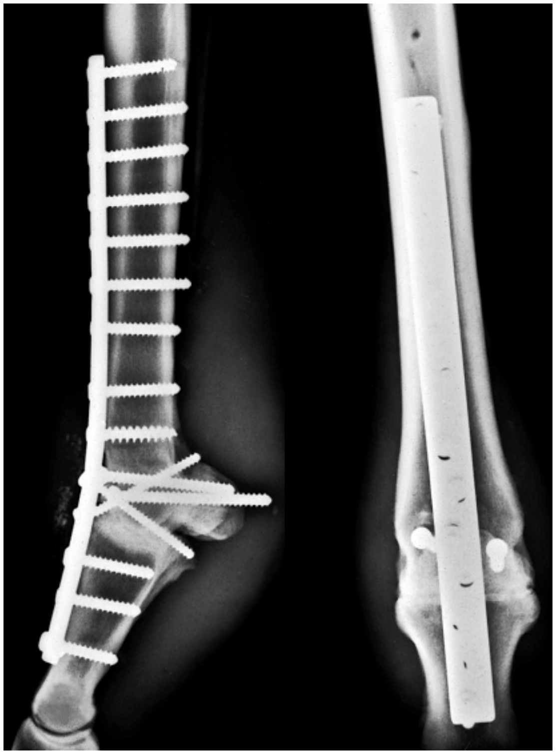


Fig. X22C: Postoperative lateromedial (left) and dorsoplantar (right) radiographs of the surgery site, depicting the fetlock arthrodesis. Note that one of the lag screws inserted into the proximal sesamoid bones is too long. It was subsequently exchanged for a smaller one.

22.4 Surgical procedure—DHS

An alternative technique involves the application of an 8-hole DHS plate to the palmarolateral aspect of MC3, with the large DHS screw and plate barrel extending into the proximal phalanx. The technique is analogous to the one described for the fixation of a metaphyseal radius fracture using a DCS plate (**chapter 14**, Radius), except that a different angled guide and barrel reamer are used. Hence the same figures will be used to illustrate salient points in the implants' application. The approach is identical to that described above (Surgical procedure—DCP).

Contour the palmarolateral aspect of the distal MC3 to accept the DHS plate.

Remove the palmarolateral ridge of the distal third metacarpal condyle with an osteotome to allow placement of the plate slightly palmarolaterally. This permits better placement of the large screw in the proximal phalanx, and the fixation of the joint at an angle of approximately 10°. If possible, insert the lag screws from the distal aspect of MC3 into the proximal sesamoid bones, as described above. Drill a 2.5 mm hole from the level of the joint into the proximal phalanx through the DHS angled guide. Then insert the threaded guide pin into the hole and seat it solidly in the opposite cortex (**Fig. F14I**, p. **146**). After its correct placement has been confirmed radiographically, use the measuring device to determine the pin's depth of penetration. **The DHS triple reamer is then assembled, and set to 5 mm less than this measurement** (**Fig. F14J**, p. **147**). The 25 mm long barrel reamer is recommended, since the 38 mm long barrel reamer is too long for the average horse and will probably penetrate the opposite cortex and result in an inadequate

Set the DHS triple reamer to 5 mm less than the total measurement.

fixation. In one step, prepare with the triple reamer: the thread hole for the DHS screw, the barrel hole, and the plate-bone junction. The triple reamer is cannulated to accept the guide pin, assuring directional accuracy. It is important to frequently withdraw and cleanse the reamer to prevent jamming with debris and the inevitable resultant heat production. **Slow, steady irrigation also helps prevent overheating of the instrument and of the surrounding bone**. After the hole has been prepared, withdraw the triple reamer and thoroughly flush the cavity in P1. Place the cannulated tap over the guide pin and prepare the threads to the desired depth (**Fig. F14K**, p. **147**). Slide the precontoured DHS plate up the shaft of the mounting device, and connect the screw of predetermined length to the device. Turn the device's handle clockwise to insert and tighten the DHS screw. The horizontal bar of the T-handle should be parallel to the long axis of the bone at final tightening. In this position the flat portions on the screw shaft jibe with those of the plate barrel ensuring coincident geometry and solid plate-to-screw union. The plate is subsequently impacted into the hole and temporarily retained with the large pointed reduction forceps. Insert the plate screws and the compression screw (**Fig. F14L**, p. **148**). Take care to assure that some of the DHS screw threads are firmly secured in the opposite cortex. If this is not the case, tightening of the compression screw will extract the DHS screw from the bone, the fixation will be unstable, and the patient will suffer unrelenting pain. Additional lag screws may be placed transarticularly as previously described (**Fig. X22D**). A recent study revealed that this technique is slightly more secure than the previously described one, both with intact suspensory apparatus and with disrupted distal sesamoidean ligaments [**9**]. However, the implants are more expensive and their application somewhat more demanding.

Fig. X22D: Postoperative lateromedial (left) and dorsopalmar (right) radiograph of a fetlock region with a DHS screw and a plate applied laterally to the limb. Note that the DHS screw is positioned too far palmarly. Placement of the plate more palmarolaterally would have improved screw placement.

Closure of the soft tissues at the end of the procedure is routine. The simple continuous suture line in the lateral digital extensor tendon facilitates a secure closure over the implants.

Continuous irrigation is important for the success of the reaming process.

A modified Cloward technique involving the implantation of a stainless-steel basket filled with cancellous bone has also been described [10]. The earlier tendency to place the horse in a more upright than normal position and apply a so-called "wave plate" [11] appears unnecessary in the light of later experience, and the abnormal posture produced often resulted in the development of osteoarthritis of the proximal interphalangeal joint.

22.5 Postoperative care

A cast is applied to the operated extremity, and changed or removed at 4 to 6 weeks postoperatively unless circumstances dictate otherwise (Fig. S22F). With the DHS technique, postoperative casting can be reduced to approximately 2 weeks (Fig. S22G). Perioperative antibiosis is maintained longer than usual due to the danger of "seeding" of the damaged soft tissues. A well-bedded stall is essential, since periods of recumbency may be prolonged in the early postoperative period, and a resilient substrate helps prevent laminitis in the overloaded opposite fore foot.

Fig. S22F: Immediate postoperative picture of the horse in Fig. S22A showing the fiberglass casts in place. The animal tolerated them very well.

Fig. S22G: The horse of Fig. X22D 2 weeks postoperatively, placing full weight on the limb.

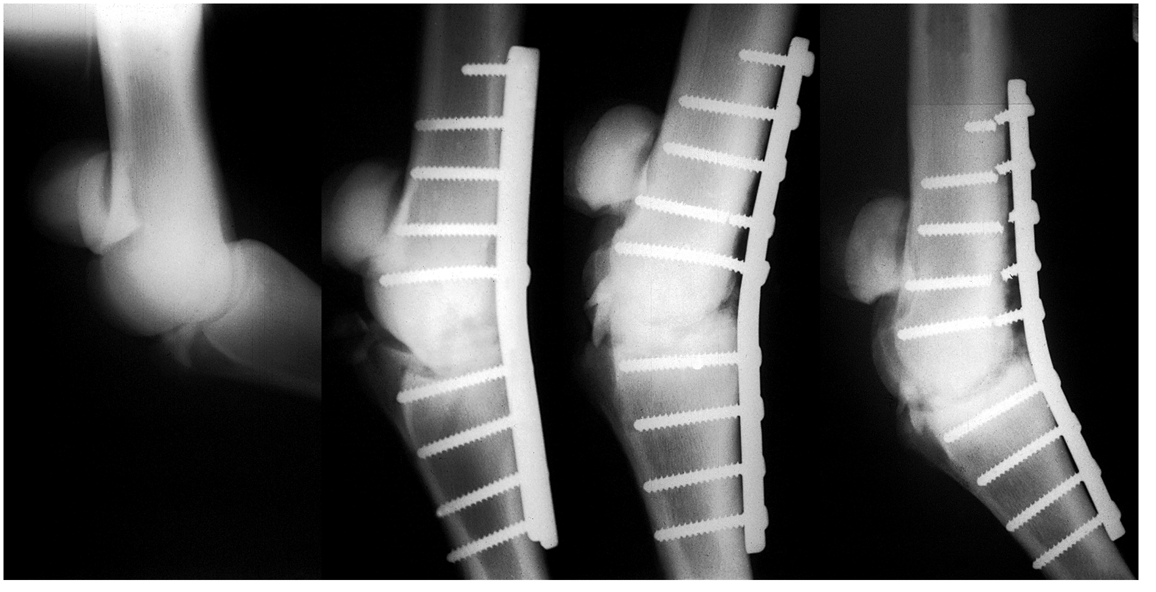


Fig. X22E: A plate that was too short, and inadequate stability led to failure of the fixation beginning at 6 weeks, and ending at 12 weeks.

Longer plates, and the use of tension band wiring to replace the distal sesamoidean ligaments, help to prevent implant failure.

22.5.1 Complications

The most common complication is implant failure (Fig. X22E, Fig. S22H), although improved surgical technique has greatly reduced this danger. Earlier, probably overzealous, inlay grafting techniques led to occasional bony failure and are no longer recommended. In bilateral fetlock arthrodeses, as occasionally performed in Peruvian Pasos due to avulsion of the insertion of both suspensory branches, bony failure has been seen despite application of ostensibly good surgical technique (Fig. X22F, Fig. X22G). Infection remains the next most common reason for failure, followed by breakdown in the integrity of the opposite limb.

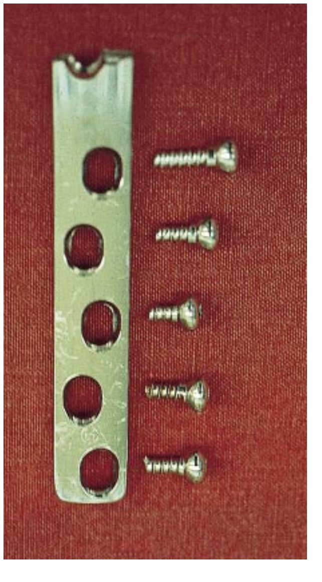


Fig. S22H: The plate from the case in Fig. X22E shows the ravages of cycling, which results in fatigue failure of the plate, overloading and breaking the remaining implants just beneath the bone's surface.

22.6 Results

Overall it appears that at least 50% of animals with "total breakdown" injuries may be salvaged [12], and this figure is improving steadily (**Fig. S22I**, **Fig. X22H**, **Fig. X22I**). The success rate is even higher for animals undergoing a metacarpophalangeal arthrodesis to alleviate pain from advanced arthrosis. The major problems develop in the early postoperative period, so that, given positive findings after 6 to 8 weeks, the prognosis improves dramatically. The technique described above has been tested experimentally (**Fig. X22J**) and its effects examined grossly (**Fig. S22J**) and histologically (**Fig. S22K**). It appears that virtually all of the horses suffering from debilitating arthritis or contracture deformities (**Fig. S22L**) may be saved (**Fig. X22K**, **Fig. S22M**, **Fig. S22N**).

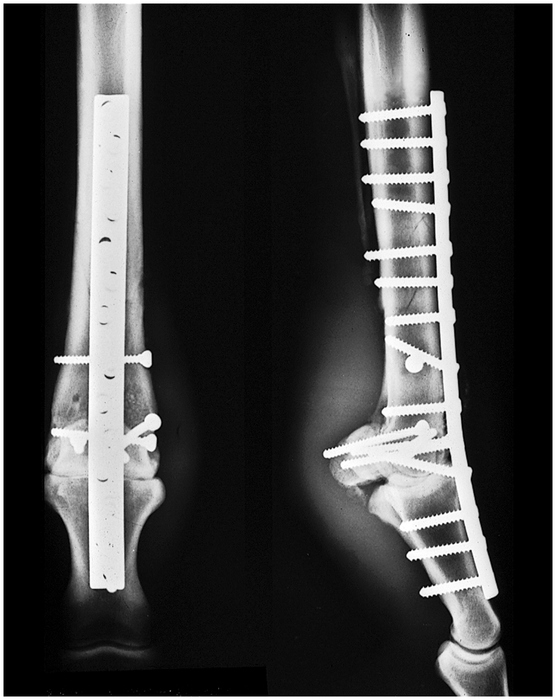


Fig. X22F: Lateromedial radiograph of the horse in **Fig. X22C** 4 days postoperatively. Note the distinct fracture lines in the metacarpus (in the region of the fourth to sixth screw from the top), demonstrating bony failure despite application of a fiberglass cast.

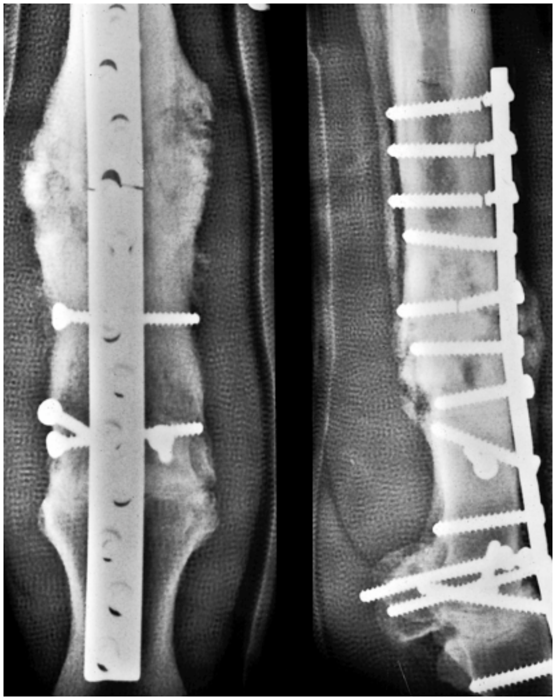


Fig. X22G: The same horse about 2 months later demonstrating extensive callus formation in the area of the fractures. By now the plate has broken as well, in addition to the four most proximal screws. Usually screw failure occurs before plate breakage.

Fig. S22I: Picture of the same horse as in **Fig. S22A** 9 months postoperatively. The animal places full weight on both rear limbs and the fetlock angle is acceptable.

Fig. X22H: Lateromedial (left) and dorsoplantar radiographs of the horse in **Fig. S22I**. The joint has fused and the implants may be removed.

Fig. X22I: Lateromedial (left) and dorsoplantar radiographs of the horse in **Fig. S22I** after implant removal. Note that a broken drill bit from the time of the original surgery could not be retrieved.

The plate in this early experimental case is too short, but adequate curettage, osteostixis and bone grafting resulted in union.

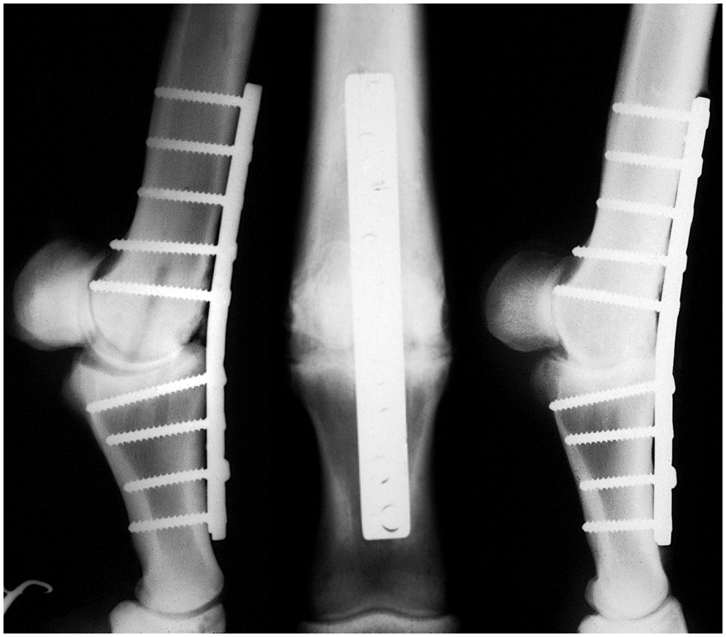


Fig. X22J: These radiographs document the 12 week healing of an experimental arthrodesis performed in a normal horse. Osteostixis, curettage, and bone grafting were carried out as ancillary procedures.

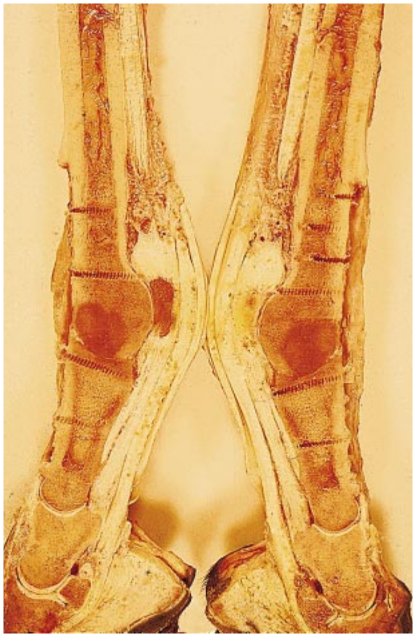


Fig. S22J: The gross post mortem specimen form the animal in **Fig. X22J** shows solid bony union.

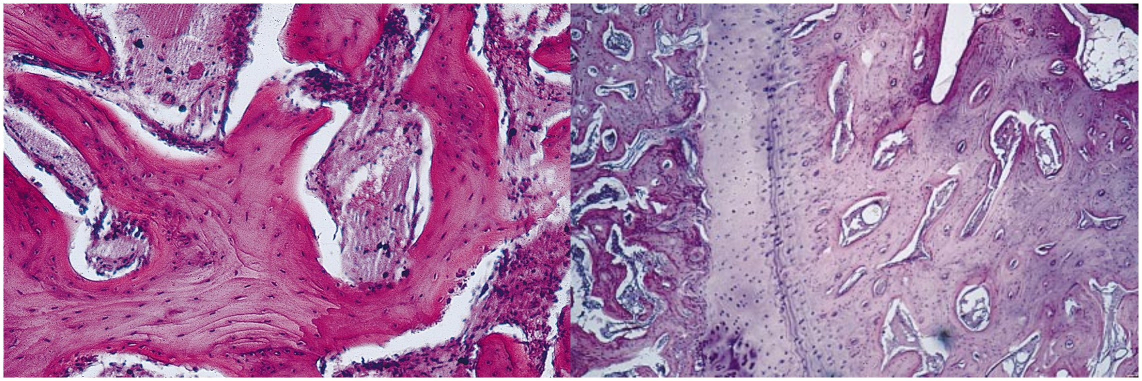


Fig. S22K: Histology of the case in **Fig. X22J** shows bony bridging of the joint space between MC3 and the proximal phalanx (left) but maintainance of the cartilaginous barrier between the proximal sesamoids and MC3 (right).

Fig. S22L: Partial radial palsy left this yearling with a permanent flexural deformity of the right fore digit. The filly had adopted the habit of grazing on one knee.

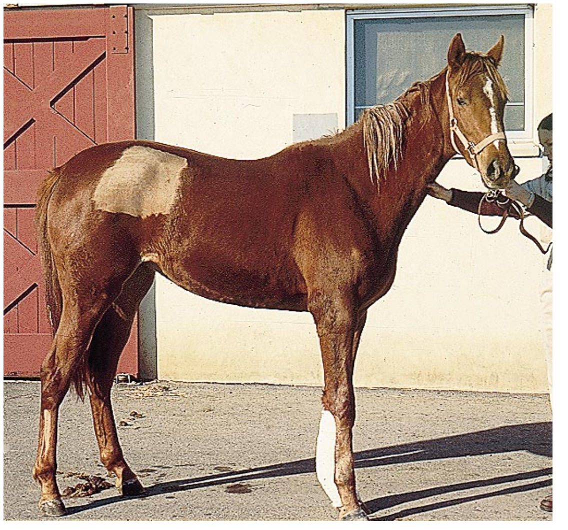


Fig. S22M: At 11 weeks postoperatively, the filly in **Fig. S22L** bore full weight on the limb, and with a stabilized digit, was willing to keep the limb extended.

Fig. S22N: Close up views of the RF limb of the filly in **Fig. S22M** immediately postoperatively and 11 weeks postoperatively document uncomplicated soft tissue healing.

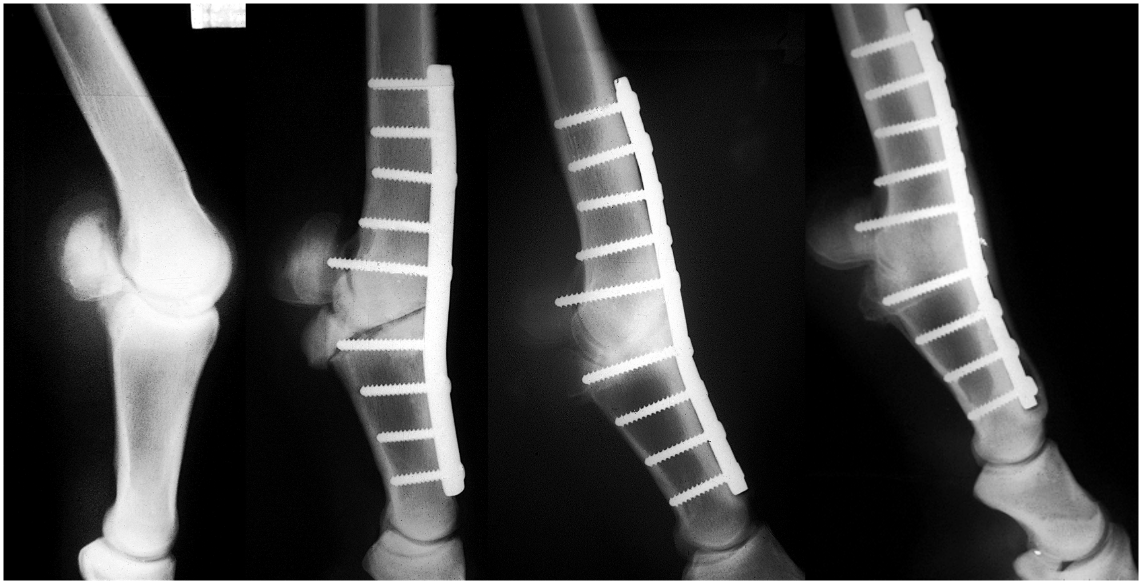


Fig. X22K: The radiographs of the case in **Fig. S22L** record the preoperative condition of the right metacarpophalangeal joint, the corrective osteotomy, and the healing of the arthrodesis over a 1-year period.

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22.7.1 Online references

See online references on the PEOS internet home page for this chapter:
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23 Carpal arthrodesis

Jörg A. Auer

23.1 Description

Carpal arthrodeses are carried out as salvage procedures in adult horses and foals with severe carpal injuries such as comminuted fractures associated with collapse of some of the carpal bones (**Fig. X23A**), luxations (**Fig. X23B**) or subluxations of one or more of the carpal joints, and advanced degenerative joint disease in one or more of the carpal joints [1]. **Generally, one distinguishes between two types of carpal arthrodesis: pancarpal and partial**. In pancarpal arthrodesis all the joints in the carpus are fused, essentially forming an extremely long bone, including the third metacarpal bone, all the carpal bones, as well as the radius [2]. A partial or subtotal carpal arthrodesis involves fusion of one or maximum two of the three carpal joints. The joint(s) to be fused are selected depending upon the level at which injury has occurred [3]. In the partial carpal arthrodesis, a certain amount of flexion is still possible.

The two types of arthrodesis are pancarpal and partial.

Fig. X23A: Flexed lateral radiograph of the carpal region of a horse that suffered a severe carpal injury. Note that the distal row of carpal bones is completely destroyed; note also a dislocation of the carpometacarpal joint.

Fig. X23B: Radiographic view of the carpal region of a horse that suffered a complete luxation of the middle carpal joint. Note that the distal row of carpal bones is positioned dorsal and slighly proximal to the proximal row. The bone slab (arrow) located distal to the proximal row of carpal bones represents an avulsion fragment off the third carpal bone.

Avoid damaging the tendon sheaths on the cranial aspect of the carpus.

Free the joint capsule from its insertions and elevate the periosteum preparatory to plating.

23.2 Surgical anatomy

The anatomy at the cranial and lateral aspect of the radial region is complex and application of bone plates to allow fusion of all the joints has to take this into consideration. **Care should be taken not to inadvertently damage the sheaths of the extensor carpi radialis or the common digital extensor tendons.**

The approach for plate application in pancarpal arthrodesis consists of two incisions, one medial to the extensor carpi radialis tendon, where there is adequate and ample space allowing application of the plate, and one between the extensor carpi radialis and the common digital extensor tendon (**Fig. F23A**). The straight, 30–40 cm long incisions are carried out through the skin, subcutaneous tissues, and antebrachial fascia to the bone in the region of the distal radius and proximal MC3. They then extend across the joint capsules uniting the three joint spaces. **The insertion of the joint capsule on the bone is freed for 6–8 mm on either side of the vertical incision. The periosteum is elevated from the underlying bone on both sides of the incision in preparation for plating.** If necessary, sharp bony proliferations and protuberances are removed with a chisel to allow maximum bone-plate contact; this will increase the stability of the fixation. Application of implants for partial carpal arthrodesis includes the same type of incision, but shorter. In a case of collateral ligament rupture, causing subluxation or luxation of the joint, the approach is moved laterally or medially. On the lateral aspect the tendon sheath, as well as the lateral digital extensor tendon itself, may be sacrificed if they unduly interfere with plate placement.

23.3 Surgical procedure—pancarpal arthrodesis

The pancarpal arthrodesis involves application of two long dynamic compression plates (DCP). The use of bone lengthening plates has also been advocated. These latter implants contain no holes in their central portions, which are placed over the joints to provide additional strength in that area. This may be especially important in animals with multiple fractures to prevent collapse (**Fig. X23C**). The plates serve purely as buttresses.

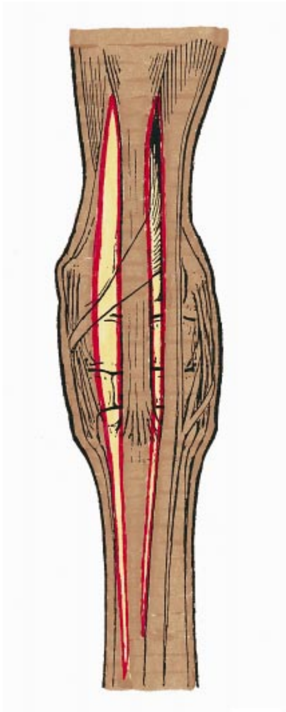

Fig. F23A

Fig. X23C: Oblique radiographic view of the carpal region of a horse which suffered a multifragment fracture of the proximal and distal row of carpal bones. A slab fracture of the radial carpal bone is easily recognized on the dorsomedial aspect of the carpus (arrow). A displaced fragment of the third carpal bone (open arrow) marks the partial collapse of the carpus.

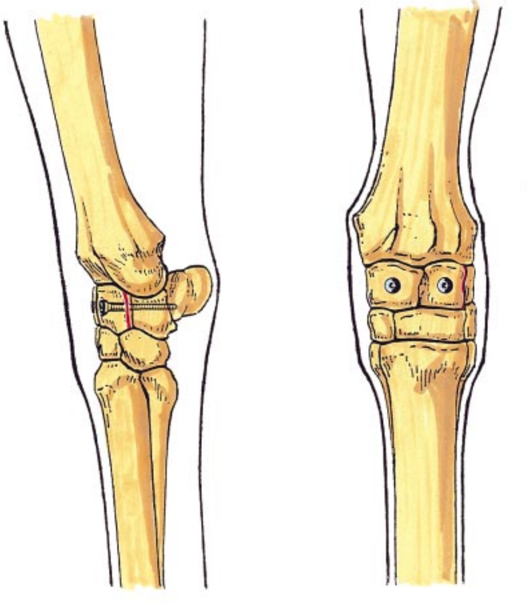

Fig. F23B

The animal is placed on the surgery table either in dorsal or lateral recumbency with the involved limb uppermost. **Dorsal recumbency allows two teams to work simultaneously,** shortening the surgery time and so facilitating recovery. Application of two 16- to 19-hole DCPs takes time, even with power drilling/ tapping/screw insertion.

Should major slab fractures be encountered, they are reduced and treated by means of lag screws (**Fig. F23B**). **As much of the articular cartilage as possible is removed, facilitating bony union** (**Fig. F23C**). Osteostixis may be performed to facilitate growth of blood vessels and a cancellous bone graft is indicated. Alternatively, a bone substitute such as tricalcium phosphate may be used. The axis of the limb favors a slightly flexed position to make the cranial/dorsal aspect the tension surface. The

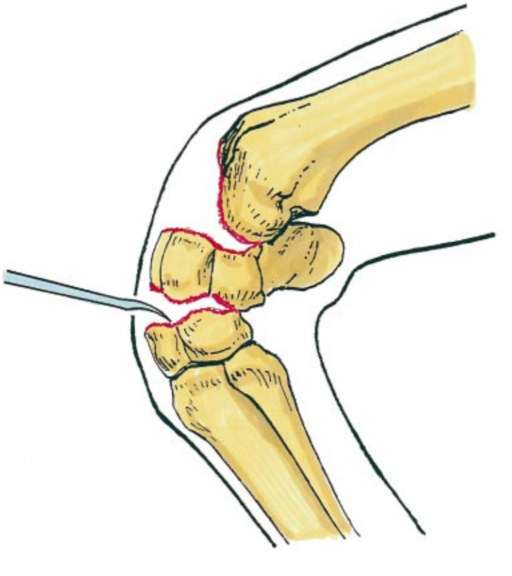

Fig. F23C

With the horse in dorsal recumbency, two surgical teams can work simultaneously.

Remove as much articular cartilage as possible.

Apply the craniomedial plate first.

Avoid interference amongst the screws of the two plates.

soft aluminium template is pressed onto the cranial/dorsal aspect of the carpal region in the exact location intended for the plates. With the help of the bending press, the two plates selected are contoured to match the templates. **When contouring is satisfactory (minimal over-bending included), the craniomedial plate is placed in position and is attached to the proximal MC3 by means of one plate screw**. For this purpose a 3.2 mm thread hole is drilled through the plate and across the entire bone. The length of the screw is determined with the help of the depth gauge and the hole tapped. The 4.5 mm cortex screw is inserted but not completely tightened (**Fig. F23D**) and the correct alignment of the plate is re-evaluated. After shifting the plate proximally to prepare for compression of the carpal region, a second plate screw is inserted in load position into the distal radius. By proceeding in this fashion, 2 mm of compression can be effected across the carpal region (**Fig. F23E**). The two screws are firmly tightened, already bringing about some stability. The same procedures are then repeated at the craniolateral site. **Care is taken to apply the second plate in such a manner as to allow insertion of the screws in the spaces between the screws in the first plate**. Since those screws are likely to be slightly convergent, impingement is readily avoided.

One 19- to 22-hole plate and one 16-hole plate should be adequate for the arthrodesis. This constellation prevents both plates beginning and ending at the same level and the inevitable

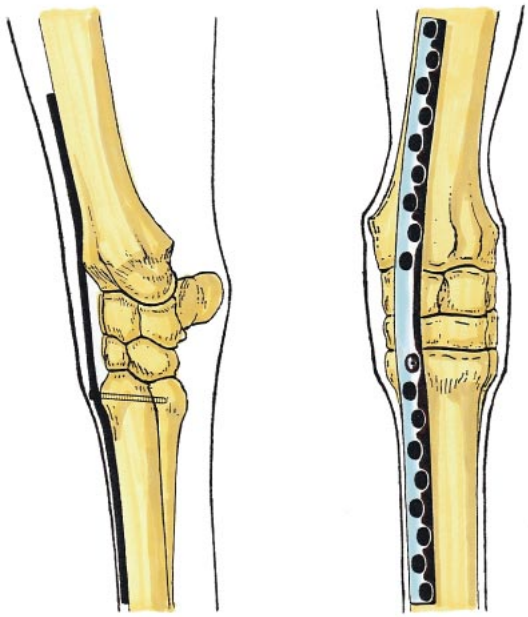

Fig. F23D:

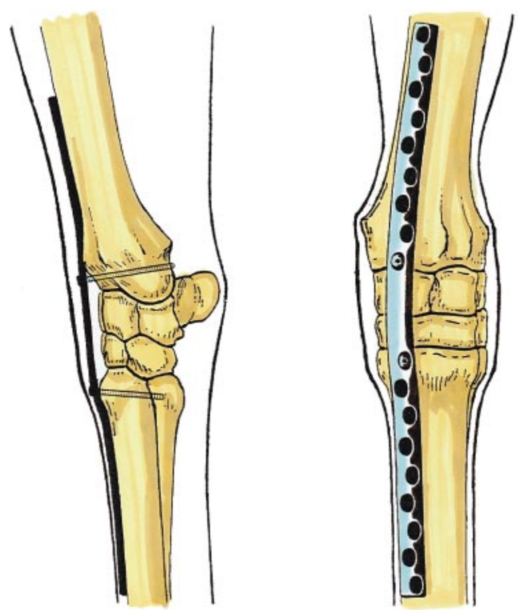

Fig. F23E:

An 18-hole lengthening plate is applied to the proximal MC III (F23D) and distal radius (F23E) with the first two screws.

concentration of stress. The additional plate screws in the distal radius and MC3 are inserted in both plates and tightened (**Fig. F23F**). If a buttress effect is desirable, the load (yellow) DCP drill guide should be set with the arrow pointing away from the joint. However, no more than two screws on either side should be placed under load. Finally, all screws are checked for tightness. When a regular DCP is used (instead of a leg lengthening plate [**Fig. X23D**]), screws, possibly only short ones, are placed in the carpal region incorporating any smaller fragments. Screws crossing any fracture plane are applied in lag fashion, providing additional strength and stability. In cases of advanced degenerative disease this is not necessary because no fractures are encountered, and plate screws can be inserted into the radiocarpal bone and C3 on the dorsomedial aspect, and into the intermediate and C3 bones on the dorsolateral aspect. Once all the screws are in place they are tightened again and, if necessary, additional lag screws are inserted in problem areas. **The incorporation of a massive cancellous bone graft on the dorsal aspect of the carpal region is strongly encouraged** (**Fig. F23F**).

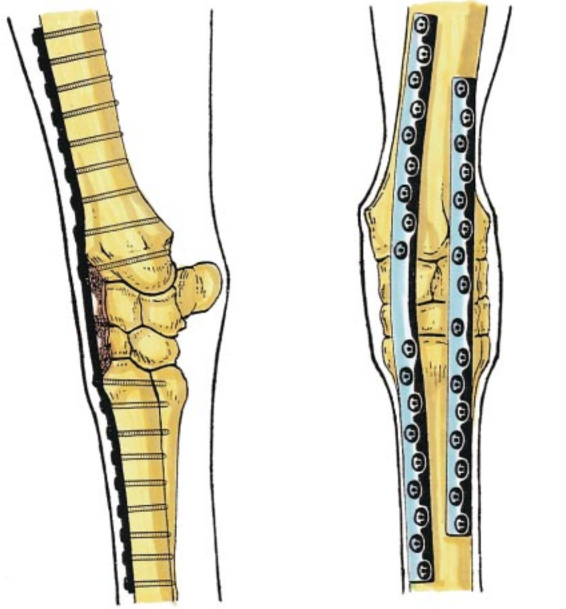

Fig. F23F

The subcutaneous tissues and the joint capsules are united over the plates, followed by a subcuticular pattern and interrupted skin sutures. Alternatively, surgical metal staples may be used in the skin.

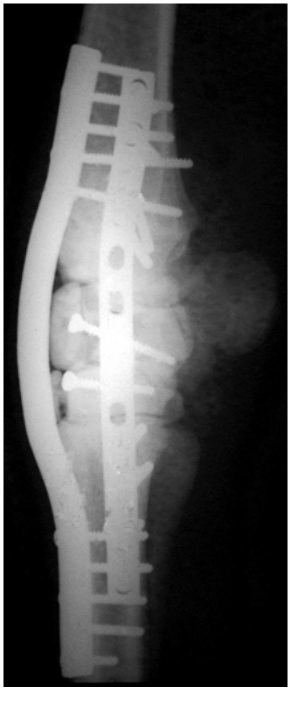

Fig. X23D: Dorsopalmar radiographic view of pancarpal arthrodesis carried out on the same horse shown in **Fig. X23C**. Note that the dorsomedial plate is of the bone lengthening type, without any plate holes in the central portion, spanning the carpal region.

To accelerate healing, apply copious amounts of autogenous cancellous bone.

23.4 Surgical procedure—partial carpal arthrodesis

Luxation or subluxations of one or two of the carpal joints may be treated with a single plate applied to the dorsal or lateral aspect of the limb. The surgical technique is basically the same as described for pancarpal arthrodesis. The animal is positioned in lateral or dorsal recumbency on the table. If one plate is to be applied, lateral recumbency with the affected side of the limb uppermost is preferred. For double plating dorsal recumbency is advantageous. The location of the plate and the approach to the joint is as previously described (**Fig. F23A**). As much of the articular cartilage is removed as possible. **Realignment of the joint is achieved and any large slab fracture(s) treated with lag screws**. For this purpose 4.5 or 5.5 mm screws are used in adults, while 3.5 mm screws are chosen in foals. In adult horses broad or narrow DCPs are used most frequently. In selected cases, where mainly tensile forces have to be counteracted, even a T-plate may be used. In foals 3.5 mm plates of various shapes and configurations may be applied (**Fig. X23E**, **Fig. X23F**).

Repair any large slab fractures with lag screws.

The plate selected is contoured to the surface prepared for it, and the first plate screw is inserted using standard technique. If this screw crosses a fracture line, the screw is inserted in lag fashion, but it is not completely tightened. Subsequently, the luxation is aligned and the plate is shifted distally to place the first screw in a loaded position. This is followed by insertion of the second plate screw into the MC3 also in "load" position. By tightening those two screws solid compression of the joint can be achieved. Additional screws are inserted, if possible, into the distal row of the carpal bones and the MC3. A maximum of two screws on either side of the joint can be placed in loaded positions. After all the screws are inserted final tightening is performed (**Fig. X23G**, **Fig. X23H**). If deemed necessary, a cancellous bone graft may be added to the dorsal region of the joint. Skin closure is routine as described previously.

Fig. X23E: Lateromedial radiographic view of a carpometacarpal luxation in a 2-months-old foal. MC3 is luxated dorsally and positioned immediately under the skin. Note the thin bone fragments distal to the distal row of carpal bones which were caused by the joint capsule avulsion off MC3.

In treating cases of comminuted fractures of the distal row of carpal bones by partial arthrodesis, one or two plates are needed and they are placed as described for the pancarpal arthrodesis. However, they do not engage the radius. Two screws may be inserted into both the radiocarpal bone and the intermediate carpal bone, one or two screws into C3 and the remaining screws into MC3. In such a case, one

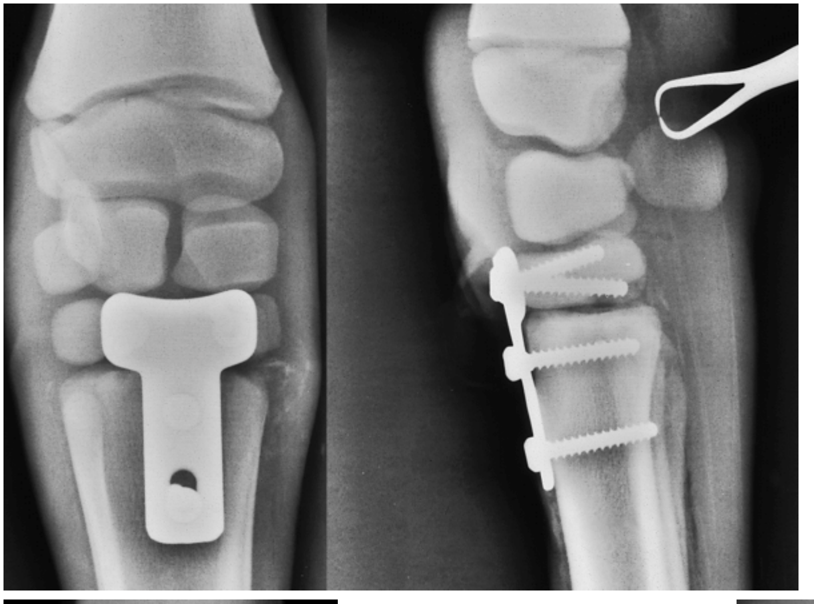

Fig. X23F: The luxation was reduced and a two hole T-plate applied to the dorsal region. Two screws were inserted into C3 and two additional screws into MC3. With time the carpometacarpal bone ankylosed.

Fig. X23G: Stressed dorsopalmar radiograph of a subluxation of the middle carpal joint after collateral ligament rupture. Additionally a fracture of the proximal aspect of MC2 and C4 was present. Note the wide gap at the medial aspect of the joint.

Fig. X23H: The subluxation in **Fig. X23G** was repaired with a broad 8-hole DCP placed medially and a narrow 5-hole DCP placed dorsolaterally. Additionally, the fractures at the medial aspect were repaired with 3.5 mm cortex screws applied in lag fashion.

"Stressed" radiographic views may help in understanding the nature of the pathology.

The plates act as buttresses, preventing collapse.

10-hole and one 6-hole plate is a recommended combination. **The plates will act mainly as buttresses, preventing collapse of the joint(s) involved**; therefore the first screw placed in each plate is tightened firmly. After previous assurance of proper alignment of the plate the second plate screw is inserted with the drill guide in an inverted load position (the arrow of the yellow guide pointing away from the joint involved) and tightened.

Application of a bone graft is indicated and closure of the skin is routine.

In an extreme case with shattered carpal bones (**Fig. X23I**), it is possible to remove the entire distal row of carpal bones and fix the proximal row directly to MC3 (**Fig. X23J**) [1]. In such a case, addition of a massive cancellous bone graft and postoperative support by a fiberglass cast or at least a solid splint is absolutely necessary.

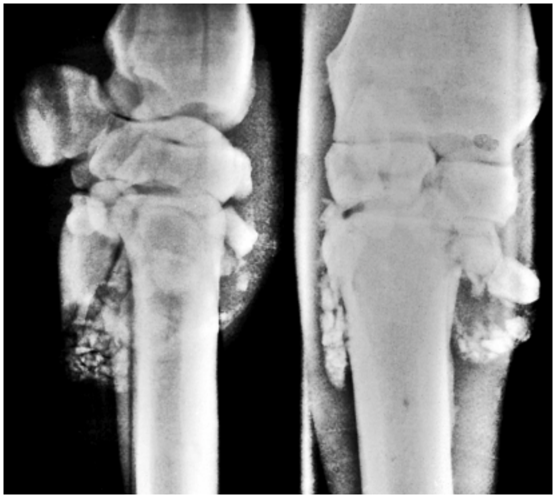

Fig. X23I: Lateromedial and dorsopalmar radiographic views of a severe carpal injury. The distal row of carpal bones is completely disintegrated and consists of a large number of small bone fragments. The proximal row of carpal bones is located on MC3. The proximal aspects of MC2 and MC4 were fractured as well.

Fig. X23J: Postoperative radiographic views of the same carpal region as shown in **Fig. X23I**. The distal row of carpal bones was entirely removed and the proximal row of carpal bones fixed directly on MC3. The larger MC4 fragment was fixed onto MC3 with two 4.5 mm cortex screws placed in lag fashion. The entire limb was placed into a fiberglass cast for 1 month. The animal recovered extremely well and was successfully used as a brood mare.

23.5 Postoperative treatment

Apply some sort of external support as protection during recovery from anesthesia.

The limb is dressed with a compression bandage at the very least. In the case of pancarpal arthrodesis or of a severely comminuted carpal fracture it is advisable to either **apply a fiberglass cast or at least a solid splint** from the foot to the elbow. This facilitates recovery and helps prevent catastrophic breakdown during recovery. In a partial arthrodesis, a heavy compression bandage, possibly with the addition of a splint for the first few postoperative days, is indicated. Once the skin staples or sutures are removed, the limb needs only to be bandaged. It is imperative to maintain the horse in a box stall and not to allow it any additional exercise. After 3 weeks to a month careful hand walking may be initiated; however, especially with pancarpal arthrodeses, this should be carried out prudently. After bony fusion, which will take 3–4 months, bandages are no longer needed and, after an adaptation period, the animal may be placed in a small paddock. It is, however, not advisable to allow an animal with pancarpal arthrodesis access to a large pasture, since the very long resultant bony structure needs further protection.

Implant removal is not necessary unless an infection develops or there is persistent pain. Ideally, it should be performed in staggered fashion, at an interval of 3–4 months. After plate removal, stall rest is indicated for an additional 1 month to 6 weeks prior to resuming any type of work.

23.5.1 Complications

Postoperative infection heads the list of complications, leading in many cases to complete breakdown of the fixation. This is especially true if it occurs early in the postoperative period and is not immediately detected. Other complications include breakdown or partial breakdown of the fixation, leading to progressive instability and also in most cases to potential destruction of the animal. It is very important to note that once breakdown of the fixation and/or infection occurs, the animal should be humanely destroyed because lasting stability can no longer be attained.

23.6 Prognosis

It is generally accepted that partial carpal arthrodesis has a better prognosis than pancarpal arthrodesis. Such a long bone without an articulation encounters extreme bending moments, which can lead to fracture distal or proximal to the implants or even in the middle of the bone following healing and implant removal. In pancarpal arthrodesis a guarded prognosis has to be given, even for an animal to be usable as a breeding prospect or as a pet. In partial arthrodeses (especially in cases where only the distal row of carpal bones is fused to MC3) animals can often be ridden. Some cases treated in foals have gone on to athletic competition at maturity. If the proximal row of carpal bones is fused to the distal row and to MC3, the range of motion is markedly decreased, precluding use in athletic events. Nevertheless, careful riding, especially in a riding arena, may be possible as a form of controlled exercise. The prognosis for such a recovery is in general good, barring the occurrence of any of the previously noted complications. In the rare instance of fusion of the proximal row of carpal bones to the distal radius, there is a marked decrease in range of motion (60%) resulting in a poor prognosis for athletic soundness.

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24 Small tarsal joint arthrodesis

Björn von Salis, Jörg A. Auer,
Gustave E. Fackelman

24.1 Introduction

The indication for arthrodesis of the distal intertarsal and tarsometatarsal joints is osteoarthritis ("bone spavin") refractory to medical treatment [1–6]. The clinical diagnosis is made based upon: the history; observed pathology (**Fig. S24A**); a characteristic lameness; and the outcome of flexion tests and intra-articular anesthesia [7, 8] (**Fig. F24A**, **Fig. X24A**). Further anesthetic techniques (**Fig. F24B**) and radiographic scrutiny [9] may be necessary to fine-tune the differential diagnosis. If available, a scintigraphic examination represents an additional aid [10]. Mild cases may be managed by corrective shoeing, possibly in combination with intra-articular long-acting corticosteroids (e.g., methylprednisolone) [11].

Fig. S24A: The typical deformation of the medial aspect of the tarsus caused by "spavin" is apparent in this Thoroughbred used for dressage.

Perform arthrodesis of the small tarsal joints for osteoarthritis that has become refractory to medical treatment.

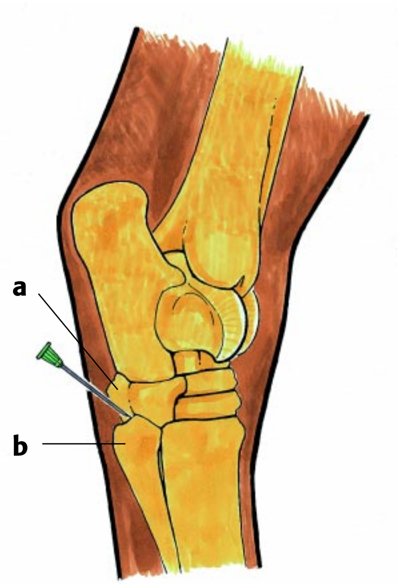

Fig. F24A: Injection site of the tarsometatarsal joint on the lateral aspect of the limb between the fourth tarsal bone (a) and MT4 (b).

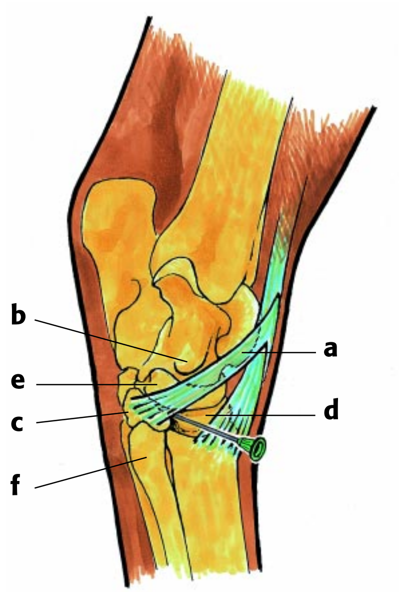

Fig. F24B: Injection site for the distal intertarsal joint from the medial side. The needle is inserted between the central tarsal bone (e), third tarsal bone (d), and fused first and second tarsal bone (c). The entrance to this space can often be felt with palpation, and is found at the distal border of the cunean tendon (a). Also illustrated are the distal tuberosity of the talus (b), and the proximal end of MT4 (f).

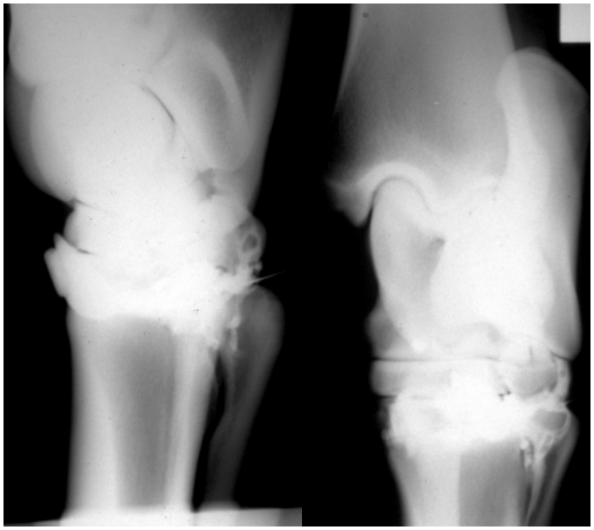

Fig. X24A: Infusion of a contrast medium shows typical distribution of a substance following injection of the tarsometatarsal joint.

24.2 Preoperative considerations

Disease is most common in the distal intertarsal joint, followed by the tarsometatarsal joint. [5, 6] Occasionally, the proximal intertarsal joint is also involved, making the problem more serious; **its communication with the tarsocrural joint may result in secondary synovitis of this structure**. The inflammatory cells involved release chondrolytic enzymes, such as neutral proteases, stromelysin, interleukin-1 and peroxide radicals. In the distal intertarsal and tarsometatarsal joint, such degradation can be beneficial, since natural ankylosis may ensue. However, in the highly mobile tarsocrural joint it is deleterious. Should the major hock joint be involved, joint lavage followed by intra-articular hyaluronic acid should be considered as adjunctive therapy.

Several techniques have been developed to stimulate osseous fusion of the small tarsal joints [2, 3, 5]. Once osseous fusion occurred, pain free motion and return of the animal to athletic events became possible. One of the techniques described involves extensive cartilage removal by drilling holes of a relatively large diameter (± 6.5 mm) in a fan-shaped pattern following the joint spaces [2]. This can cause articular instability, and often results in extreme postoperative pain. Animals treated in this fashion may remain recumbent for an extended period of time. Additionally, rather marked bony proliferation is the rule, which compromises a cosmetically acceptable result.

Another technique [3] involves drilling only two to three smaller (4.0 mm diameter) drill holes along each joint space. This process denudes adequate areas of opposing bony surfaces of their articular cartilage, while apparently inducing a negligible amount of instability. Eventually, the drill holes are filled by bone, enhancing fusion. This technique has been combined with internal fixation by means of a bone plate placed over the involved joint spaces. The surgical procedures without plate application enhance ankylosis of the joint, while those involving internal fixation represent true arthrodesis [1].

Another approach [12] involves implantation of stainless-steel baskets, filled with a bone graft and inserted in the affected joints. This operation seems, however, to cause greater early postoperative pain than many other methods. In this chapter, T-plate arthrodesis and application of a bone graft is described in detail.

Under certain conditions, the tarsocrural joint may become secondarily involved.

24.3 Surgical anatomy

The accessory tendon of the cranial tibial muscle ("cunean" tendon) provides a convenient, readily palpable landmark for the surgical approach. The proximal intertarsal joint space will be located just distal to the point at which the tendon crosses the midpoint of the hock, measured from cranial to caudal (Fig. F24B). This joint may be probed by the insertion of a 20 g hypodermic needle. With this as a point of reference, preoperative measurements may be applied to locate the other joint space(s).

Use the accessory tendon of the cranial tibial muscle as a landmark to locate the proximal intertarsal joint space.

24.4 Surgical procedure

Ensure access to the surgical site for intraoperative radiography.

Preserve the integrity of the saphenous vein.

The animal is placed under general anesthesia in lateral recumbency. **Surgical and intraoperative radiographic access to the dorsomedial aspect of the tarsus is secured**. Local exsanguination by means of an Esmarch bandage is preferred by some. If applied correctly, hemorrhage will be minimal during surgery. The surgical site is routinely prepared for aseptic surgery (**chapter 3**, Pre- and postoperative considerations). If autogenous bone grafting is anticipated, either the medial aspect of the proximal tibia or the tuber coxae should also be carefully prepared. A 10–15 cm straight or slightly curved skin incision is made at the dorsomedial aspect of the tarsal region. The incision starts at the level of the talus and extends distally to the proximal third of MT3 (**Fig. F24C**). It should comfortably span the joints to be fused. **The saphenous vein, which crosses the site diagonally, is isolated and protected from trauma**. It may be useful to undermine the vein, and place a Penrose drain around it to facilitate its manipulation. The cunean tendon is dissected, and approximately 5 cm of its length

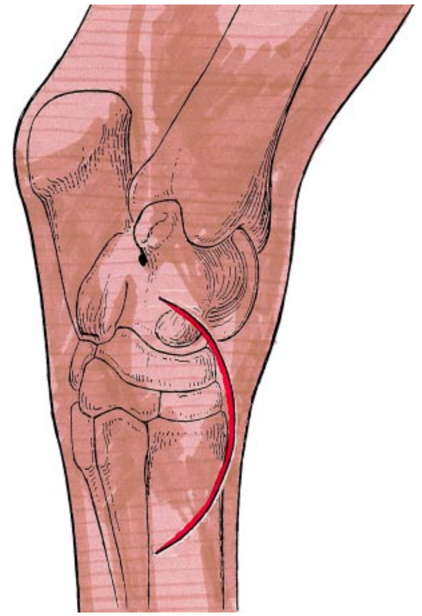

Fig. F24C: The skin incision is centered over the tarsometatarsal joint. It may be carried out either as a straight or slightly curved incision.

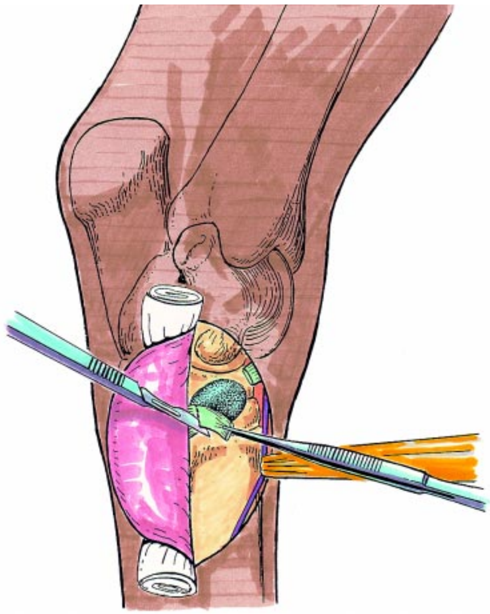

Fig. F24D: The skin flap is reflected over a gauze sponge to minimize trauma to the peripheral vasculature. The Penrose drain placed around the saphenous vein faciliates its gentle manipulation. The cunean tendon is transected and a 5 cm section is removed.

Fig. S24B: Periosteal new bone is at least partially removed with a chisel and mallet. The margins of joints may become visible, and contouring of the plate is simplified.

within the surgical field are removed (**Fig. F24D**). During preparation and resection, the cunean bursa is inevitably opened and partially destroyed. Any exuberant exostosis is at least partially removed with osteotome and mallet (**Fig. S24B**). Removing these periosteal proliferations facilitates identification of the involved joint spaces and flattens the area to be occupied by the plate. **Placement of two hypodermic needles or two 2 mm drill bits into the joint spaces (Fig. S24C), followed by a radiographic examination, helps verify correct anatomic orientation**. Accurate spatial relations are important, since tolerances are low. Two drill holes of 4 mm diameter are drilled along each joint surface (**Fig. F24E**). The drill holes in each joint are 2 cm apart and are drilled to a depth of 20–25 mm.

Place radiopaque markers in one or two of the joint spaces.

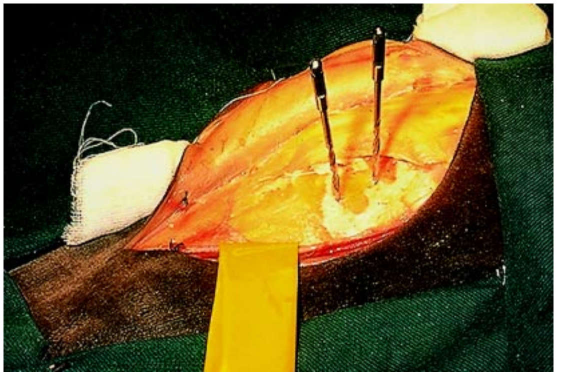

Fig. S24C: The distal intertarsal and tarsometatarsal joints are marked by 2 mm drill bits.

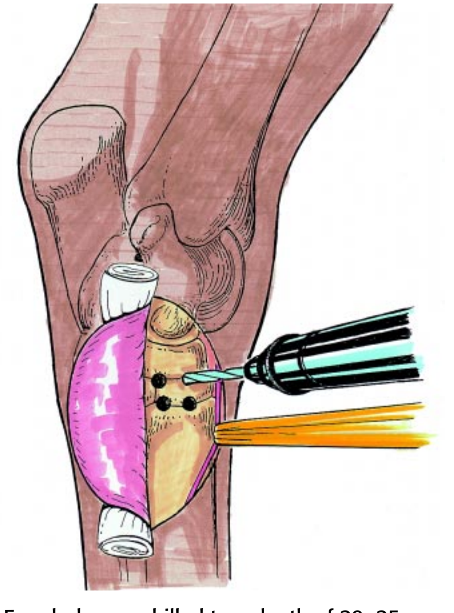

Fig. F24E: Four holes are drilled to a depth of 20–25 mm, carefully following the joint spaces and removing cartilage along the opposing surfaces.

Meanwhile, a second surgical team may harvest cancellous bone plugs of corresponding diameter from the proximal tibia or the tuber coxae (Fig. F24F). The bone plugs (Fig. S24D) may be harvested either with a trephine, or electric bone biopsy drill (Fig. F24G). Previously harvested and preserved homologous bone plugs [13] might also be used [14] (chapter 28, Allogeneic grafts and bone substitutes). The bone plugs are pressed snugly into the drill holes (Fig. F24H).

Subsequently, a T-plate is contoured to the surface of the bone in such a way that the proximal two screws through the horizontal bar of the plate can be placed in the central tarsal bone. Care is taken during screw placement to maintain centering in the bone (Fig. S24E). The

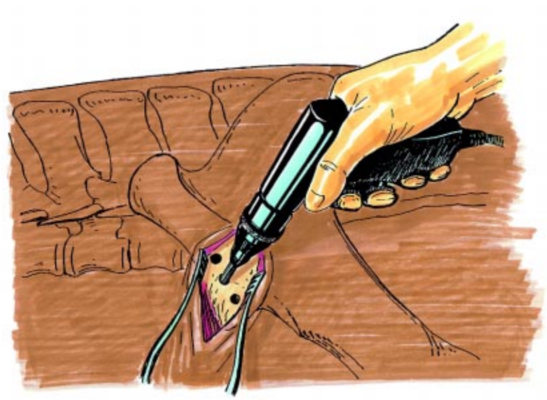

Fig. F24F: The tuber coxae is exposed through a small incision, and four corticocancellous bone plugs of 4 mm diameter are harvested.

Fig. F24G: After harvesting a bone plug, the hollow drill bit is disconnected and the graft tissue is extruded using the push rod.

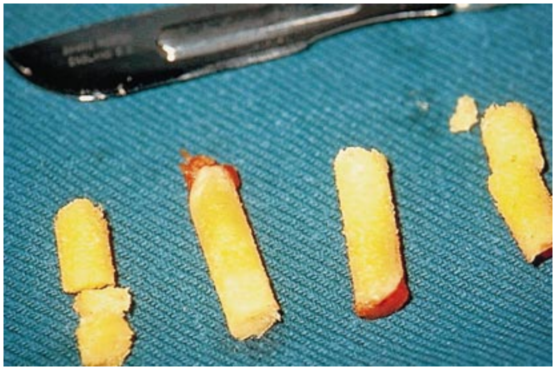

Fig. S24D: Bone plugs ready to be implanted are shown. One or two extra plugs may be harvested to allow for breakage during extraction from the hollow bit.

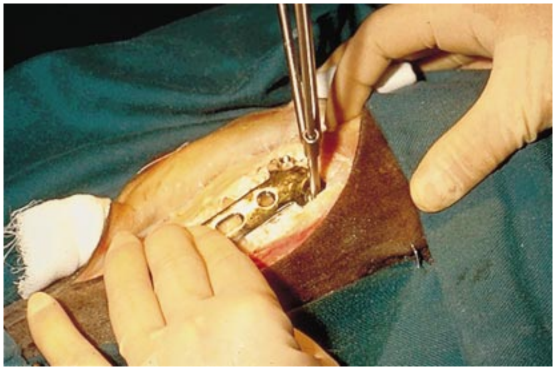

Fig. S24E: After contouring the plate, two screws are inserted in the central tarsal bone.

central tarsal bone is relatively thin but its usual dimensions will accept an approximately 30 mm long 4.5 or 5.5 mm cortex screw. The plate's location is selected so that it partially covers the bone plugs and in doing so prevents their displacement. The tension device may be fastened to MT3 and mild tension applied to the 3- to 5-hole plate prior to insertion of the next screws. This assures a correct final biomechanical constellation (chapter 2, General techniques and biomechanics). One screw is placed in the third tarsal bone; this is followed by the placement of two to three screws (depending upon the length of the plate) in the proximal aspect of MT3. The tension device is removed, all remaining screws inserted (Fig. F24I), and final tightening of all screws is conducted. It is advisable to take an intraoperative radiograph to assure correct placement of the implants (Fig. X24B).

If "dead space" is a concern, a suction drain is installed and exteriorized through a portal separate from the primary incision (Fig. F24J). The fascia and subcutaneous tissues are closed using a simple continuous suture pattern with a 3/0 or 2/0 monofilament, resorbable suture material. An intradermal suture followed by staples or sutures of an interrupted pattern are used to close the skin. An elastic bandage protects the surgery site and provides counterpressure to prevent edema in the more distal portion of the limb. After recovery from anesthesia, negative pressure is applied to the suction drain, usually by means of a "blocked" syringe taped to the bandage (Fig. F24K).

The central tarsal bone is relatively thin, requiring accurate centering of the screws placed in it.

Place a suction drain if considerable "dead space" has been created.

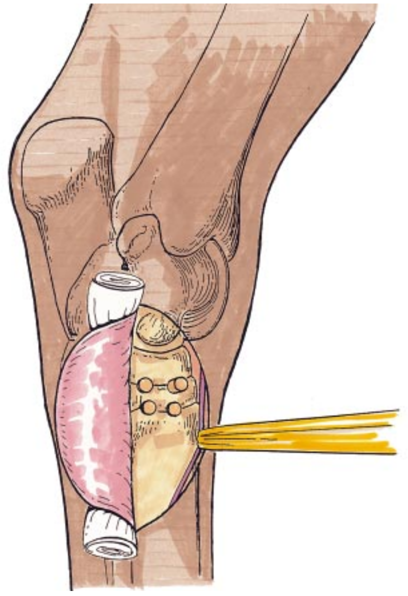

Fig. F24H: The bone plugs are firmly pressed into the four drill holes. Excess graft tissue is removed with a chisel.

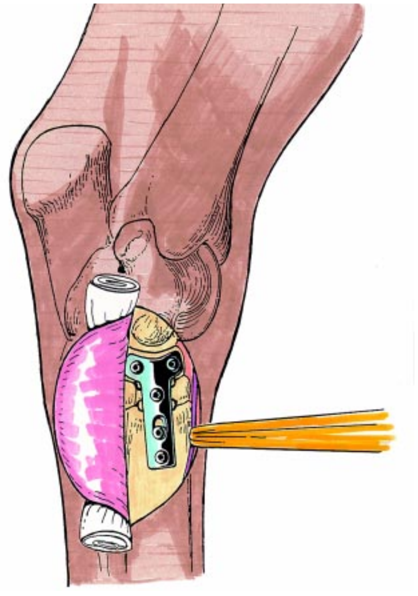

Fig. F24I: By inserting the third screw at the distal margin of the oblong plate hole, compression is also applied to the tarsometatarsal joint.

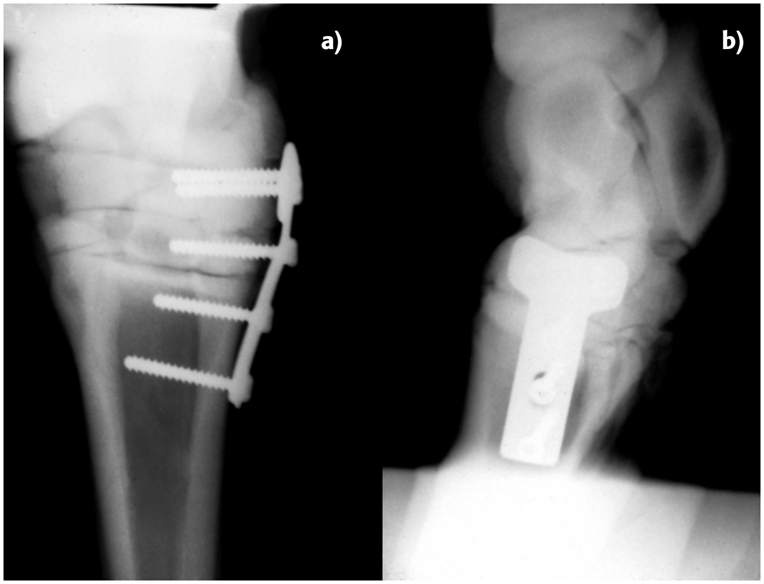

Fig. X24B: Dorsoplantar (a) and lateromedial (b) projections show the immediate postoperative appearance of the joint spaces and their relationships to the implants.

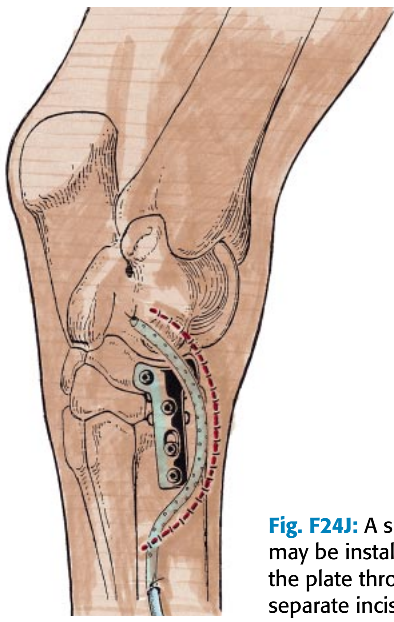

Fig. F24J: A suction drain may be installed next to the plate through a separate incision.

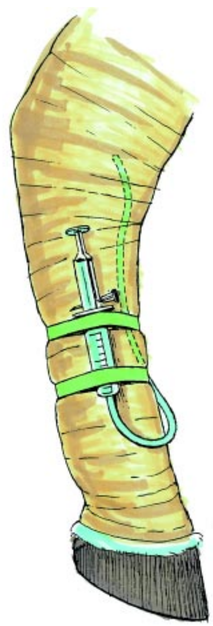

Fig. F24K: A full limb bandage is applied and a 20–60 ml syringe is connected to the drain. The syringe is "blocked" by a stout needle placed crosswise through the plunger.

24.5 Postoperative treatment

Perioperative antibiotic therapy is advocated for this procedure, since metal implants are used, a bone graft is applied, and articular surgery is involved. Systemic antibiotics are applied initially 30 minutes prior to induction and continued up to 5 days postoperatively. The amount of fluid drawn through the drain should be closely monitored, and when a sharp drop in the quantity is recognized the drain is removed. This should be done at the latest 2 days postoperatively. During the first 2 weeks, the animal should be kept in a box stall and the bandage checked daily. Bandage changes should be performed at 2–3 day intervals until the skin sutures or the staples are removed. Thereafter the animal may be hand walked daily until swelling has subsided and wound healing has progressed. After these initial short daily exercise periods, the duration of exercise can slowly be increased and, if no complications arise, the animal may be hand walked within 2 months up to 1.5 hours (3 times for half an hour) per day. After this period, if lameness is no longer visible at the walk, the animal can be ridden at a walk for another 3 month period. Should, however, lameness recur, the exercise program has to be reduced. A slow rehabilitation training program may then be conducted and the animal returned to full work within another 3–6 months.

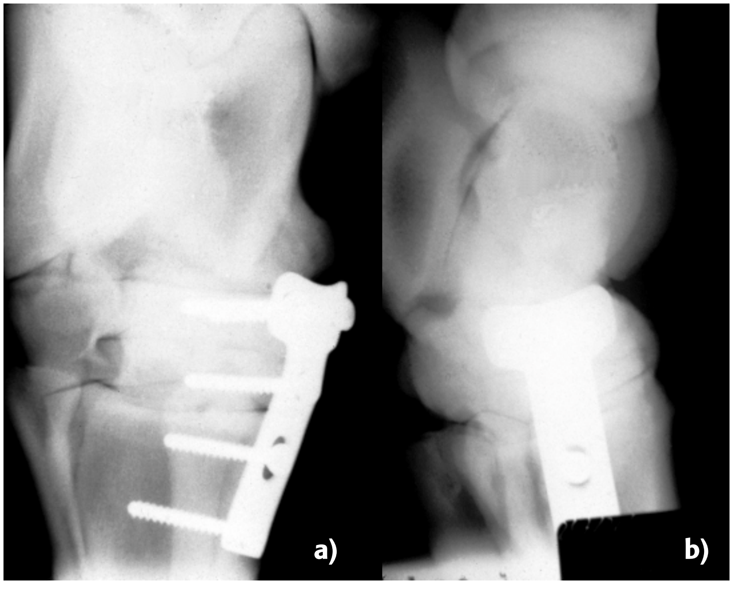

Fig. X24C: Dorsoplantar (a) and lateromedial (b) radiographic projections show healing of the arthrodesis seen in **Fig. X24B** at 3 months postoperatively. Obliteration of the joint spaces is progressing without an excessive amount of periosteal proliferation.

24.6 Results

Generally a good prognosis can be given for animals with bone spavin of the distal intertarsal- and tarsometatarsal joints for solid fusion (**Fig. X24C**), a good cosmetic appearance, and resumption of an athletic career. However, if the proximal intertarsal joint is also involved, a much more guarded prognosis has to be given (see above). **The convalescent period and a slow retraining program are of paramount importance in the restitution of soundness.** During this period of time repeated radiographic re-evaluations demonstrate the osseous fusion of the joint (**Fig. X24D**), which can also be confirmed histologically should such an opportunity present itself (**Fig. S24F**).

Early postoperative mobilization and gradual retraining are important for the ultimate outcome.

Implant removal is not necessary if the animal is pain-free and shows no adverse local reactions. Pain and low grade lameness not directly related to surgery have been observed during cold spells and may constitute indications for implant removal.

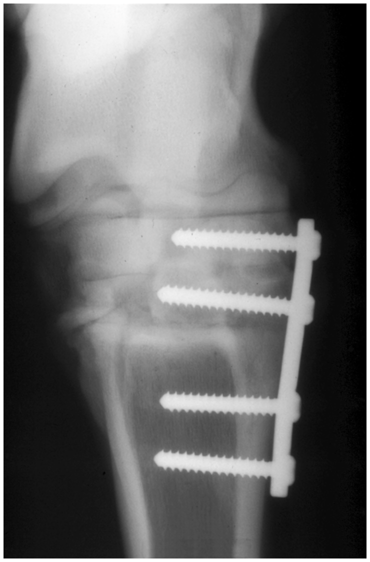

Fig. X24D: 3-month postoperative radiograph of a tarsal arthrodesis with a 4-hole narrow dynamic compression plate (DCP) showing good fusion of the involved joints with a satisfactory result.

24.7 Complications

A small number of complications have been recognized. If aseptic technique has been broken, infection may develop. This can also occur if the animal does not tolerate a high bandage and kicks continuously. Since the soft tissue covering is rather sparse in the area, incisional dehiscence will rapidly lead to infection of the operative site. Good hemostasis during surgery and postoperative drainage enhance an infection-free postoperative period. Screw fracture can occur. This can possibly be prevented by the use of

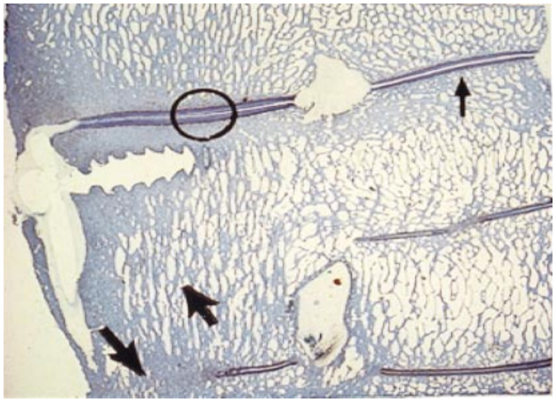

Fig. S24F: A longitudinal section through a fused tarsus 3 years postoperatively shows bony bridging of the distal intertarsal and tarsometatarsal joints (arrows), while the untreated proximal intertarsal joint (circle) is maintained.

5.5 mm screws instead of 4.5 mm screws if the size of the horse permits the use of these larger implants. One case of plate failure was observed when a 3.5 mm plate was used.

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25 Carpal and tarsal deviations

Jörg A. Auer & Gustave E. Fackelman

25.1 Introduction

Axial deviations are common in foals, and their aftermath may be diagnosed in adults. No breed or sex predilection has been established [1–4]. A majority of foals are born with a degree of axial deviation of the limbs, predominantly in the carpi or tarsi. This posture may be accentuated because the animals are so narrow chested and because their elbows are drawn by the subscapular musculature toward the thoracic wall. **With increasing age and development the chest widens and the upper forelimbs spread, thus the previous deformations are partially or completely obliterated** [5]. This is especially notable in foals with upright, outwardly rotated limbs as neonates, and explains subsequent spontaneous correction (Fig. S25A). Compensatory asymmetric proliferation at the growth plates may also be operative in effecting correction of valgus or varus deformities in the weeks following birth. Other deviations may develop in the postnatal period, either as a result of asymmetric growth or local overloading. Physeal fractures often lead to the development of deviations and ultimately to painful articular problems due to abnormal loading of joint surfaces.

Some foals are born prematurely, physiologically or chronologically after an abbreviated gestation period. These animals suffer from incomplete ossification especially of the cuboidal carpal and tarsal bones (plus the true epiphyses of the distal radius and tibia, which develop in a manner analogous to the cuboidal bones). **Both early detection and prompt treatment are important if permanent damage is to be averted** (Fig. S25B). Since treatment is by means of external coaptation, these problems will not be part of the succeeding discussion, and the reader is referred to other sources [2–4].

Treat incomplete ossification of the cuboidal bones promptly.

Fig. S25A: Frontal view of a 4-month-old donkey foal with an apparent valgus deformity of the forelimbs (left). The animal is narrow chested and the entire limbs are rotated, allowing the toes to point outward. Outward rotation of the limbs at the level of the elbows corrects the angular limb deformity (right).

Deformations may disappear as the animal's shape assumes more adult proportions.

25.2 History and diagnosis

It is important to closely evaluate foals at an early age so that a deviation may be recognized as soon as it develops. If a problem such as incomplete ossification is not treated within 1 week of its occurrence, permanent damage may occur [2–4]. Time is not as critical in developmental angular limb deformities, although close evaluation is indicated here as well [5]. The owners of a foal with an angular limb deformity problem often suppose that the animal suffers from a deviation at a joint. This may prove true, but the lesion is located much more frequently in the bones above and below the joint. **To properly diagnose an angular limb deformity of the carpal region, the evaluator should position him/herself directly in front of the foal.** If the animal's forelimbs are rotated outward, the observer should move until he/she is looking at right angles to the face of the carpus (Fig. F25A). An imaginary frontal plane is passed from proximal to distal through the carpus. Frontally bisecting planes are similarly imagined for the metacarpophalangeal joint and the hoof. The orientation of these planes and their relationships to each other are then compared. Ideally, all three should be parallel. In such an animal exhibiting a pure rotational deviation of the entire limb, this deviation will most likely derotate spontaneously during development and not require any surgery [5, 7]. Medial or lateral deviation of the two distal planes relative to the carpal plane is cause for major concern (Fig. F25B). Close scrutiny of appropriate radiographs is essential for a correct diagnosis. **A disproportionate growth in the phalangeal region may be demonstrated to be the root of the cause. The rear limb presents an analogous situation.**

The evaluator's position is critical to a correct evaluation of angular limb deformities.

Radiographically evaluate all joints from the level of deviation distad.

Fig. S25B: Frontal view of a 1-month-old Appaloosa foal with a marked carpal valgus deformity in the right carpal region resulting in an outward rotation of the right forelimb. Additionally, a carpal varus deformity is diagnosed in the left limb with the associated inward rotation of that limb.

Once the seat of the abnormal angulation is located, further radiographs are in order. Long narrow films are preferred, visualizing as much as possible of the bones' length proximal and distal to the articulation (Fig. X25A). In selected cases, dorsopalmar views of the phalangeal and carpal/tarsal regions are indicated. If these are taken from the same location, they can be assembled into a composite picture of the entire limb, allowing confirmation of the exact nature of the deformity. For additional information on the subject of diagnosis, the reader is referred to the current literature [3–6].

When the deviation has been accurately diagnosed and it is decided to perform surgery, various techniques are available. These include growth acceleration, growth retardation and, ultimately, corrective osteotomy. Corrective osteotomies are carried out to treat deviations after the growth plate has closed and no longer offer the possibility of modification.

The surgical techniques will be described according to the anatomic location.

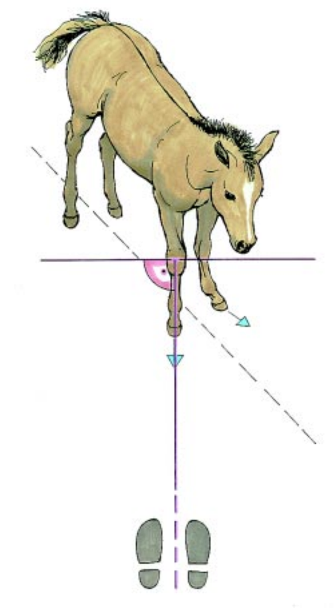


Fig. F25A: Artist's drawing of a foal with an outward rotation of the forelimbs. The carpal region and the distal limb including the toes point in the same direction—outward. This foal may correct itself when its chest widens and does not need surgery immediately.

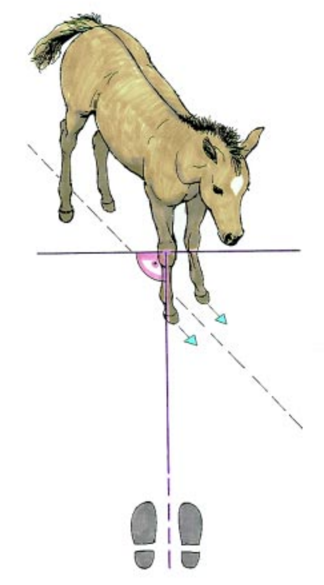


Fig. F25B: Similar drawing as in **Fig. F25A**. However, the toes point straight forward, whereas the carpi point dorsolaterally. With widening of the chest during the ensuing months the limbs will rotate inwardly, resulting in a pigeon-toed conformation of the forelimbs. Therefore, immediate surgery is of great importance.

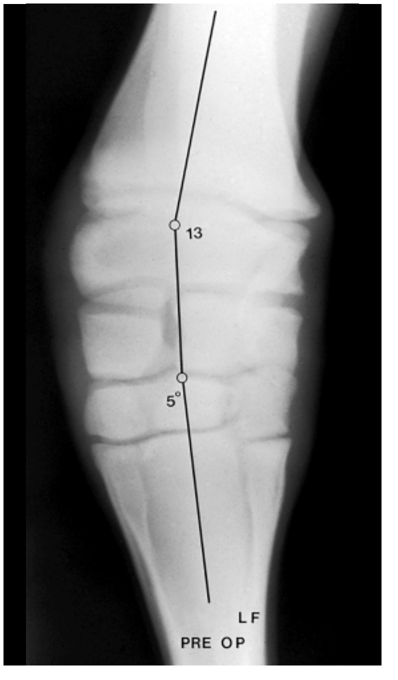


Fig. X25A: Dorsopalmar radiograph of the carpal region of a foal with a valgus deformity. By combining the long axes of the adjacent long bones with lines drawn across the various joints and the distal radial growth plate, an exact, differentiated diagnosis of the deformity can be made. In this case a 13° deformity is located within the radius and a 5° deformity within the carpal bones.

25.3 Surgical treatment—Radius

25.3.1 Description

The most common axial deviation affects the carpus.

Determine as soon as possible whether a carpal deformity involves the joint itself.

Most commonly, acceleration is performed laterally, retardation medially.

The majority of axial deviations are found in the carpus. Disproportionate growth at the distal radius may affect the distal metaphysis, the distal epiphysis, or both. **Determination of the exact location of the deformity within the bone itself is not as important as deciding whether or not it resides in the carpal joint.** For instance, a 1-month-old foal born prematurely might be presented with a marked angular limb deformity stemming from the carpal region. The radiographic evaluation would most likely reveal that the deviation is located in the carpus. Premature foals usually exhibit a certain degree of incomplete ossification in the cuboidal bones of the carpus and tarsus. Under postnatal weight bearing conditions the shape of these bones may be altered, leading to an axial deviation [2–4]. These problems are only marginally amenable to treatment [8, 9]. It is possible to straighten the axis of the limb, but the joint surfaces involved may in the end no longer be perpendicular to the long axis of the bone. The results are uneven loading and shear forces, accentuated during rotational movement, and degenerative joint disease [3, 4].

The corrective techniques described below are intended for use in valgus deformities in foals with open growth plates. Should a varus deformity be encountered, the same procedures would suffice, but they would be carried out on the opposite side of the bone. Manipulations of the active growth plate may be conveniently classified as either acceleration or retardation techniques.

25.3.2 Surgical anatomy

The dorsomedial aspect of the radius is only covered by skin and subcutaneous tissues. On the lateral aspect, however, the common digital extensor tendon (dorsolaterally) and the lateral digital extensor tendon (laterally) span that region. Beneath the lateral digital extensor tendon, the rudimentary ulna, which is in most cases fibrous in nature, can be palpated. This structure inserts at the ulnar styloid process, which in young foals represents a separate center of ossification and unites with the articular portion of the distal radius within the first 5 months of life. The level of the physis is easily identified. It is located at the broadest aspect of the distal radius where a prominent medial bulge is easily appreciated. **The growth acceleration procedures are conducted at the lateral aspect of the distal radius, whereas growth retardation is applied to the medial aspect.** To generalize, retardation is carried out on the convex side of a deformity while acceleration is practiced on the concave aspect.

Growth acceleration

The anatomic landmarks include the common digital extensor tendon dorsally, the lateral digital extensor tendon and the rudimentary ulna palmarly, and the level of the distal radial physis distally (Fig. F25C). The triangular space outlined by the above structures allows easy access to the bone.

Growth retardation

The antebrachiocarpal joint as well as the physis are easily identified by palpation. Other than the collateral ligament, which originates at the medial aspect of the epiphysis and courses distally, no major soft tissue structures are encountered.

25.3.3 Surgical procedure

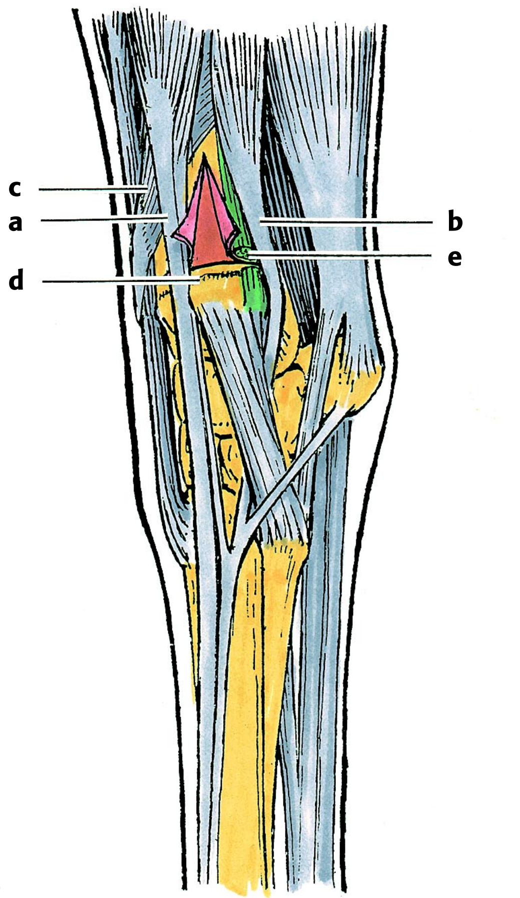


Fig. F25C: Drawing of the surgical landmarks for the approach to the lateral aspect of the distal radius. The skin incision is made between the common digital extensor tendon (a) and the lateral digital extensor tendon (b). Surgery is performed just proximal to the distal radial physis (d). The periosteum including the rudimentary ulna (e) are transected and the two flaps elevated, exposing the underlying bone. If the surgery is performed further proximally, the oblique muscle (c) has to be dealt with.

Growth acceleration

A 5–6 cm straight skin incision is made that ends about 1 cm proximal to the physeal level. Sharp dissection is continued to the level of the periosteum. Hemostasis is maintained by ligature or electrocoagulation. A curved hemostatic forceps is advanced cranially, perpendicular to the long axis of the bone between the subcutaneous tissues and the periosteum. It is important to stay close to the latter to prevent interposition of vascular subcutaneous tissues. The common digital extensor tendon is undermined and palpated between the skin and the hemostatic forceps. **The instrument is advanced to a level just beyond the common digital extensor tendon and the handles are gently lifted away from the bone.** This allows introduction of the curved #12 Bard Parker scalpel blade between the slightly spread jaws of the hemostatic forceps. Once the scalpel blade is placed in the correct location, the hemostatic forceps is withdrawn. Minimal pressure is applied to the scalpel as it is drawn toward the skin incision transecting the periosteum in a horizontal direction. The procedure is then repeated on the caudal aspect of the distal radius. This time the forceps passes caudally between the lateral digital extensor tendon and the rudimentary fibrous ulna. When the instrument has passed the rudimentary ulna, its position is shifted to a more frontal plane and the fascia is penetrated with a sharp stabbing motion. The forceps is subsequently placed at the caudal aspect of the radius, the jaws slightly spread and the scalpel blade introduced. The forceps is withdrawn and the periosteum incised in the same manner as previously described for the cranial aspect (**Fig. S25C**).

Carefully elevate the common digital extensor tendon prior to periosteal transection.

Caudally the periosteal transection should include the rudimentary distal ulna.

Care is taken to also transect the rudimentary ulna. If the rudimentary ulna is ossified, a portion about 1 cm in length is removed with the help of a rongeur. The two horizontal incisions are connected and, using the same scalpel blade, a vertical incision is created resulting in an inverted "T". The periosteal elevator is inserted at a 45° angle at the intersection of the vertical and the horizontal incisions, and the periosteum is lifted from the underlying bone (**Fig. S25D**). When the periosteum is replaced, a gap of about 5 mm typically forms (**Fig. S25E**).

The subcutaneous tissues are closed with a simple continuous pattern using a 2/0 or 3/0 monofilament resorbable material (e.g., PDS), and an intradermal suture is placed using the same pattern and suture material (**Fig. S25F**) [**10**, **11**].

Growth retardation (Video 31020)

The skin incision curves toward the caudal aspect of the carpus from the level of the antebrachiocarpal joint (**Fig. S25G**) to a point about 7 cm proximally. The curve allows for better coverage of the implants at closure. The subcutaneous tissues are incised straight proximodistal at the bone's most medial aspect. A straight longitudinal incision parallel to the fibers of the collateral ligament is carried down to the bone of the epiphysis. Bleeding vessels are ligated or electrocoagulated.

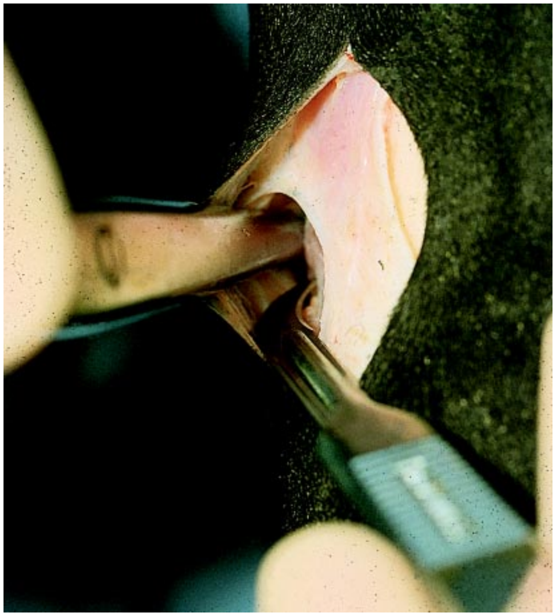


Fig. S25C: A pair of forceps or scissors are positioned between the subcutaneous tissues and the periosteum in a caudal direction and abducted, allowing the #12 scalpel blade to be placed caudal to the radius and pulled toward the skin incision. In doing so, the caudal horizontal periosteal incision is performed.

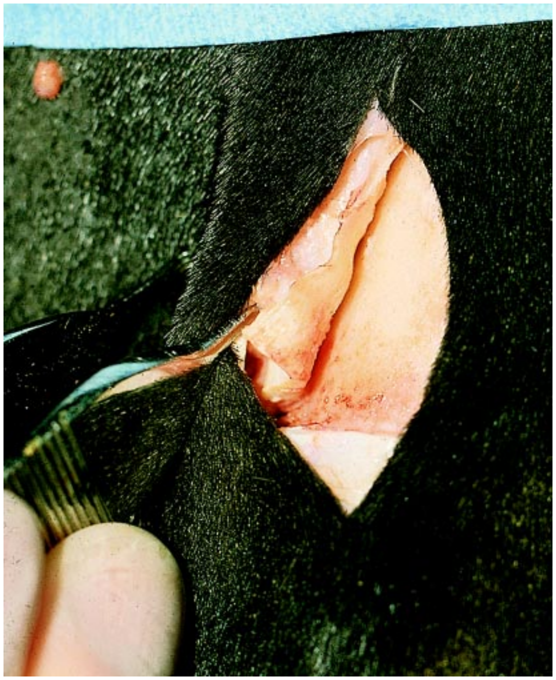
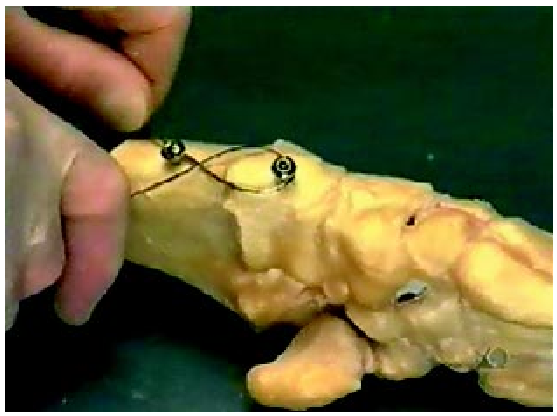


Fig. S25D: The elevated caudal periosteal flap is shown demonstrating its considerable thickness.

Fig. S25E: Both periosteal flaps are elevated and placed back on the underlying bone. Note the gap which developed between the edges of the flaps and the undisturbed periosteum.

Fig. S25F: The skin incision is closed with an absorbable suture material (2/0) in a simple continuous intradermal pattern.



Video 31020: Growth retardation.

A 3.2 mm hole is drilled in the epiphysis perpendicular to the long axis of the bone halfway between the physis and the antebrachiocarpal joint (**Fig. S25H**). To minimize trauma the drill guide is passed between the edges of the incision in the collateral ligament down to the bone prior to drilling. The hole is taken to a depth of 30–40 mm and subsequently tapped. Following

Fig. S25G: A slightly curved skin incision is made centered over the medial distal radial physis to prevent placement of the implants directly under the incision.

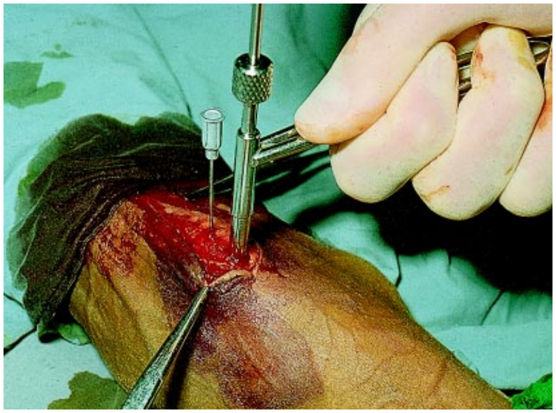


Fig. S25H: The thread hole for the distal screw is drilled parallel to the antebrachiocarpal joint surface in the epiphysis. Note that the level of the physis is marked with a hypodermic needle. (This is done here only for demonstration purposes.)

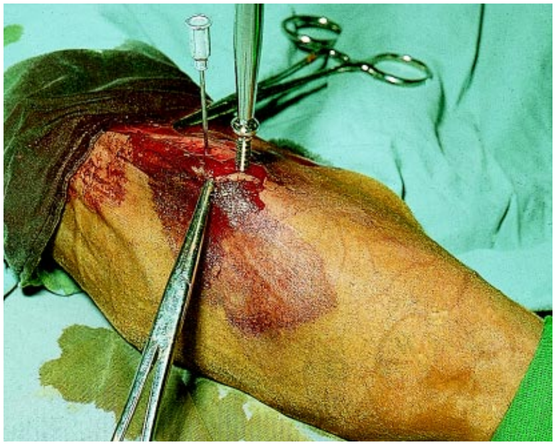


Fig. S25I: After tapping the hole the screw of pre-determined length (about 30 mm) is inserted into the epiphysis but not tightened.

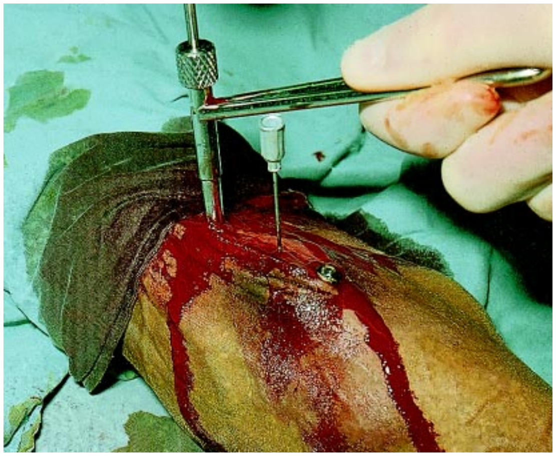
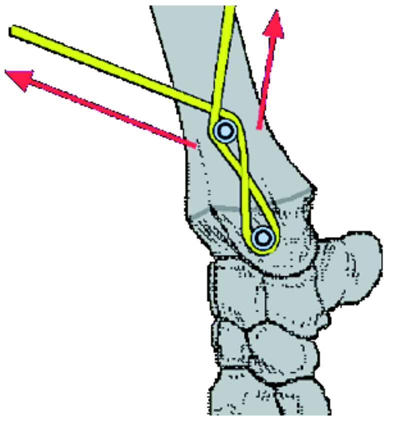


Fig. S25J: The thread hole for the proximal screw is prepared about 3 cm proximal to the physis.

irrigation, a 30 mm x 4.5 mm cortex screw is inserted (**Fig. S25I**). **The screw is not tightened but allowed to protrude above the level of the ligament.** About 3 cm proximal to the physis, at the medial-most aspect of the bone, a second 3.2 mm hole is drilled (**Fig. S25J**) and tapped, using standard technique. After introduction of a 30 mm x 4.5 mm cortex screw, a 12–15 cm length of 1.2 mm cerclage wire is applied in figure-8 fashion around the screw heads (**Video CERC_B**). **Under steady tension, the two ends are twisted evenly about each other above the proximal screw**. A wire tightener or a flat pair of pliers may be used. The situation wherein one strand is twisted around a straight standing end leads to loosening or breakage and must be avoided. In addition to steady tension, even twisting is achieved by assuring that a 90° angle is maintained between the ends during the entire process (**Fig. F25D**). Once the wire is firmly twisted over a length of 7–8 mm, the ends are cut. **The screws are then completely tightened, which introduces additional tension in the wire, resulting in compression of the growth plate** (**Fig. X25B**). The wire ends are bent against the bone and the incision is closed in the manner described for the growth acceleration procedure (**Fig. S25K**) [**3**, **4**, **12**, **13**].

Alternatively, 3.5 mm screws and an approximately 5 cm long x 2.7 mm cuttable plate may be used instead of the 4.5 mm screws and cerclage wire. The same soft tissue approach is employed. A 2.5 mm hole is drilled and tapped into the epiphysis to a depth of 30 mm. The 3.5 mm screw of approximately 30 mm in length is placed through the distal-most hole in the plate and minimally tightened. After applying tension and displacing it slightly proximally, finger pressure is applied to the



Video CERC_B: Cerclage wiring.

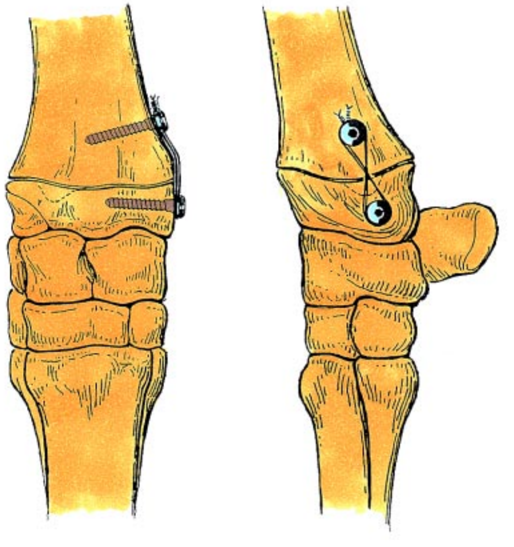


Fig F25D: Drawing of the implant configuration for growth retardation. Note that the figure-8 wire is twisted above the proximal screw which reduces the strain on the wire and decreases the risk of wire breakage.

Do not tighten the screw, but allow it to protrude above the surface of the ligament.

Keep tension on the wire as it is twisted.

Tightening the screws increases the tension in the wire loop due to screw head geometry.

A cuttable plate may be used instead of the figure-8 wire to bridge the physis.

surface of the plate to adapt its contours to those of the bone. About 1 mm proximal to the most proximal hole in the plate the second 2.5 mm hole is prepared. The hole is tapped and a 30 mm, 3.5 mm cortex screw is introduced through the plate into the radius. Both screws are tightened placing the plate under strong tension, and the incision is closed as previously described (**Fig. X25C**) [3, 4].

Another technique involves the application of titanium staples centered over the physis (**Fig. X25D**). This procedure is only rarely applied today although it was once quite common. Difficulty in removing the implants, especially in comparison with the techniques described above, have led to its almost complete abandonment. It will, therefore, not be described in detail. For additional information the reader is referred to the current literature [3, 4].

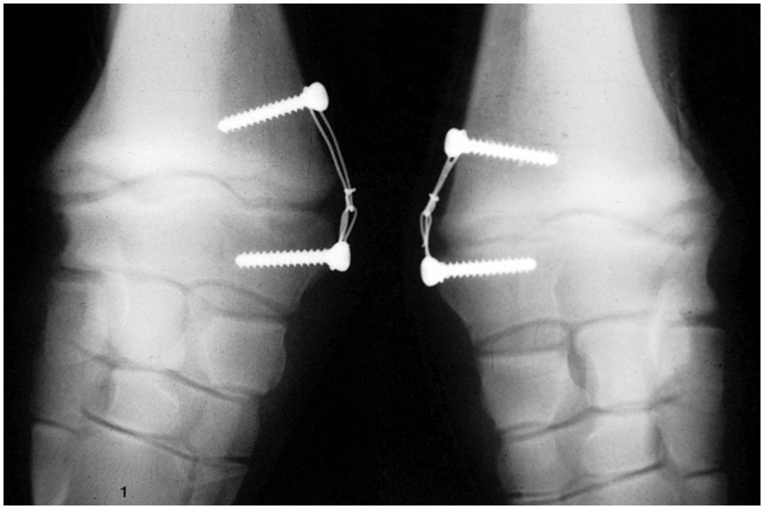


Fig. X25B: Immediate postoperative radigraph showing the implants of a bilateral growth retardation in place. Note that the wire was tightened with the "hook in eye" technique.

Fig. S25K: The wire is tightened and the screws fully inserted. Next, the subcutaneous tissues and the skin will be closed using routine technique.

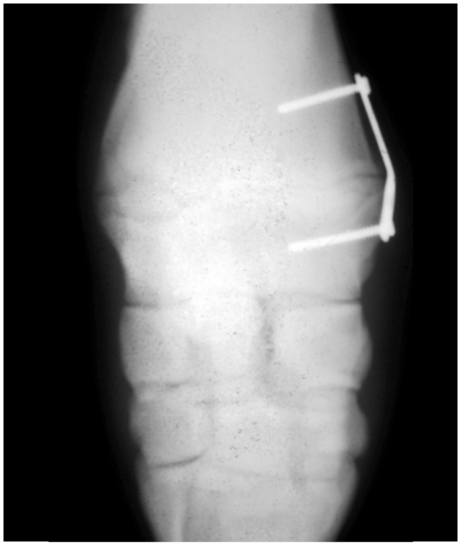


Fig. X25C: Dorsopalmar radiograph of a carpal region with a 2.7 mm plate bridging the medial distal radial physis. The plate is connected to the bone by two 3.5 mm cortex screws.

Fig. X25D: Dorsopalmar radiograph of a carpal region with a titanium staple bridging the medial distal radial physis.

25.3.4 Postoperative treatment

Following a growth retardation or growth acceleration procedure the carpal regions are lightly bandaged (**Fig. S25L**). It is not necessary to apply a full limb bandage. **In most cases the animal can be released from the clinic the same day**. The bandage should stay in place for 3–4 days and then be replaced by a similar one. After 7–10 days any skin sutures should be removed. No bandages are needed after 10 days. It is important to maintain the animal in a box stall for the first month postoperatively and to reduce postoperative exercise and associated trauma to the vulnerable articular cartilage. The course of straightening the limb should be evaluated carefully (**Fig. S25M**, **Fig. X25E**). This is especially important following growth retardation (**Fig. S25N**, **Fig. X25F**). Straightening may take 1–3 months, depending upon the age and the severity of the deformity at surgery. Only when correction is complete may the animal enjoy free exercise. No additional surgery is needed following growth acceleration. However, timely removal of implants is of paramount importance following growth retardation. **This can be conducted through stab incisions located directly over the screw heads**. The proximal screw head is always readily palpable and the first incision is placed over it (**Fig. S25O**) enabling its removal (**Fig. S25P**). The distance between the screw heads is measured on preoperative radiographs (**Fig. S25Q**) and the second (distal) incision is made accordingly (**Fig. S25R**). At the time of removal the distal screw is almost always obscured by the collateral ligament and surrounding soft tissue. **It may be helpful to probe the area, following measurement, with a hypodermic needle for verification of accuracy**. When the screw head is identified

> These surgeries are usually performed on an outpatient basis.

> Screws and wires are removed through stab incisions.

> Probe with a sterile needle to identify screw heads prior to making stab incisions.

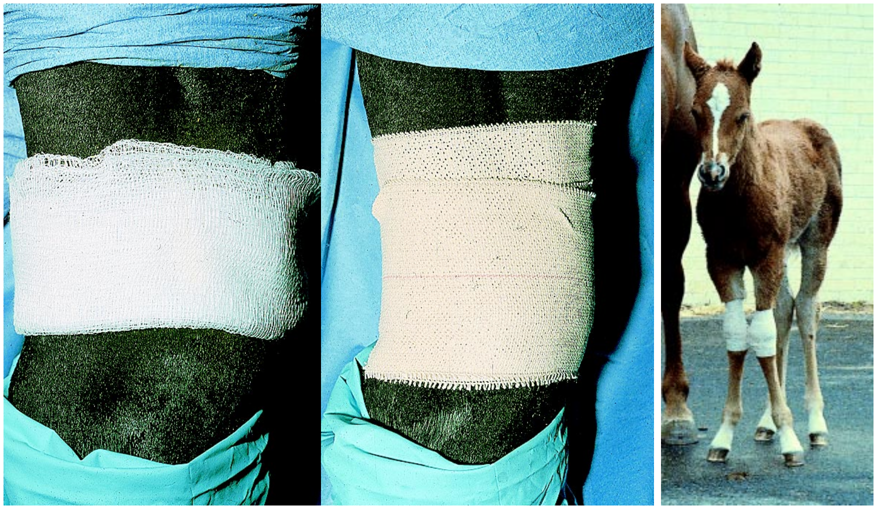


Fig. S25L: The incision is covered with a folded sponge (left) taped in place with an elastic adhesive bandage (middle). Immediate postoperative pictures of a foal.

Fig. S25M: Frontal view of a 2-months-old foal before bilateral growth acceleration at the lateral aspect of the distal radius (left) and 2 months later (right). The limbs have corrected to a normal axis.

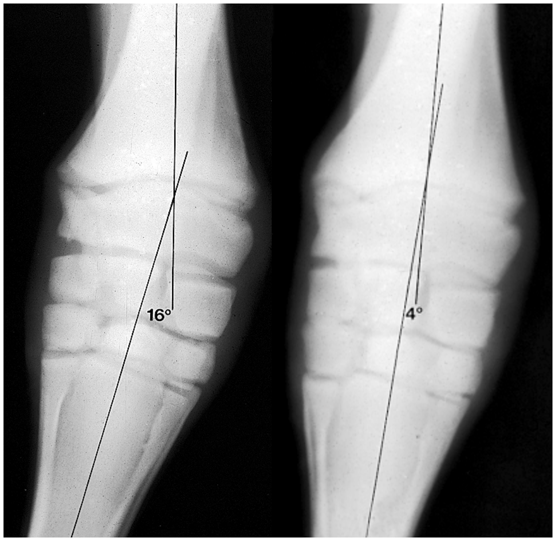


Fig. X25E: Dorsopalmar radiographs of the foal in **Fig. S25M**. Left: preoperative radiograph showing a 16° deviation. Right: 2 months follow-up radiograph showing correction to a 4° deviation which is within normal limits.

Fig. S25N: Frontal view of the same foal in Fig. X25D 11 weeks postoperatively. The axes of the limbs are corrected.

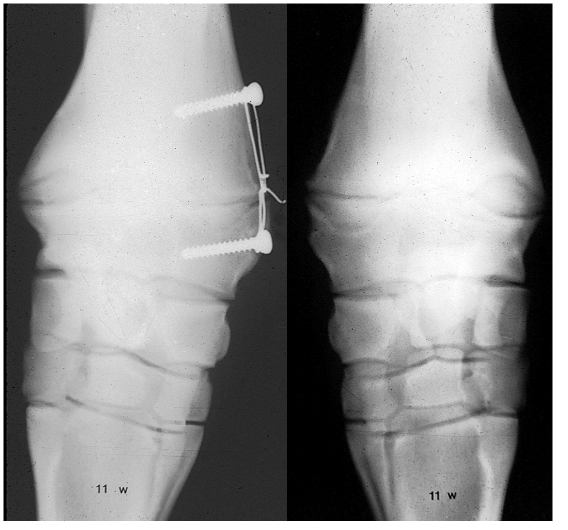


Fig. X25F: Dorsopalmar radiographs of the carpal regions of the foal in Fig. S25N. The implants in the right limb were removed 4 weeks earlier. At that time the right limb was straight but the left limb was still markedly deviated. The implants in the left limb are still in place and can now be removed. Note the lifted-up wire end protruding into the soft tissues causing irritation. The tension on the wires exerted by the growth plate caused this elevation of the previously folded-down wire end. It is possible that additional growth would cause the wire end to slip out of the "eye" resulting in complete loss of compression of the growth plate, rendering the implants useless.

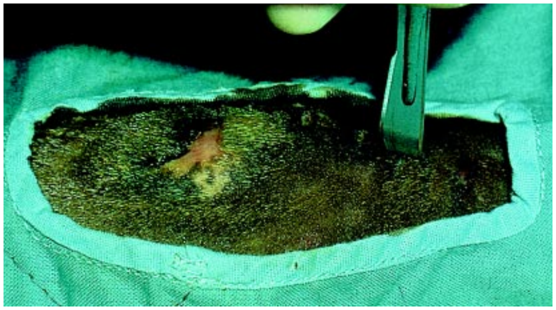


Fig. S25O: The proximal screw head is palpated and a stab incision is made directly over the screw head.

Fig. S25P: With the hexagonal-tipped screwdriver, the proximal screw is removed.

Fig. S25R: At the predetermined distance a second stab incision is made allowing access to the distal screw head which is buried deeper in the tissues.

and sufficiently cleared, the hexagonal tipped screwdriver is inserted and the screw is removed (**Fig. S25S**). Using a curved hemostatic forceps introduced into the proximal incision, the cerclage wire (**Fig. S25T**) or the cuttable plate is identified and withdrawn. This may require a quick forceful motion to free the implant from the surrounding tissues. One or two simple interrupted sutures are placed uniting the skin edges (**Fig. S25U**). The limb is bandaged and after 7–10 days the animal may be allowed free access to pasture.

Fig. S25Q: The distance between the proximal and distal screw heads is determined on an immediate preoperative radiograph.

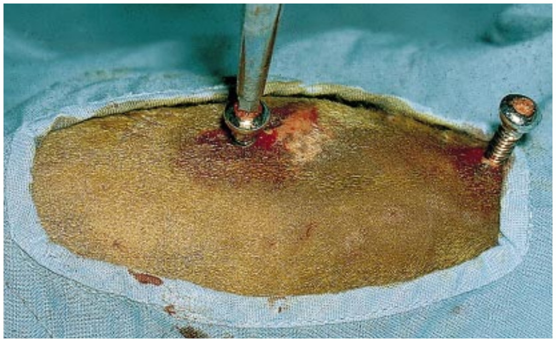


Fig. S25S: The distal screw is removed using identical technique.

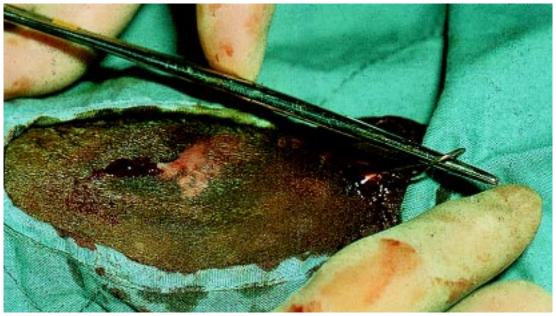


Fig. S25T: With the help of a curved hemostatic forceps the figure-8 wire is removed through the proximal incision.

Fig. S25U: The two stab incisions are closed with simple interrupted sutures.

25.3.5 Complications

Growth acceleration

No major complications have been encountered. Minor hematomas can be treated using pressure bandages. Partly because no implants are utilized, postoperative infection is very rare. Should dehiscence of the skin incision occur, second intention healing progresses with no ill effects. New bone formation may become radiographically apparent during the postoperative period, but this will disappear commensurate with the normal remodeling processes related to growth [1].

Growth retardation

Strict asepsis should be applied and perioperative prophylactic antibiotics administered (**chapter 3**, Pre- and postoperative considerations). Postoperative infection is a more significant problem in growth retardation and can lead to a septic physitis. **This can be very serious, resulting in permanent damage to the growth plate and corresponding deformity**. It is important that the implants are removed at the correct time to prevent overcorrection. If marked, a second growth retardation procedure performed at the lateral aspect of the limb may be necessary. If both forelimbs were treated by growth retardation, staggered implant removal may be indicated, since bilateral correction may not be exactly contemporaneous. If implant removal is delayed until the second limb is straight, overcorrection may already have occurred in the first limb.

Avoid infection in this sensitive area.

Special technical problems may ensue related to the application of the cerclage wire. If the "hook-in-eye" technique (**Fig. X25F**) is used, the end of the wire may be pulled up as tension increases due to growth and may irritate the

An even symmetric twist resists breakage under tension.

surrounding tissues. It may actually slip out of the loop resulting in loss of compression across the physis and cessation of any corrective effect. **When a twisted connection is used, the wire may break where tightening began**. This is especially true if the wire ends were twisted between the two screws, producing an unfavorably acute angle between the wire and the twisted ends.

25.3.6 Prognosis

A good to excellent prognosis can be given for the growth retardation as well as growth acceleration techniques, given prompt treatment, good surgical technique, and timely implant removal. The general rule is:

- Perform corrective surgery early for faster correction, fewer secondary changes, and a better long-term result.

The implant in the epiphysis of the distal tibia must be positioned very carefully.

25.4 Tarsal deviations

25.4.1 Description

The most common tarsal deviation affects the distal tibia.

The deformity most commonly encountered in the tarsal region is a valgus deviation at the distal tibia. Diagnostic procedures are identical to the ones previously considered for the radius. However, dorsopalmar radiographs are not very helpful because MT3 and the tibia do not occupy the same frontal plane, due to the angulation encountered in the tarsocrural joint. Therefore, the determination of the degree of deformity needs to be carried out clinically and cannot be confirmed 100% radiographically [3, 4].

The extensor tendons are elevated and protected during periosteal transection.

25.4.2 Surgical anatomy

Only rarely are varus deformities seen in the tarsus, therefore the common surgical approaches are performed on the lateral side for growth acceleration or on the medial side for growth retardation.

Growth acceleration

The surgical approach is carried out in the distal metaphyseal region of the tibia between the long and the lateral digital extensor tendon (Fig. F25E). An alternative possibility includes performing the vertical skin incision caudal to the lateral digital extensor tendon at the same level.

Growth retardation

Anatomic landmarks for correction of a valgus deformity consist of the medial physis of the distal tibia, the collateral ligament, and the tarsocrural joint. **The complex geometry of the distal tibia and the tarsocrural joint require that the distal implant be particularly carefully positioned.**

25.4.3 Surgical procedure

Growth acceleration

A 5 cm-long incision is performed, ending 1 cm proximal to the distal tibial physis. The periosteum is identified. At the distal end of the incision a curved hemostatic forceps is introduced and advanced cranially parallel to the physis. **Care is taken to undermine the long or lateral and long digital extensor tendon (the latter if the skin incision is performed caudal to the lateral digital extensor tendon).** The handles of the hemostatic forceps are raised

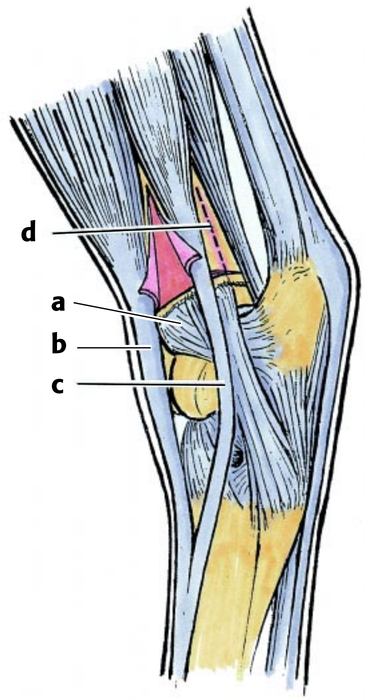


Fig. F25E: Drawing of the surgical landmarks and the periosteal flaps for growth acceleration of the distal tibia. Note that the surgery can be performed at two levels. In the drawing the procedure is shown for the cranial incision and the incision site (d) caudal to the lateral digital extensor tendon (c) is marked with a dotted line. (a) Distal tibial physis, (b) long digital extensor tendon.

and the curved scalpel blade is introduced between the slightly spread jaws of the instrument. The forceps is withdrawn and the scalpel, under light pressure, is drawn back toward the incision, transecting the periosteum. The same procedure is performed caudally either just beneath or caudal to the lateral digital extensor tendon. The horizontal periosteal incision is performed in a manner identical to that performed cranially. The two halves of the hemicircumferential incision are thus united. From that point, a 2 cm vertical periosteal incision is carried proximally. The two flaps of periosteum are separated from the underlying bone with the help of a periosteal elevator (**Fig. F25E**) and then returned to their original positions. The periosteum here is as thick as, or thicker than, that of the distal radius. Closure of the incision is routine.

Growth retardation

The skin is incised at the medial aspect of the distal tibia in a slightly curved pattern, while the subcutaneous tissues and the collateral ligament are divided longitudinally. The distal tibial epiphysis is identified and a 3.2 mm hole 15–20 mm in length is made in a **pronounced mediodistal to lateroproximal direction, parallel to the plane of the abaxial portion of the growth plate**. This prevents damage to the physis and inadvertent penetration of the tarsocrural joint (**Fig. S25V**). The 3.2 mm hole is tapped and a 14–20 mm, 4.5 mm cortex screw inserted (**Fig. X25G**). A short screw is adequate, due to the angle at which tension will be applied, and if a longer implant were used, the growth plate might be compromised. A second screw hole is drilled 30 mm proximal to the physis, perpendicular to the surface of the bone. After tapping of the cortex, a 26–30 mm, 4.5 mm cortex screw is inserted. A cerclage wire is applied in figure-8 fashion around the screw heads. The two ends are twisted evenly around each other above the proximal screw head. The technique of wire twisting is illustrated (**Video CERC_B**). The twisted wire ends are cut 6–8 mm from the initial twist. **Tightening of the screws causes additional tension in the wire and localized compression of the growth plate** (**Fig. X25H**). Closure of the incision is routine.

Both growth plate and articular surface must be protected during screw insertion.

As the screws are tightened, tension increases in the wire loop.

Fig. S25V: Postmortem specimen of the distal tibia demonstrating the undulating articular surface of that bone which makes the growth retardation surgery more complicated to perform. Note the screws and wire in place.

An alternative method of growth retardation includes the implantation of 3.5 mm screws and a 2.7 mm cuttable bone plate. The initial hole is placed at the same location as used for the screw and wire technique; however, its diameter is only 2.5 mm. The hole is tapped and a 16–20 mm, 3.5 mm cortex screw is inserted through the distal-most hole in the plate. The screw is not completely tightened and, using digital pressure, the plate is bent to conform to the contours of the underlying bone. One millimeter proximal to the most proximal hole in the cuttable plate, a similar hole is prepared in the distal tibia. It is then tapped and a screw is inserted through the proximal hole in the plate. Both screws are firmly tightened, creating compression across the tibial growth plate (**Fig. X25I**). Closure of the incision is routine.

Fig. X25G: Dorsopalmar radiograph of the tarsal region. The distal screw is in place demonstrating the steep angle needed for correct implantation.

Fig. X25H: Dorsoplamar radiograph of the same foal as **Fig. X25G** with the growth retardation implants in place.

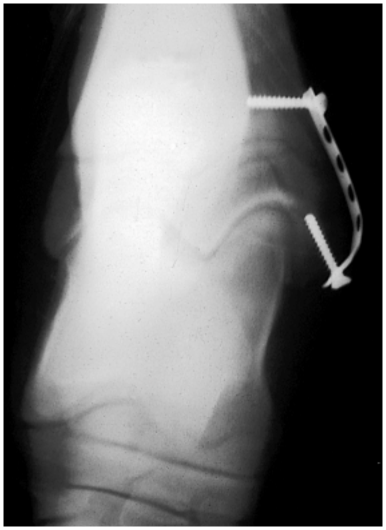


Fig. X25I: Dorsopalmar radiograph of the tarsal region with two 3.5 mm screws attaching a 2.7 mm plate to the distal tarsus.

25.4.4 Postoperative treatment

Maintenance of a firm bandage for the first 2 weeks postoperatively is important and care should be taken not to overtighten the bandage over the Achilles tendon, as pressure necrosis may occur. The feet should be balanced and the animal maintained in a box stall for 3–4 weeks. Subsequently, pasture exercise may be allowed. Correction of the deviation should be monitored closely, especially following growth retardation.

Fig. X25J: Dorsopalmar radiograph of a foal with a screw and wire growth retardation in place. Note that the distal screw penetrates the joint. This technical error needs to be corrected immediately.

25.4.5 Complications

With the growth acceleration technique the only complication known is dehiscence of the skin incision, which heals by second intention without any further difficulty. Dehiscence and local sepsis constitute a more serious problem following growth retardation, as resolution thereof usually requires removal of the implants.

With the growth retardation technique accidental penetration of the articular surface represents an additional complication (**Fig. X25J**). **It is therefore important to take intraoperative radiographs to assure proper placement of the implants**. Should such a technical error be recognized, immediate removal of the screw should be performed, followed by its correct placement. Despite the articular trauma the prognosis is still good if immediate correction of the error is carried out.

Intraoperative radiographs are strongly recommended during growth retardation of the distal tibia.

25.4.6 Prognosis

Prognosis for correction is in most cases good, provided that the surgery can be performed well enough in advance of physeal closure. In most cases the animals enter an athletic career without any lasting adverse effects.

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25.5.1 Online references

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26 Metacarpophalangeal/ metatarsophalangeal deviations

Jörg A. Auer & Gustave E. Fackelman

26.1 General description

In rare instances a severe bend not associated with a disproportionate growth of the metaphyseal region can be encountered in MC3/MT3 (Fig. X26A). Some foals born with a varus deformity in the forelimbs may be similarly afflicted behind, but to a lesser degree.

The conformational defect known as "bench knee" or "offset knee" (Fig. S26A) results from a combination of a valgus deformity at the distal radius and a varus deformity in MC3 (Fig. X26B). In these cases, treating only one of the disorders usually leads to a greater overall deformity. Therefore, if treatment is initiated, two surgeries need to be performed and it is important that they take place in the first 3 months of life. Some deviations are clearly visible and readily diagnosed. Others are much more subtle and require a trained eye for their proper analysis.

Bench knees are the result of carpus valgus combined with metacarpus varus.

Fig. X26A: Dorsoplantar radiograph of a foal with a marked metaphyseal deviation in MT3.

Fig. S26A: Frontal view of a mare with a marked bench knee conformation.

The surgical techniques will be described according to the anatomic location: MC3/MT3 and proximal phalanx. Corrective osteotomies are discussed last.

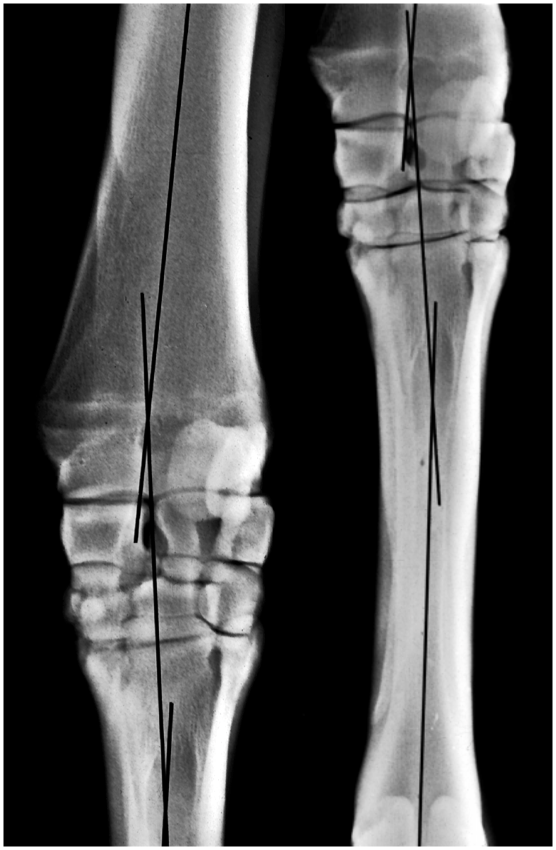


Fig. X26B: Dorsopalmar radiograph of the left forelimb of the horse in **Fig. S26A**. The axes drawn on the long bones comprising the limb show that the bench-kneed conformation derives from a combination of a valgus deformity of the distal radius (left) and a varus deformity in MC3 (right).

26.1.1 Surgical anatomy

The surgical approach is carried out either on the medial aspect (varus deformity) or the lateral aspect (valgus deformity). In that region the bone is covered only by skin, subcutaneous tissue, and periosteum. The surgical approach is therefore straightforward, involving a straight incision down to the periosteum (**Fig. S26B**). The procedure to be performed is depicted in **Fig. F26A**.

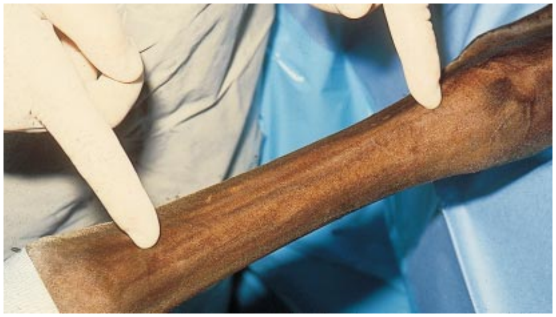


Fig. S26B: The medial aspect of the limb is prepared for aseptic surgery and draped accordingly. The surgeon's index fingers indicate the length of the skin incision.

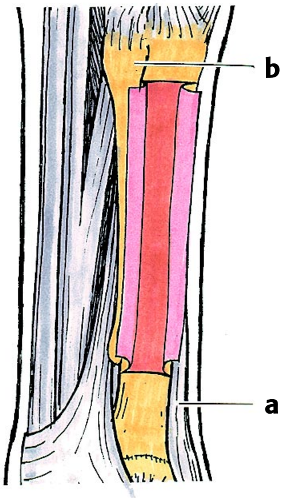


Fig. F26A: Drawing of the growth acceleration procedure performed over the entire length of MC3. The "barn door" flaps are shown. a) Common digital extensor tendon; b) MC2.

Fig. S26C: The skin incision is carried through the thin periosteum down to the bone in a straight line.

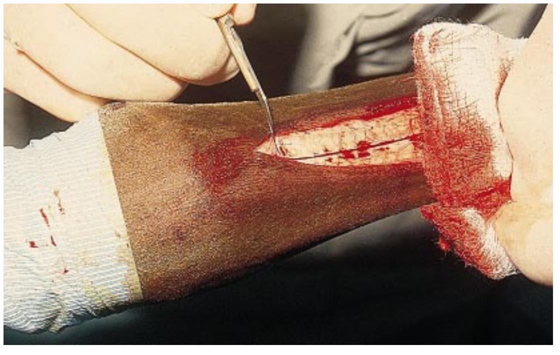


Fig. S26D: At the level of the distal end of the splint bone the distal horizontal periosteal incision is carried out avoiding the palmar outpouching of the metacarpophalangeal joint.

26.1.2 Surgical procedure

Growth acceleration

The vertical skin incision reaches from the proximal end of MC3 to about 5 cm proximal to the distal physis. The periosteum is vertically divided along the same line (Fig. S26C). The horizontal periosteal incision is performed at the level of the distal end of the splint bone (Fig. S26D). **Care is taken not to inadvertently penetrate the palmar outpouching of the metacarpophalangeal joint.** The dorsal part of the horizontal incision reaches to the common digital extensor tendon. The proximal horizontal incision is performed about 1 cm distal to the carpometacarpal joint (Fig. S26E). The palmar/ plantar half of the incision extends to the splint bone. The two flaps of periosteum are subsequently elevated from the underlying bone (Fig. S26F). **It is interesting to note that the periosteum in this region is very thin when compared to that of the distal radius** (Fig. S26G).

The subcutaneous tissues are closed in a simple continuous pattern using a 2/0 or 3/0 monofilament resorbable suture material (PDS, Maxon®). In this area, interrupted skin sutures

Take care not to penetrate the joint capsule when making the distal transverse incision.

The metacarpal periosteum is quite thin and tears easily.

Fig. S26E: The proximal horizontal periosteal incision is carried out about 1 cm distal to the carpometacarpal joint.

Fig. S26F: The palmar periosteal flap is elevated with a periosteal elevator back to MC2.

Diaphyseal deformities cannot be corrected with growth retardation techniques.

Fig. S26G: Both periosteal flaps are elevated to demonstrate the relatively thin periosteum compared to the one located at the distal radius and tibia.

Fig. S26H: The subcutaneous tissues and the skin are closed with two simple continuous sutures using an absorbable suture material of 2/0 size. An intradermal pattern is selected in this foal for the skin. Lately skin staples are being used to prevent dehiscence of the skin sutures.

Fig. S26I: Dehiscence of the skin sutures placed in a continuous pattern intradermally.

or metal staples are preferable to an intradermal pattern (**Fig. S26H**). A good pressure bandage has to be applied postoperatively over the surgery wound [3, 4].

Growth retardation

Diaphyseal **deformities cannot be corrected with growth retardation techniques because they do not involve the metaphysis.** Other treatment alternatives would include a corrective osteotomy (see later).

26.1.3 Postoperative care

Postoperative care includes stall rest for 1–2 weeks followed by pasture exercise, and a radiographic re-evaluation 2 months postoperatively. The younger the animal, the faster and more complete will be the correction.

The major complication is dehiscence of the relatively long skin incision, made in a relatively avascular field.

26.1.4 Complications

The only **major complication is dehiscence of the relatively long skin incision** (**Fig. S26I**), **made in a relatively avascular field.** Good pressure bandaging is important and such protection should be maintained for 2 weeks postoperatively. Should dehiscence occur, second intention healing typically occurs without a lasting blemish. This complication does not seem to alter the corrective effects of the surgical procedure.

26.1.5 Prognosis

This procedure, when carried out on an animal under the age of 3 months has a good prognosis for complete correction (**Fig. X26C**). If the surgery is carried out to **correct a bench kneed conformation, it must be performed in conjunction with a corrective procedure on the distal radius. Otherwise, increased deformity will develop postoperatively** (**Fig. S26J**, **Fig. X26D**).

Fig. X26D: Dorsopalmar radiographs of the carpal region of the same foal as shown in **Fig. S26J**. Left: preoperative appearance. Right: 2 month follow-up appearance. Note the osseous reaction at the surgery sites.

Fig. X26C: Dorsoplantar 3 month follow-up radiograph of the same foal as in **Fig. X26A**. Note the marked filling in of the lateral cortex and the cosmetic improvement of the bone shape.

Fig. S26J: Frontal view of a 2-months-old foal with bench knees (left). On the right the same foal is shown 2 months after performing growth acceleration surgeries laterally on both distal radii and medially over the entire length of both MC3.

Bench knees are corrected by combined procedures on the proximal metacarpus and the distal radius.

26.2 Metacarpophalangeal/metatarsophalangeal deviations

26.2.1 Description

Use the same analytic methods as described for the carpus/tarsus to accurately diagnose these problems.

An accurate diagnosis of these deviations is dependent upon the careful application of the principles described for the carpus (**chapter 25**, Carpal and tarsal deviations). Varus deformities are the ones most frequently encountered (**Fig. S26K**, **Fig. X26E**) [5]. It is important to simultaneously evaluate the proximal phalanx for a deviation in the opposite direction [14]. In that instance, the proximal joint surface will not be parallel to the ground or perpendicular to the long axis of the limb that leads to outward rotation during flexion. The **majority of growth occurs during the first 3 months of life, placing rather narrow limits on the time frame for effective treatment**. Surgery carried out at a later stage will, in most cases, not be successful. The surgical treatment possibilities described below are for a varus deformity of the distal MC3/MT3.

For best results, perform surgery in the first 3 months of life.

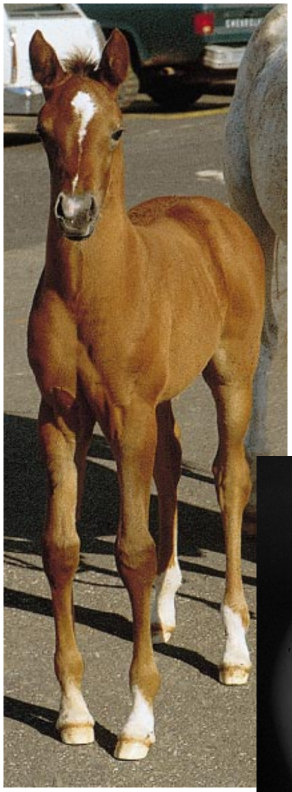


Fig. S26K: Frontal view of a 2-months-old foal with bilateral varus deformities located in both distal MC3. Note the marked toed-in conformation.

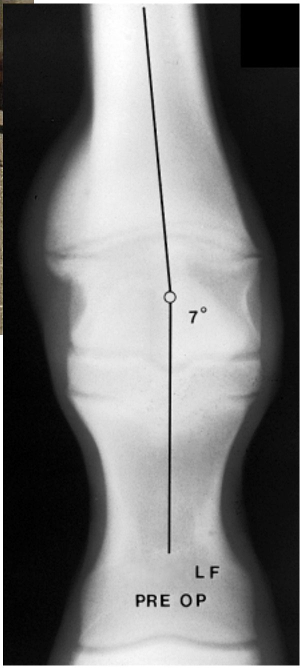


Fig. X26E: Dorsopalmar radiograph of the metacarpophalangeal region of the foal in **Fig. S26K**. Note the location of the deformity in the distal metacarpal epiphysis and the new bone formation in the distal metaphyseal region.

26.2.2 Surgical anatomy

MC3/MT3

The surgical landmarks include the distal end of the medial splint bone and the common digital extensor tendon. The distal MC3/MT3 is covered only by skin, subcutaneous tissue, and the periosteum (**Fig. F26B**).

Proximal phalanx

The surgical landmarks include the proximal epiphysis, the physis, and the extensor branch of the suspensory ligament, which crosses the surgical site. The surgery is performed at the lateral or medial aspect of the bone, distal to the proximal physis (**Fig. F26B**).

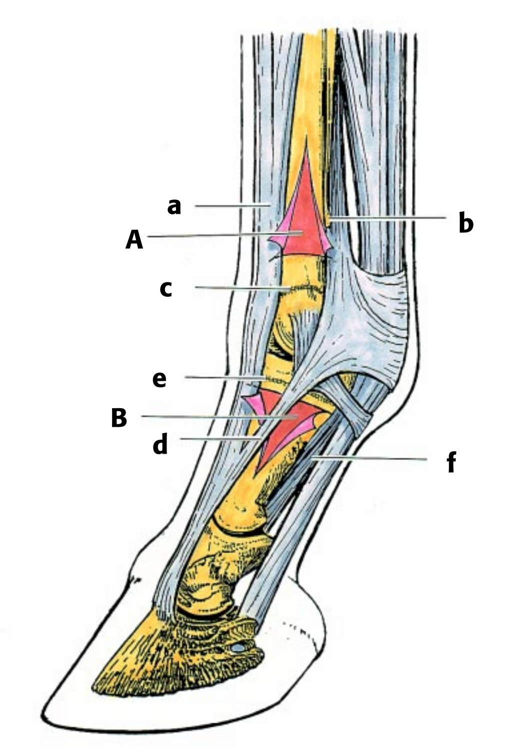


Fig. F26B: Drawing of the surgical landmarks and the procedure for the growth acceleration of the distal MC3 and proximal phalanx. In selected cases these two procedures need to be combined on opposite sides of the same limb. a) Common digital extensor tendon; b) distal end of the vestigial metacarpal bone; c) distal metacarpal physis; d) extensor branch of the suspensory ligament; e) proximal physis of the proximal phalanx; f) oblique distal sesamoidean ligaments; A) growth acceleration procedure at the distal MC3; B) grow acceleration procedure at the proximal phalanx.

26.2.3 Surgical procedure

Growth acceleration

MC3/MT3

Growth acceleration techniques are, as usual, carried out on the concave aspect of the deformed bone. For instance, the surgical site is located on the medial aspect of the bone in a case of varus deformity. A vertical skin incision 3 cm in length is centered over the distal MC3 beginning at the distal end of MC2. A curved hemostatic forceps is inserted perpendicular to that incision to separate subcutaneous tissues from the periosteum at the distal end of MC2. **Care is taken not to injure the palmar outpouching of the metacarpophalangeal joint.** The jaws of the hemostatic forceps are slightly spread and the curved scalpel blade introduced. The periosteum is transected horizontally back to the level of the skin incision. This procedure is repeated at the dorsal aspect of the bone. A vertical incision is performed proximally over a length of 2–3 cm. Using an elevator, the periosteum is lifted from the underlying bone (**Fig. F26B**) and allowed to fall back to its original position. The subcutaneous tissues and the skin are closed in routine fashion. Preoperative radiographs (**Fig. X26E**) demonstrate the lesions found in a foal (**Fig. S26K**), while postoperative radiographs (**Fig. X26F**) show the results of surgery after 75 days (**Fig. S26L**).

> Protect the palmar outpouching of the fetlock joint when making the distal transverse incision.

Proximal phalanx

The surgical procedure performed to correct a deformity located in the proximal phalanx involves only the growth acceleration techniques and is therefore carried out at the concave aspect of the bone. A 2 cm vertical skin incision 2 cm in length is centered over the extensor branch of the suspensory ligament in the proximal third of the affected phalanx. Subcutaneous

Protect the tendinous tissues with a curved hemostatic forceps during the periosteal incision.

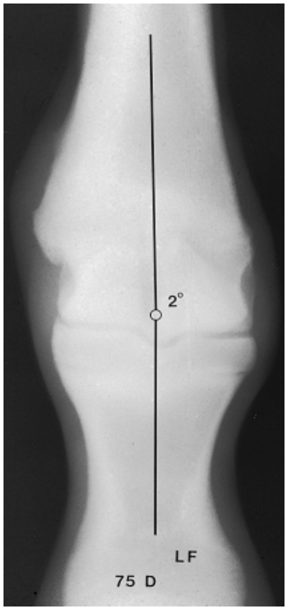


Fig. X26F: Follow-up radiograph 75 days after medial growth acceleration of the distal MC3 of the foal in Fig. S26K. Note the marked correction and the reduction of the periosteal new bone formation demonstrated in Fig. X26E.

Fig. S26L: Frontal view of the distal limb of the foal in Fig. S26K 75 days postoperatively. There is a marked improvement of the conformation.

tissues are separated using sharp dissection and the periosteum is identified. Care is taken to prevent inadvertent injury to the extensor branch of the suspensory ligament. The **curved hemostatic forceps** is introduced at a level 1–1.5 cm distal to the proximal physis in a cranial direction beneath the extensor branch and the extensor tendon. This separates the subcutaneous tissues from the periosteum. The jaws of the forceps are spread slightly to facilitate introduction of the curved scalpel blade. After withdrawal of the hemostatic forceps the periosteum is transected by applying minimal pressure onto the tip of the scalpel blade and drawing it back at the same time. Once the scalpel has reached the level of the vertical skin incision, pressure is released. The same procedure is repeated in a caudal direction, where the insertion of the oblique distal sesamoidean ligaments is penetrated. The scalpel blade is introduced in the same manner and the horizontal periosteal incision is performed and connected with its cranial counterpart. After elevating the extensor branch and the subcutaneous tissues distally, the vertical periosteal incision is performed creating an inverted “T”. The two periosteal flaps are then elevated from the underlying bone (**Fig. F26B**) and subsequently repositioned. Closure of the incision is routine [**14**]. Preoperative and postoperative radiographs (**Fig. X26G**) show the typical findings of a successfully treated case.

Growth retardation

Growth retardation is performed on the convex aspect of a deformed bone. In MC3/MT3, this technique is only applied distally. The skin incision is made as described for the growth acceleration technique, but it is centered further distally. The width of the epiphysis is palpated and the level of the physis determined. The collateral ligament and perichondrium located

Fig. X26G: Dorsopalmar radiographs of the phalangeal region of a foal suffering from a disproportionate growth of the proximal phalanx (left). The arrow points to the shorter side of the proximal phalanx. The follow-up radiograph (right) shows the corrected bone a few months later.

in that region are divided in a vertical direction. A 3.2 mm drill guide is positioned in the center of the epiphysis and a 3.2 mm hole prepared to a depth of 30 mm. The hole is tapped using the tap sleeve to protect the collateral ligament and a 28 mm, 4.5 mm cortex screw is partially inserted into the epiphysis. Four cm proximally an identical hole is prepared in the metaphysis and a second 28 mm, 4.5 mm cortex screw partially inserted into MC3/MT3. The two screws are subsequently bridged by a cerclage wire applied in figure-8 fashion. With a pair of flat pliers, a twist is created above the head of the proximal screw (**Fig. F26C**). **Care is taken to twist the two strands of wire around each other evenly, and not simply to wind one around the other** (**Video CERC_B**). The latter condition is significantly weaker and would probably fail. The two ends are subsequently cut 6–8 mm from the first twist. Skin closure is routine. This technique is applied only rarely to the proximal phalanx, due to the technical difficulties occasioned by its narrow proximal physis.

Maintain equal tension in both strands of wire so that the twist remains symmetric.

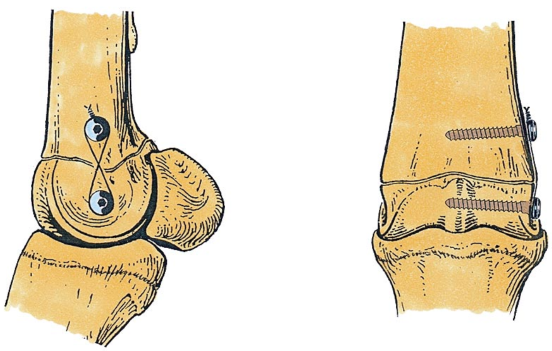
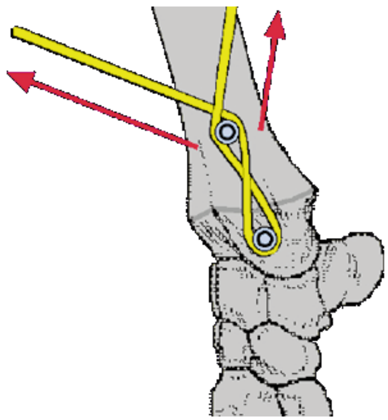


Fig. F26C: Drawing of the growth retardation procedure involving screws and wire. Note that the cerclage wire is twisted above the proximal screw.



Video CERC_B:
Animation of cerclage technique.

A cuttable plate may be easier to apply to the proximal phalanx, due to the narrow tolerances in the epiphysis.

Alternatively, 3.5 mm screws and a 2.7 mm cuttable plate may be applied instead of the screws and wire. For that purpose, a 2.5 mm, 30 mm long hole is drilled and tapped in the physis at the location described above. A 28 mm long, 3.5 mm cortex screw is inserted through the distal-most plate hole. The screw is inserted partially and after displacing the plate in a proximal direction, finger pressure is applied to contour the plate to the surface of the bone. The main bend occurs at the physeal level. One millimeter proximal to the proximal-most hole of the plate the second 2.5 mm hole is drilled and tapped using routine technique. A 24 mm long, 3.5 mm cortex screw is inserted through the proximal-most hole in the plate. Both screws are firmly tightened, exerting compression upon the growth plate. Closure of the incision is as previously described.

26.2.4 Postoperative treatment

The postoperative bandage applied following all surgical manipulations of growth in the metapodealphalangeal region are the same (see above).

26.2.5 Complications

Complications relate mainly to inadvertent soft tissue damage.

Complications include inadvertent transection of a tendon, nerve, or blood vessel, or penetration of the adjacent joint. Dehiscence of the suture line may also be a problem. Postoperative infection and overcorrection are complications encountered more frequently with growth retardation procedures, largely due to the presence of foreign metallic material (chapter 22, Carpal and tarsal deviations).

If the corrective surgical procedure is carried out on a foal with local damage to the physeal region of the proximal phalanx, a compensatory deformity may develop (Fig. X26H), resulting in an obliquely oriented articular surface.

26.2.6 Prognosis

Axial deviations diagnosed and treated early bear a good to excellent prognosis for full restoration of normal axes and a future athletic career. After 3 months of age, growth at the distal physis is minimal and complete correction of a deformity is doubtful. The prognosis rapidly falls to zero.

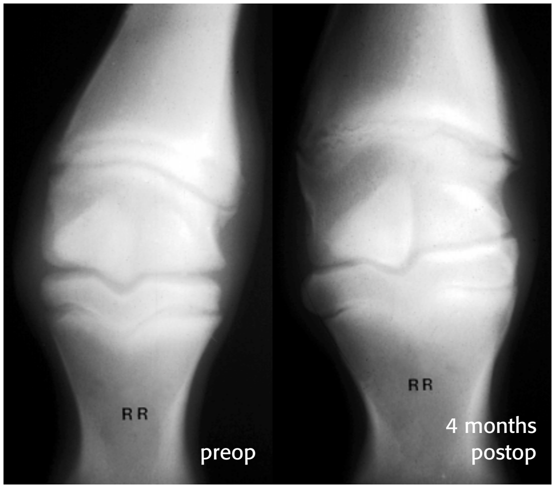


Fig. X26H: Dorsoplantar radiographs of the metatarsophalangeal region of a 7-week-old foal with a severe varus deformity (left). Four months after growth acceleration of the medial and distal aspect of MT3 the axis is corrected (right). However, most of the correction was achieved because of the compensatory deviation which developed in the proximal phalanx.

26.3 Corrective osteotomies

Corrective osteotomies provide the only surgical solution for deformed foals with closed physes. These surgical procedures require broad exposures and are demanding for the surgeon. They need to be planned in detail prior to surgery. It is probably best that their performance be limited to experienced clinicians with a special interest in orthopedic surgery. The following types of osteotomies/ostectomies are possible in veterinary surgery: closing wedge ostectomy, dome osteotomy, and step osteotomy/ostectomy.

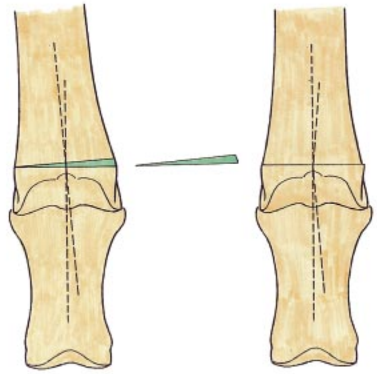


Fig. F26D: Drawing of the wedge ostectomy procedure. A triangular piece of bone is removed, shortening the bone.

26.3.1 Closing wedge ostectomy

The closing wedge ostectomy is the simplest form and has been repeatedly described in the literature (Fig. F26D) [4, 15–17]. The techniques described below are considered superior since they are at least as stable and allow maintenance of leg length.

The closing wedge ostectomy is the simplest form of corrective osteotomy.

26.3.2 Dome osteotomy

The dome osteotomy represents an interesting approach to correct severe bony deformities, basically on the surface of a cylinder (Fig. F26E). This technique is difficult to apply in the metaphyseal region of a bone where only a small distal bone segment must be affixed to the rest of the bone. Additionally, rotational deformities cannot be corrected with this technique. One equine case has been described with a poor result [4, 17], but the technique probably deserves further investigation.

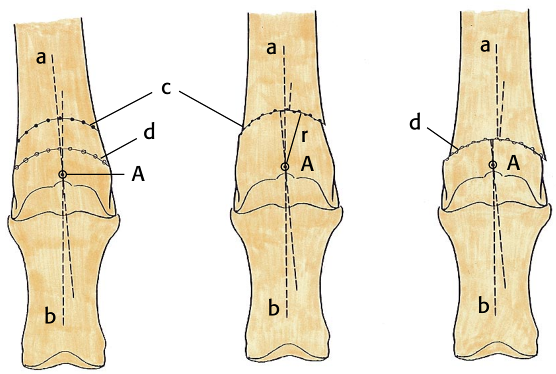


Fig. F26E: Drawing of the dome osteotomy procedure. The bone is separated across an osteotomy carried out with the osteotome through connecting the multiple holes drilled across the bone previously. The two bone fragments are subsequently rotated in axial alignment and fixed in that position. A) Pivot point of deviation; a) axis of MC3; b) axis of P1; c) circle with the center A and the radius r; d) circle with a radius > r and a different center; The dots on the circles represent drill holes.

26.4 Step ostectomy/ osteotomy

26.4.1 Description

The step ostectomy is particularly useful for varus ± rotational deformities of the distal metacarpus/metatarsus.

Ensure that the direction of the toe can be appreciated intraoperatively.

The step ostectomy is performed in the sagittal plane where a bony wedge is removed (**Fig. F26F**). It is also possible to correct a rotational deformity with this procedure, by removing a triangular bone piece from the dorsal (**Fig. F26G**) or palmar cortex. The step osteotomy, on the other hand, is carried out in the frontal plane, not necessarily involving the removal of a wedge (**Fig. F26H**). **The step ostectomy in the sagittal plane will be described in detail as a representative of corrective osteotomies for varus deformities of the distal MC3/MT3** (**Fig. S26M**). The limb is prepared for aseptic surgery, including clipping of the hair of the distal limb circumferentially to a level proximal to the carpus or tarsus. After the surgical preparation of the distal limb, drapes are applied. The hoof is covered with sterile drapes. **Care is taken to assure recognition of the direction in which the foot points despite the drapes.** This will be important in the intraoperative evaluation of correction of the deformity. Another disposable drape (split sheet or lap drape) is applied just distal to the carpus/tarsus. Such a draping technique allows visualization of the distal limb, facilitating evaluation of the correction achieved (**Fig. S26N**).

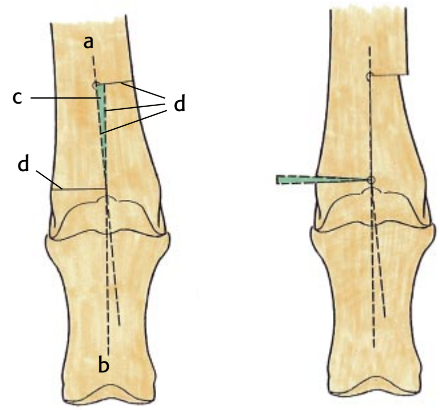


Fig. F26F: Drawing of the step ostectomy procedure performed in the sagittal plane. A triangular piece of bone is removed from the center of the bone. Subsequently, a Z-plasty is performed across the bone. After removing the triangular wedge, the two bone fragments can be moved in axial alignment and fixed by means of internal fixation with a plate and lag screws. a) axis of MC3; b) axis of P1; c) triangular bone piece to be removed from MC3; d) Z-plasty osteotomies.

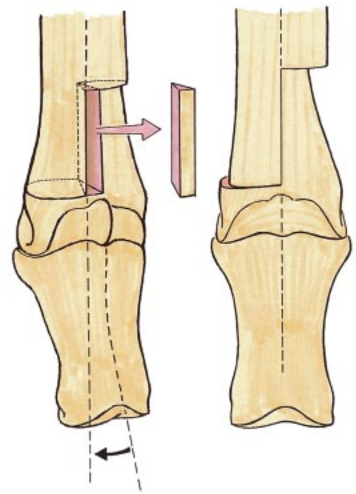


Fig. F26G: Derotational step ostectomy with a triangular bone wedge (the broad side located on the dorsal cortex) is removed from the distal MC3. Note that a Z-plasty has to be performed as well.

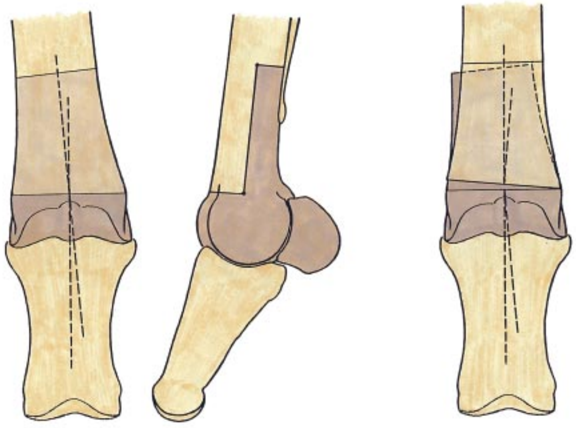


Fig. F26H: Drawing of the step osteotomy procedure performed in the frontal plane. In this technique the two bone fragments are axially aligned without removal of a triangular bone piece.

Fig. S26M: Frontal view of a 7-months-old Arabian foal with marked fetlock varus deformities in both forelimbs.

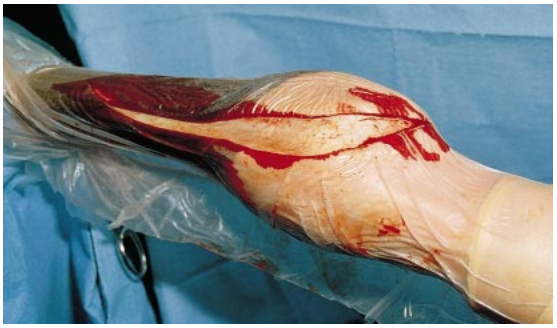


Fig. S26N: The metacarpophalangeal region is draped for aseptic surgery. Note that it is important to visualize the entire distal limb without bulky drapes to allow evaluation of the correction achieved through the osteotomy or ostectomy. Therefore, the foot is draped separately and the surgical region covered with an incise drape. The skin is incised over the lateral digital extensor tendon. The tendon is subsequently split longitudinally to gain access to the periosteum.

26.4.2 Surgical anatomy

The lateral digital extensor tendon courses from the lateral-most aspect of the proximal MC3 to the dorsolateral aspect at the level of the proximal phalanx, where one part of it inserts. Prior to surgery, **the pivot point for the deviation is determined by drawing bisecting lines through MC3 and the phalanges on an acetate foil, placed over the radiograph (Fig. X26I). The intersection of these two lines represents the pivot point**. The correction angle is determined and a template manufactured out of aluminum foil, which can be sterilized for use during surgery.

Determine the precise location of the pivot point preoperatively.

Mark the previously determined pivot point on the bone.

Use an aluminum template to guide the second saw cut.

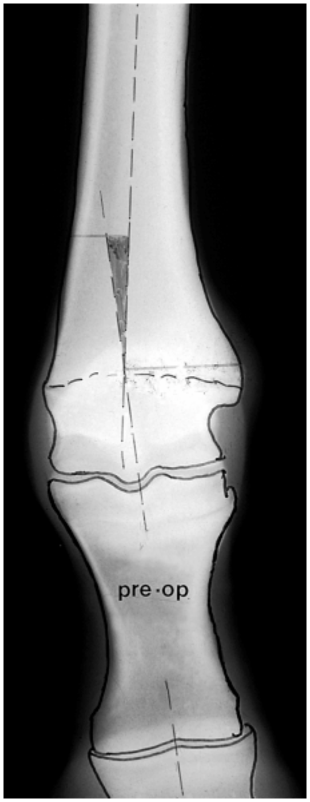
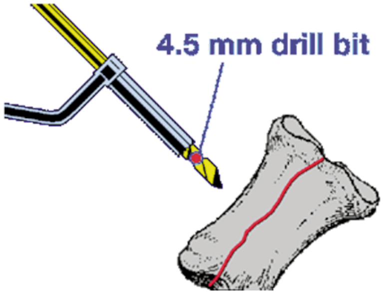


Fig. X26I: Dorsopalmar radiograph of the fetlock region of the foal in **Fig. S26M**. An acetate foil was placed over the radiograph and the presurgical planning drawn on it depicting the surgical osteotomies to be performed.

26.4.3 Surgical technique

The incision is made parallel to and over the lateral digital extensor tendon. In a single incision the skin, subcutaneous tissues, lateral digital extensor tendon, and periosteum are split over the entire length of MC3. At the level of the distal physis pressure on the scalpel is eased to avoid penetration of the metacarpophalangeal joint. From there a curved incision is continued across the skin, subcutaneous tissue, and lateral digital extensor tendon in a lateral direction. The periosteum is elevated from the bone around the entire circumference. **Through comparing the anatomic landmarks in the surgical site with the ones on the radiograph, the pivot point for the deviation is marked on the bone**. A 3.2 mm hole is drilled across the bone perpendicular to the frontal plane. An additional 3.2 mm hole is drilled 3–4 cm proximal on the axis of the bone. Using the oscillating saw, a saw cut is performed across the bone between the two 3.2 mm holes in a sagittal plane. **The previously prepared aluminum template, representing the correction angle, is placed on the bone with one side parallel to the initial saw cut.** The second saw cut is made along the other side of this triangle perpendicular to the frontal plane of the bone. The Z-plasty of the bone is completed by two horizontal cuts connecting the proximal 3.2 mm hole with the lateral and the distal 3.2 mm hole with the medial aspect of the bone. The bone wedge thus created is subsequently removed and the two remaining portions are brought into alignment. In doing so, the deformity is corrected. Some minor adjustments may be required at the corners of the saw cuts. Should a rotational deformity also be present, this can be corrected at this point by removing an additional bone wedge from the dorsal or palmar/plantar cortex, dependent upon the type of rotational deformity present. After the axial correction is assured, the two bone portions are held in apposition by means of two pointed reduction forceps. Permanent fixation is by means of cortex screws inserted in lag fashion. For this purpose either 4.5 mm or 3.5 mm screws can be used. It is important to preview the correct location for plate application and avoid this area with the lag screws. **Alternatively, the location for the cortex screws can be planned to coincide with the plate holes.** Routine lag technique is employed to insert the screws (**Video DBASICS**). After interfragmentary compression has been achieved, the pointed reduction forceps are removed and the soft aluminum template pressed to the lateral aspect of the limb. After properly contouring the plate it is applied to the bone and held in place either by plate-holding forceps or manually. Plate screws are inserted into the bone through the plate using the 4.5 mm or, in selected cases, 5.5 mm screws. Any screw crossing the vertical saw cut is inserted in lag fashion (**Fig. X26J**). Some compressive forces may be exerted across the osteotomy by applying the initial two screws in load position. The remaining screws are inserted in neutral position.

An alternate approach is represented by the step osteotomy in the frontal plane. In such a case, the vertical saw cut is performed in the frontal plane, parallel to the long axis of the bone. This osteotomy is completed by a second dorsal horizontal osteotomy at the distal end of the frontal cut and a cut parallel to the distal one at the palmar and proximal end of the initial osteotomy. Care has to be taken in this region to preserve the interosseus as well as the neurovascular structures located in this region.



Video DBASICS: Basics animation of screw fixation.

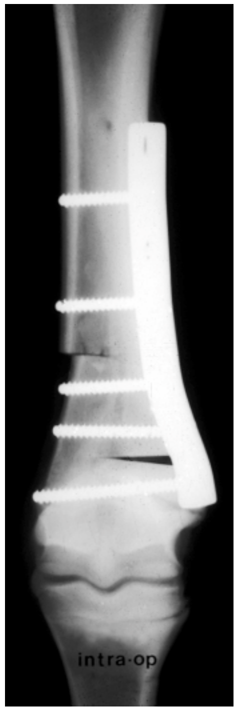


Fig. X26J: Intraoperative radiograph depicting the bone plate located on the medial aspect of the bone. Only one screw was placed in the distal fragment. However, the two screws located just proximal were inserted applying lag screw technique to achieve interfragmentary compression. The animal used the limb well postoperatively. An external PVC splint was applied for 2 weeks.

Consider the location of the lag screws relative to the intended placement of the plate.

Both splint bones will necessarily be transected during this osteotomy. Subsequently, the two parts of the bone are rotated into a corrected position and fixed by means of a plate applied dorsally (**Fig. F26H**). Additional cortex screws can be inserted in lag fashion across the osteotomy site dorsomedial and dorsolateral to the plate. By rotating the two bone ends some protrusion of bone may be encountered on the medial aspect of the bone (in a varus deformity), which can be trimmed using the oscillating saw. This type of corrective osteotomy is not suited to the distal MC3/MT3, because the dorsal plate would interfere with the metacarpophalangeal joint. However, a deformity in the diaphyseal region of the bone may be corrected with such a procedure.

Skin closure is routine, involving a simple continuous suture pattern of a monofilament, absorbable suture material (PDS, Maxon) in the lateral digital extensor tendon and the subcutaneous tissues, as well as interrupted sutures or staples in the skin.

26.4.4 Postoperative treatment

A tight pressure bandage is applied to the limb, extending to the elbow, in the immediate postoperative period in the foal. Larger horses are bandaged only to the carpus/tarsus. A splint is added to the bandage for the first 2–3 weeks postoperatively. The bandage is changed every 2–3 days.

It is advisable in selected cases to apply suction drainage for 2–3 days. Such a drain would have to have been inserted at the time of surgery and the soft tubing brought out through a small stab separate from the main incision. Once postoperative exudation has ceased, the suction drain may be removed.

The skin sutures or staples are removed 10 days postoperatively. Stall rest is mandatory for 6–8 weeks postoperatively. After that, controlled exercise can be allowed. It is advisable to take 2 month follow-up radiographs to evaluate the healing progress (**Fig. X26K**). In a young animal healing will be almost complete. An esthetic result requires that the implants be removed. This is especially true of the plate if the animal is destined for an athletic career (**Fig. S26O**). The lag screws may be left in place if they are overgrown by bone. It is highly unlikely that these screws will have any adverse side-effects.

The advantages of the step ostectomy over closing wedge ostectomy include better bone-

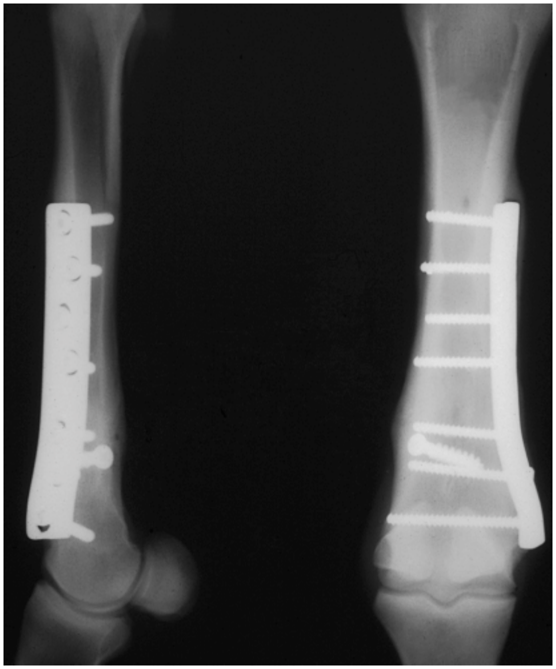


Fig. X26K: Six month follow-up radiograph of the foal in **Fig. S26M**. Note that the ostectomy has healed with only a minimum of periosteal new bone formation.

on-bone contact and reduced tendency for the development of a rotational deformity. The surgical site is further proximal, away from the pivot point, which allows placement of additional implants in the distal fragment. **The achievement of adequate fixation is a major problem in the closing wedge ostectomies when carried out at the pivot point, which is, in most cases, located close to the joint**. Rotational deformities can easily be corrected with the step ostectomy, as mentioned previously, and still allow good stable fixation and interfragmentary compression across the vertical osteotomy cut. Bone length is maintained except in the closing wedge ostectomy, where it is actually reduced. The step ostectomy is probably the best technique currently available for correcting deformities in the presence of a closed growth plate. Although only a limited number of foals have thus far been treated with this procedure, it seems to have bright future [4, 17].

Fig. S26O: Frontal view of the same foal as shown in **Fig. S26M** 6 months postoperatively. The limbs look cosmetically acceptable with only minor irregularities at the medial aspect. These irregularities are caused by the bone plates and will disappear after plate removal.

Achieving adequate stability in closing wedge osteotomies can be a major problem.

26.4.5 Complications

Development of postoperative infection, dehiscence of the skin incision, breakdown of the fixation, and development of laminitis in the opposite forelimb are all complications to be considered. Other than laminitis, management of these complications has been mentioned above. Development of laminitis in the opposite forelimb is of major concern, especially in adult horses. It is therefore important to maintain the animal comfortably on its feet and prevent continuous overload of the sound forelimb, especially in the immediate postoperative period. This can be achieved through the daily administration of an analgesic like phenylbutazone to effect. Excessive amounts of this class of drug should be avoided due to their documented side effects of renal papillary necrosis and gastric and duodenal ulcers. In addition, high doses may allow overloading of the operated limb and enhance a breakdown of the fixation.

Simple screw fixation after a step ostectomy is not adequate, even if a fiberglass cast is applied. The cast adds additional weight to the operated limb and does not prevent rotation of the limb within the cast (**Fig. X26C**). This may predispose the limb to fracture at the surgery site within the cast (**Fig. X26L**). **It is therefore of great importance to apply a plate to the corrected bone.**

Application of a bone plate would have prevented the complication shown in Fig. X26L.

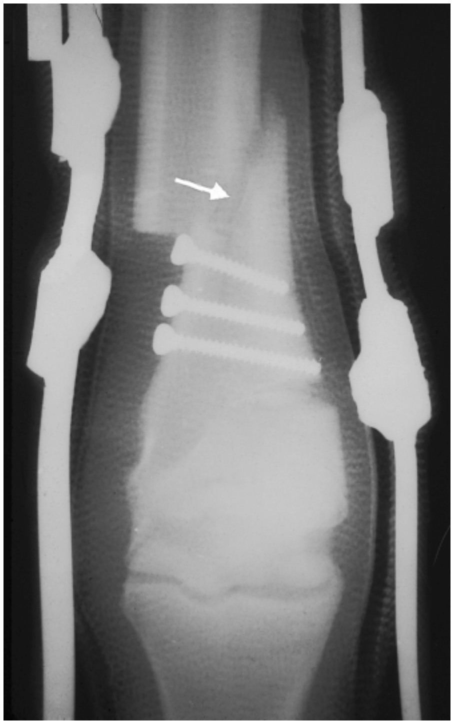


Fig. X26L: Dorsopalmar radiograph of the metacarpophalangeal region of a foal on which a step ostectomy was performed. The ostectomy was fixed with three cortex screws applied in lag fashion and supported with a fiberglass cast and a walking bar. The cast and walking bar added weight to the limb and did not fix the distal limb in rotation because the cast extended to just distal to the carpus. The friction of the cast on the ground during turning caused a fracture of MC3 at the proximal aspect of the Z-plasty. Note the 45° angle of the fracture line (arrow). It is therefore of paramount importance to use a bone plate for internal fixation of the ostectomy.

26.4.6 Prognosis

The use of the step osteotomy shows the most favorable results if the operative and postoperative plans can be followed. Absence of secondary problems such as articular damage are prerequisites for a positive outcome. If the animal is of sufficient quality to be retired for breeding purposes, the technique is justified without qualification. Allowing the deformity to persist, even in breeding stock, is to sentence the patient to inexorable degenerative changes and increasing levels of pain.

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26.5.1 Online references

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27 Bone graft biology and autogenous grafting

Gustave E. Fackelman & Jörg A. Auer

27.1 Basic biology

A basic distinction is made between living or fresh transplants and nonliving transplants, the latter including specially prepared bone tissue, e.g., decalcified, freeze-dried, irradiated, or sterilized. Ceramics belong to the same group of nonliving transplants, two good examples being tricalcium phosphate (TCP) and hydroxy-apatite (HA), which mimic the microstructure of their forerunner, coral.

Another classification system is founded upon the origins and destinations of the grafts. A graft that is harvested from one site and applied to another within the same individual is called an autograft. Allograft refers to tissue removed from one individual and implanted into a genetically different individual within the same species. Tissues transferred between two members of different species are called xenografts. The adjectival terms autogenous, allogeneic and xenogeneic are respectively applicable. If tissue is transferred from one location and applied to an anatomically similar one, the graft is said to be orthotopic. If the implantation site is dissimilar, the graft is referred to as heterotopic, for example calcified or cancellous bone implanted subcutaneously or into a muscle.

Grafts may comprise more than one tissue: e.g., corticocancellous or osteochondral. Fresh grafts are transferred immediately from donor site to implant site. When placed into a bone bank and stored for a period of time before their application, they represent nonliving transplants.

In equine orthopedic surgery, fresh grafts are almost without exception autografts. Among the remaining fresh grafts are: free cortical grafts, which depend on the ingrowth of host vessels for their nutrition; and vascularized cortical bone grafts, which are harvested with their afferent blood vessels intact using micro-surgical techniques, the vessels later being anastomosed to the blood supply of the recipient site. Bone grafts taken from a bone bank function as scaffolds for the ingrowth of new host bone. During the manipulations carried out on the bone to allow its safe and sterile storage, such as decalcification, freezing, freeze-drying, irradiating, acid decalcification, and sterilization [1], any remaining osteoblasts are eliminated. The matrix acts as a substrate upon which osteoblasts can reside, multiply, and begin to elaborate new bone. Substances within the transplanted tissue probably act locally to

Grafts are most commonly classified according to their origins and destinations.

Bone g rafts provide suppor t and stimulate osteogenesis.

New bone is created by both cells of the g raft and cells of the recipient site.

"induce" bone formation, and the physical presence of the graft tissue may actually act as a "placeholder" (**Fig. S27A**) and a guide to more orderly healing than that which occurs in the nongrafted situation (**Fig. S27B**). Extensive research serves to document the interest in such grafts and the need for bone grafting, especially in the fields of human and veterinary traumatology [2–17].

The two main functions of bone grafts are osteogenesis and support. Osteogenesis occurs partially due to activity of cells aligned on the surface of the living bone graft. Therefore, the greater the surface, the more lining cells are available and the greater the osteogenic potential. This is especially important if one considers that up to 90% of the living cells die following their transfer. From these observations, it is reasonable to accept that cancellous bone grafts are among the most desirable to be applied in the horse. **New bone produced in the graft may derive from superficial lining cells of either the endosteum or the periosteum of the host, or from osteoblasts of the graft itself.** Surface cells of a freshly trans-

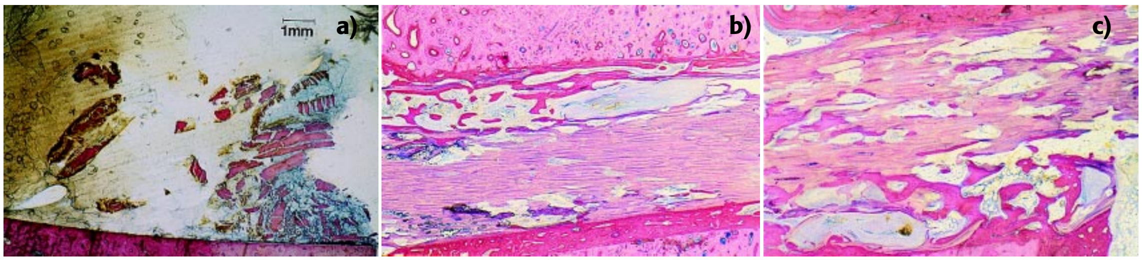

Fig. S27A: A cortical defect was filled with a plug of demineralized bone matrix (DBM). It is seen here a) a few days postoperatively, b) after 7 weeks, and c) after 12 weeks. Healing is orderly and proceeds from all sides.

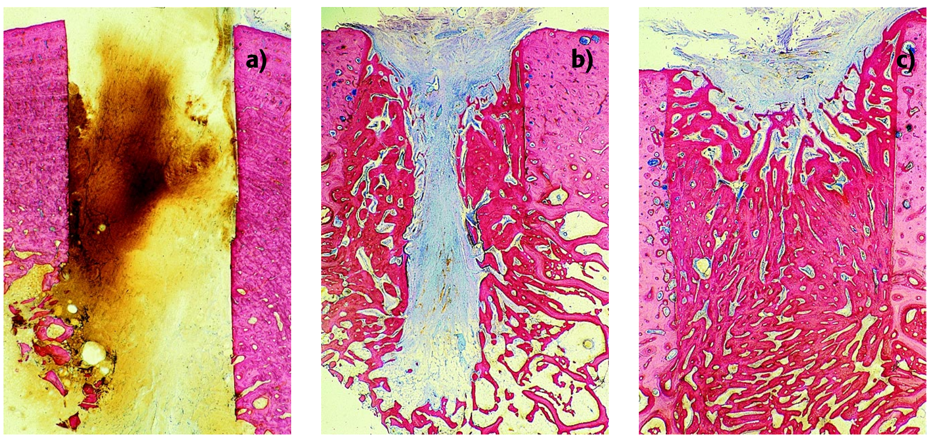

Fig. S27B: A 4.5 mm cortical defect was created and allowed to heal spontaneously. It is seen here a) a few days postoperatively, b) after 7 weeks, and c) after 12 weeks. The hematoma in the defect becomes organized, and the resultant fibrous tissue "plug" must be physically displaced by the front of bone advancing from the marrow cavity. Note the minimal periosteal involvement in healing.

planted autogenous bone graft can survive. The number of surviving cells is also influenced by the handling of such a graft. Bone grafts may exhibit an osteoinductive function by recruiting undifferentiated mesenchymal cells that differentiate into bone. This induction is probably aided by bone morphogenic proteins (BMP) which are hydrophobic, nonspecific glycoproteins [18–20]. They have been extracted from immature bone and dentin matrix, and can be elaborated by genetically engineered strains of E. coli.

Support, representing the second function of bone grafts, is mainly derived from cortical cancellous or osteochondral grafts. Cancellous bone grafts and bone substitutes provide no immediate support to the recipient bed. With the exception of vascularized cortical bone grafts, the graft types adding the most support have far fewer cells than the cancellous bone grafts. The nutrition of the graft depends on the formation of new Haversian systems and Volkmann's canals, which is a slow process at best. To summarize, the six major factors involved in the successful incorporation of a bone graft are: the host bed, the viability of the bone graft, the volume of the grafted material, BMP activity of the host bed, the metabolic activity index (MAI), and the homostructural function of the bone graft.

The bone substitutes represented in the next chapter include HA and TCP implants, as well as anorganic bovine bone. Allogeneic grafts to be discussed are those treated by acid decalcification and freezing. Those stemming from autogenous bone are the most frequently applied grafts in the horse and they will be considered first.

27.2 Autogenous bone grafts

For the most efficient transfer of a fresh bone graft, it is advisable to assign a separate surgical team to harvesting [21]. Ideally, the fresh bone graft should be harvested and immediately implanted into the recipient bed [22]. Grafting should be planned in advance and the second surgical team should be ready to perform. Any lag time between harvesting and implantation results in the loss of viable cells [23]. If only one surgical team is available, either the main surgery is interrupted when the bone graft is needed, in which case the graft is immediately transferred, or **the graft is harvested prior to fracture fixation and is stored in blood-soaked sponges.** The exposure of the graft to air or to sponges soaked with physiologic saline solution has a deleterious effect on cells and should be avoided [23]. Similarly, antibiotics should not be added to the soaked sponges since viability of the cells can thereby be compromised [24]. When the graft is added to the recipient bed, several measures should be taken. The soft cancellous bone chips should not be packed too solidly, to maintain a large surface area. This facilitates ingrowth of blood vessels. Excessive packing of the graft slows revascularization and diminishes the graft's nourishment [25]. **A cancellous bone graft should be in intimate contact with living bone and its periosteum or its medullary cavity** [26, 27].

Rigid internal fixation is important to incorporation of the graft into the parent bone, as is asepsis. Movement repeatedly disrupts angiogenesis, and bacteria bring about microvascular thrombosis.

Corticocancellous and osteochondral g rafts can confer immediate suppor t.

Wrap the tissue to be transplanted in blood-soaked sponges.

Ideally, the graft tissue should be in intimate contact with the periosteum or the endosteum.

Harvest bone g rafts from the tuber coxae, the sternum, or the proximal tibia.

A cancellous bone graft may conveniently be harvested from three locations in the horse: the tuber coxae, the sternum, and the proximal tibia [28] (Fig. F27A). All three locations are easily accessible and provide plentiful material. The surgical anatomy and surgical technique employed in the collection of autogenous grafts from the three different sites will be described below. Complications are the same for all three locations and they will be discussed collectively.

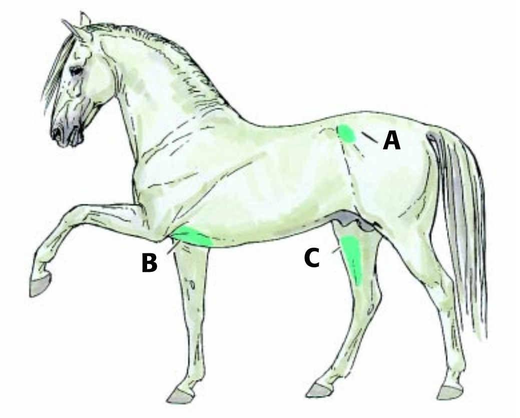

Fig. F27A: Location of the most frequently used donor sites for autogenous cancellous bone grafts:
A) tubercoxae; B) sternum; C) medial aspect of the proximal tibia.

27.3 Tuber coxae

The tuber coxae is the most frequently used donor site for cancellous bone grafts in the horse [25, 28, 29]. Until the middle of the last decade it was also the only site in routine use for harvesting such a graft in this species.

27.3.1 Surgical procedure

Harvest the g raft through an opening 5.5 mm x 1 2 mm.

The tuber coxae (Fig. F27A) is palpated and its longitudinal axis (about 10 cm long) is identified. At its center, and at a 90° angle to its long axis, a 2–3 cm skin incision is made. Sharp dissection is continued through the subcutaneous tissues and fat pad, down to the bone. Using a periosteal elevator, the periosseous tissues are partially cleared from the bone. Using the 5.5 mm drill bit, two holes are drilled through the cortex. The drill holes are prepared parallel or slightly divergent, beginning 5 mm apart. The small incision must be slightly spread. The two holes should be aligned along the long axis of the tuber coxae. **Using a small osteotome the two holes are conjoined to form an opening 5.5 mm wide and about 12 mm long. The graft material can then be harvested with a curette** (Fig. S27C). It is important to avoid breaking through the thin cortex of the ilium, which could possibly cause complications at a later stage. The required amount of bone graft is harvested and either transferred immediately or stored in blood-soaked sponges as previously described (Fig. S27D). This donor site supplies the largest amount of cancellous bone graft and represents the site of choice if the animal is in lateral recumbency. Two or three deep sutures are placed using a monofilament resorbable suture material and the skin is closed either with simple interrupted sutures or with stainless steel staples. It is advisable to suture a stent bandage over the incision as protection. A small incision is preferred over a large one because this relatively vulnerable area is difficult to protect, not only during the recovery period but also during the postoperative stage.

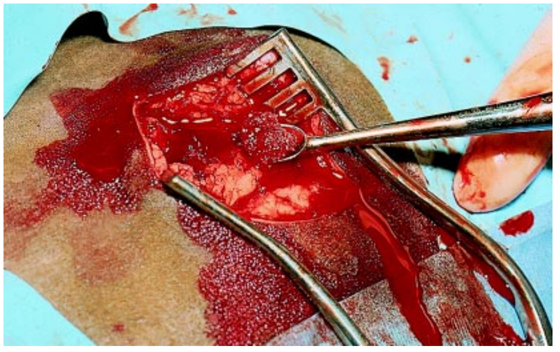

Fig. S27C: The tuber coxae is approached. The skin and soft tissues are spread with a Weitlaner retractor and the cortex is locally removed. With a large curette the cancellous bone graft is harvested.

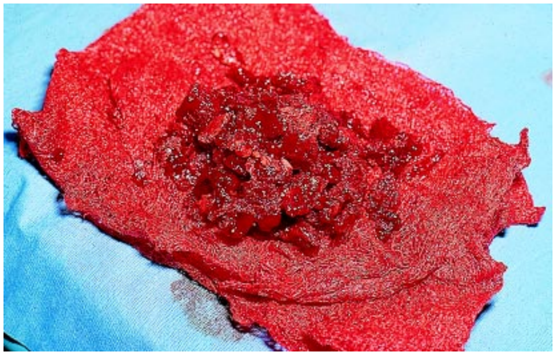

Fig. S27D: The harvested cancellous bone graft is stored in blood-soaked sponges until it is incorporated in the host bed.

27.4 Sternum

This donor site (**Fig. F27A**) is preferred during procedures carried out in dorsal recumbency (**Fig. S27E**), such as repair of long bone fractures by two surgical teams working opposite each other [30]. The sternum may also be approached with the animal in lateral recumbency, but there are several disadvantages to this: the procedure is more awkward; the uppermost forelimb has to be lifted, which is not ideal should that extremity be the one being repaired; the two surgical incisions are close together making effective draping difficult; and blood from the limb wound may enter the donor site and transmit contamination.

27.4.1 Surgical procedure

A straight incision is made on the midline along the axis of the sternum across the skin and subcutaneous tissues down to the sternum. The hyaline cartilage coverage of the sternebrae is split along the same line until the nuclei of the sternebrae can be identified (**Fig. S27F**). **The periosteal elevator is used to separate the cartilage from the individual bony elements to facilitate curettage**. The cartilage is spread with a Weitlaner retractor to improve access,

Use a periosteal elevator to separate car tilage from bone.

Fig. S27E: The horse is positioned for this procedure in dorsal recumbency. The surgical sites are draped for aseptic surgery, including the sternum serving as donor site for a cancellous bone graft.

Protect the donor site by applying a stent bandage.

and the bone graft is harvested (**Fig. S27G**). Only cancellous bone is harvested, without any of the surrounding cartilage. Once the supply in one sternebra has been exhausted the procedure is repeated until the desired total amount is obtained. About six sternebrae are readily accessible. The incision may have to be extended to provide access to enough sternebrae. Closure of the surgery site consists of an initial simple continuous layer using the Ford interlocking pattern along the outside border of the sternal cartilage. Care is taken to prevent excessive tension on the suture opposing the two cartilage flaps to prevent the suture form cutting through. By uniting these two flaps, pressure is exerted upon the cartilaginous incision helping to control postoperative hemorrhage. The subcutaneous tissues are closed with a simple continuous pattern and the skin in a simple interrupted pattern using nonresorbable suture material (Supramid) or stainless-steel staples. **A stent bandage is applied over the surgery site to protect it from contamination, especially during the recovery period.** Bandaging of the area is impractical.

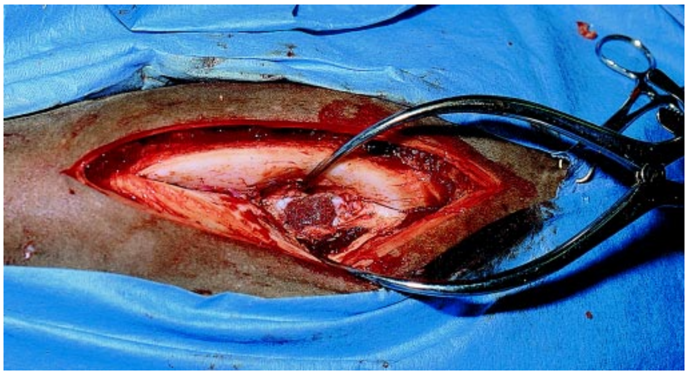

Fig. S27F: A sternebra is approached exhibiting its cancellous nature. The cancellous bone graft can be harvested.

Fig. S27G: The amount of cancellous bone graft that can be harvested from one sternebra is shown on a sponge. If more graft is needed another sternebra is approached through the same incision.

27.5 Proximal tibia

Early reports indicated that the proximal tibia was not suited for harvesting bone grafts because of the danger of postoperative fracture. **More recent work showed that this risk is small if the donor site is close to the femorotibial joint**. Harvesting of a cancellous graft from this region is now considered safe [31].

27.5.1 Surgical procedure

The medial and proximal aspect of the tibia is identified and palpated. This area is covered only by skin, subcutaneous tissues, fascia, and periosteum (**Fig. F27A**). A straight incision is made in the selected region starting 3 cm distal to the joint surface and extending over a length of 5–6 cm. The periosteum is elevated from the underlying bone and, using a 5.5 mm drill bit, the cortex is penetrated in one or two places. This allows adequate access to the bone marrow for harvesting a bone graft. If two holes are placed relatively close to each other, they can be connected by removing the intervening lamina with a chisel or rongeur forceps. This creates a relatively large hole, through which removal of a massive bone graft is facilitated. Closure of the incision is routine and the surgery site is covered with a stent bandage for the initial 4–6 postoperative days.

27.6 Postoperative treatment

Since all three regions are very difficult to bandage, stents are sutured over the skin incision to provide at least some protection. No other treatment is required. Regular postoperative assessment of the donor site is indicated, allowing early recognition of any developing complication.

Obtain g rafts from the proximal tibia close to the femorotibial joint.

27.7 Complications

Skin dehiscence should at all costs be avoided because infection usually follows and can prove refractory to treatment. Perioperative antibiotics are used in the postoperative phase following all fracture repairs. Administration of broad spectrum antibiotics may be the best treatment for such a complication. However, treatment should be applied in conjunction with establishing drainage of the infected site. Since the marrow cavity was opened during the collection of the bone graft, deep infection must be presumed. Gravitational forces further enhance extension of the infection distally. Therefore drainage of the tibial marrow cavity (for instance) should be established further distal. If an infection occurs at the tuber coxae, drainage of the fluids should be established through the original incision, or through a stab incision prepared next to it. Propagation of the infection along the bone surfaces results in the development of deep abscesses that are very difficult to drain. Septicemia with metastasis to the surgical site may occur, often necessitating euthanasia.

Infection at the donor site(s) can prove par ticularly difficult to manage.

Postoperative fracture at the donor site of the proximal tibia may be a sequel of harvesting a bone graft and has been reported in the past. Should this occur, euthanasia is the only reasonable solution.

27.8 Results

Prognosis for the healing of the donor site is, in the large majority of cases, excellent.

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27.9.1 Online references

See online references on the PEOS internet home page for this chapter:
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28 Allogeneic grafts and bone substitutes

Jörg A. Auer & Gustave E. Fackelman

28.1 Description

The use of allogeneic grafting materials in the horse was inspired by the desire to **eliminate the need for a second (harvesting) operation** (**chapter 27**, Bone graft biology and autogenous grafting), thus saving time and avoiding potential complications. More recently, in other species, further interest has been spurred by the need to prevent the spread of transmissible disease (HIV, FIV) [**1**, **2**].

28.2 Surgical procedure

Many techniques for preparing the bony tissue for storage ("banking") and subsequent use have been investigated, but the most practical for use in clinical practice appears to be acid decalcification followed by freezing, as previously described [**3**]. Typically, a young horse free of systemic disease but destined for euthanasia is selected as a donor. One side of the thorax is clipped and scrubbed prior to lethal injection. The horse is then positioned for aseptic surgery, and final scrubs and disinfections are carried out. Following draping, the soft tissues over one hemithorax are removed (**Fig. S28A**) and the individual ribs are circumferentially freed from their periosteal covering (**Fig. S28B**). The ribs are then cut in serial cross-sections (**Fig. S28C**) and the bony tissue is cleansed of soft tissue tags.

The use of allografts eliminates the need for a second (harvesting) operation.

Fig. S28A: Under aseptic conditions, the ribs on one side of the thorax are exposed in a young, recently euthanazied horse.

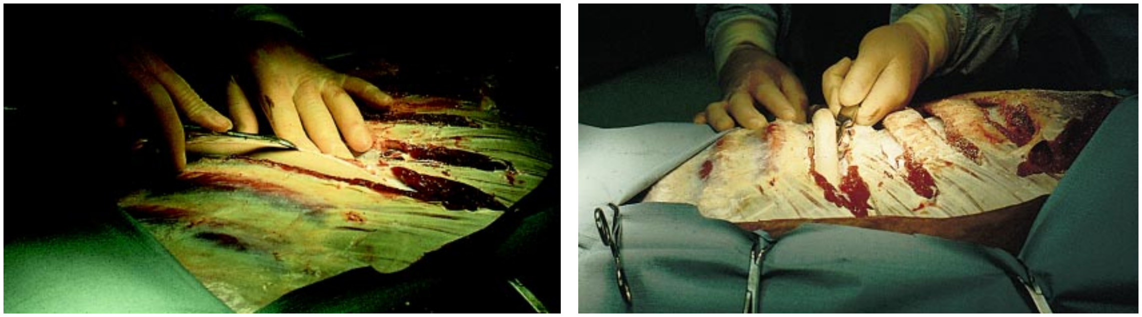
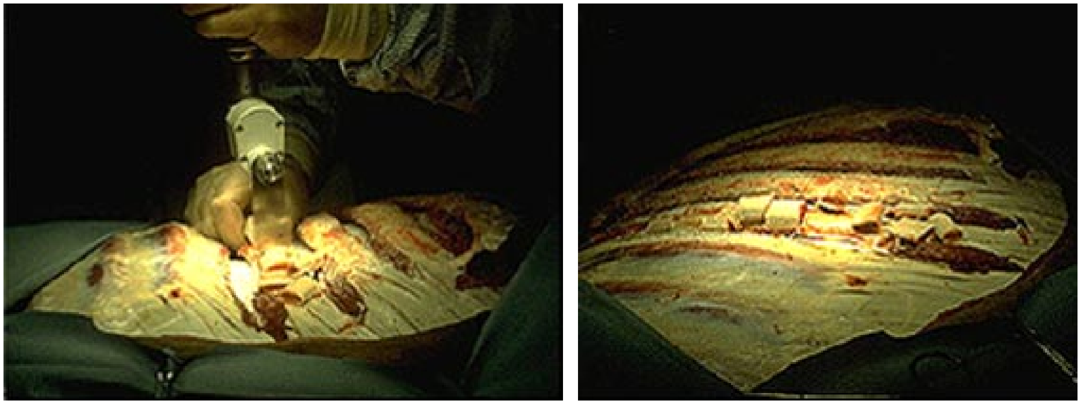


Fig. S28B: The periosteum is removed first from the parietal side of the ribs, then from the visceral side. There is a periosteal elevator made specifically for the latter operation.

Fig. S28C: Beginning closest to the spine, the readily accessible ribs are cut into 2.5–3.0 cm cross-sections.



The short cross-sections are split longitudinally by tapping with a chisel and placed in a saline bath (**Fig. S28D**). Any blood remaining in the marrow spaces is removed by washing, and the cleaned tissues are placed in the acid bath to decalcify (**Fig. S28E**). In 1 hour enough graft material can usually be obtained to supply the average referral practice for a year or more. The fluid is changed daily, and periodic radiographic monitoring reveals the degree of decalcification. Individual pieces of bone are placed in vials and frozen (**Fig. S28F**). When removed they thaw rapidly in physiologic saline at room temperature and may be cut to fit into many different-sized defects (**Fig. S28G**).

Acid decalcified frozen bone has a rubber-like consistency when reconstituted, and can be easily cut and modeled to fit into a defect. It has been shown to be osteogenic in both heterotopic and orthotopic locations. Treatment with 0.6 N hydrochloric acid results in greatly reduced, if not completely eliminated, immunogenicity and in sterilization of the product. The material can be used as a carrier for other substances [4, 5], or its volume can be augmented by the addition of bone substitutes [6–8].

Decalcified bone matrix is easily cut to fit a defect.

Fig. S28D: Using a chisel, the individual sections split easily with a tap. Any remaining soft tissue tags are removed and the sections are placed in a saline bath.

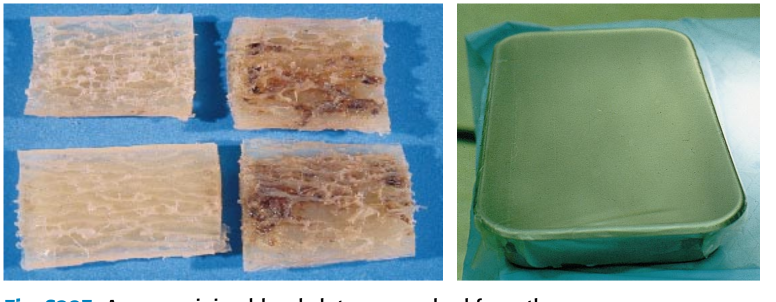


Fig. S28E: Any remaining blood clots are washed from the marrow spaces, and the bone pieces are placed in a sterile, covered acid bath and kept under refrigeration.

After decalcification, freeze the bone and store it in small quantities.

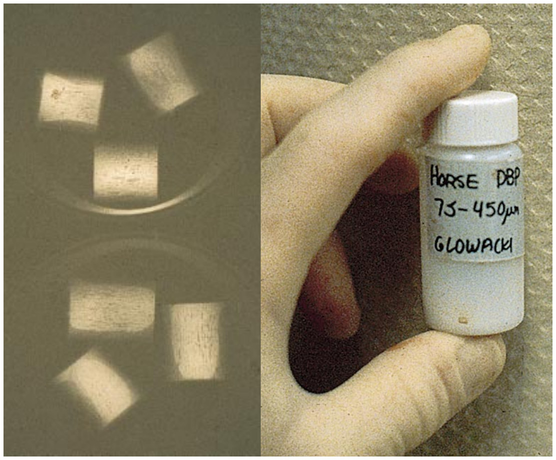


Fig. S28F: Decalcification typically takes 5–9 days; perodic radiographic exposures monitor progress. When decalcification is complete, the bone pieces are frozen in individual sterile vials.

28.3 Complications

To date no "rejection" response has been reported, but infection at the site constitutes more of a disaster as concerns the long-term outcome or "take" of the graft than it does in the case of an autogenous graft.

28.4 Results

There is an initial lag phase in revascularization relative to autogenous material, but this appears to disappear with time and by 9 weeks post-operatively the two graft materials show about the same degree of repopulation by osteoblasts. As is the case with autogenous grafts, it appears important not to "pack" the material too tightly into the defects, as the penetration of new vessels is thereby placed at a disadvantage.

The risk of transmitting infectious disease is reduced by using bone substitutes.

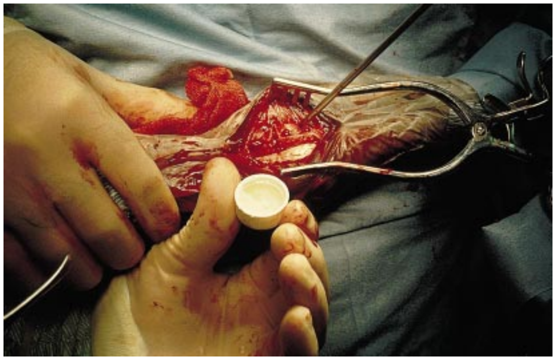


Fig. S28G: After thawing, the pieces may be cut with scissors into appropriate sized and shaped grafts, here being fitted into a cyst in a proximal sesamoid bone.

28.5 Bone substitutes

Especially in human surgery, research into the use of various types of ceramics and artificial bone substitutes has expanded greatly in the last few years, mainly because of **the fear of transmitting diseases such as hepatitis and AIDS from one human to another** [9]. The danger of transmitting such a fatal disease in humans is about 15 times smaller if a bone transplant is used compared to a blood transfusion [10]. This level of danger cannot be ignored in human surgery. Veterinary surgery may well profit from the knowledge gained through research in bone substitution, most of which is carried out in animals.

Bone substitutes are also necessary in cases where an insufficient amount of autogenous bone graft is available to be transferred either from one site to another within the same animal, or from one animal to another [11]. This is not frequently encountered in the horse; however, in small animals it might be a real factor. However, the application of a bone substitute does eliminate the need for a second surgical procedure on the same animal. This would reduce the total surgery time or the surgery personnel in cases where a second surgical team is used to harvest the bone graft [11]. The morbidity of the animal is also reduced because the cumulative effect of trauma to various sites can be spared. The prerequisite, however, for a bone substitute to be used is the availability of an ideal material containing the desirable attributes of living bone, which would be rapidly accepted by the body and incorporated into a bone structure, possibly even substituted or biodegraded and replaced by normal bone [9, 12, 13]. This is a great deal to ask of such a material.

The most important prerequisites for the ideal bone substitute include: good tolerance without reaction from the host, high osteoconductive or possibly even osteoinductive actions; mechanical stability to allow earlier loading of the implants; and, a timely incorporation, possibly associated with resorption of the material and substitution by normal bone [14]. No material fulfills all these criteria and therefore the surgeon needs to make a compromise based on the particular materials available and the particular surgical situation encountered.

For a calcium containing implant, such as tricalcium phosphate (TCP) or hydroxyapatite (HA) to be accepted by the recipient bed, a biologic apatite layer has to be deposited onto the implant surface. Such a deposition could also be demonstrated if the bone substitute was implanted in an ectopic site, such as in soft tissue structures. The apatite layer probably serves as the substrate for protein adsorption and the subsequent attachment of bone cells [10]. Implants containing natural bone material (e.g., Bio-Oss®) are incorporated more rapidly into the host bone than are synthetic bone substitutes because their surface already contains the biologically active apatite. This fact underlines the necessity of this biologic apatite layer to be present for ideal bone bonding, and may be one of the reasons for the increased use of inorganic bovine bone as a bone substitute.

Among the clinically important bone substitutes are two synthetic calcium phosphate products (TCP and HA) and one inorganic specially prepared bovine bone (Bio-Oss®). As previously mentioned, bone bonding, which is needed for good incorporation of the graft, is basically the same for all three materials , but somewhat faster for the inorganic bovine bone [10]. The fragmentation and resorption process is the same for all three substitutes, although the speed with which degradation occurs is substantially different. All bone substitutes, even those that are non-resorbable, are degraded to a certain extent over time. Not all of the resorption processes are understood, and different studies seem to show different results. A 1-year study with TCP showed that osteoclasts or macrophages could take up a substantial quantity of small TCP granules [13]. The cells with the incorporated TCP seemed to lie in the TCP block being resorbed without demonstrating any activity. The HA implants are, for all practical purposes, not resorbable, but a certain amount of resorption does take place. According to the literature, fragmentation of bone substitutes is based on chemical/physical processes [11]. Some bone substitutes are actually resorbed, meaning that they are degraded through osteoclastic activities

Hydroxyapatite (HA) is resorbed very slowly, if at all.

Porous bone substitutes can act as carriers for other substances.

[12]. The speed at which this fragmentation or resorption occurs depends on the composition and density of the material. A dense material containing small pores may take longer to be resorbed than one with relatively large pores. **One interesting attribute of the porous substitutes, as well as of inorganic bovine bone [14], is their ability to absorb other substances, such as drugs (e.g., antibiotics)**. Special bonds, which these medications establish with the calcium phosphate, may allow a release over several weeks. This may be advantageous in certain situations, such as open fractures. The three substitutes HA, TCP, and anorganic bone (Bio-Oss®) will be discussed in more detail below.

28.5.1 Hydroxyapatite (HA)

It has been shown that HA is well tolerated by living tissues and that the pores within an implant are readily filled by new bone [15]. HA can be manufactured in any shape or form such as cylinders, blocks, and granules of various degrees of porosity. **This material has osteoconductive properties [16] and is very slowly resorbed—some classifications in fact consider it a nonresorbable implant.** HA has a certain resistance to pressure when compared with TCP. In human spinal applications, the substitute facilitates fusion between vertebrae.

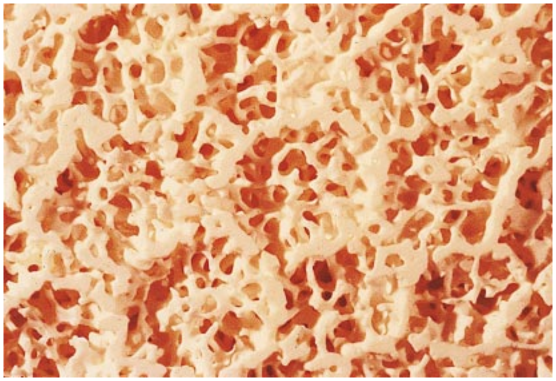


Fig. S28H

Fig. S28I: Graphic representation of the scaffold character of a porous bone substitute block when it is implanted (left) and during the process of being filled in with bone (right): A) the cavity is filled in with granulation tissue; note the centrally located vessels.

A subgroup of HA is coralline hydroxyapatite containing the same structure as coral (**Fig. S28H**). The structure serves as a scaffold (**Fig. S28I**), facilitates ingrowth of vessels, and accommodates the subsequent deposition of new bone within its pores (**Fig. S28I**). This material has also been studied in the horse [17, 18]. Cylindrical defects were created in the distal MC3 and filled with this material. It could be shown that bone grew into the scaffold at the distal two thirds of the implant (**Fig. S28J**). However, the portion near the articular surface was not covered by bone, possibly due to the washout effect of the synovial fluid. Bone ingrowth into the implant was studied for up to 6 months. HA is currently applied infrequently in the horse. In humans, however, it is being applied as coverage of metal implants [15], such as acetabular cups. This coverage facilitates ingrowth of bone, which helps stabilize the cup [13].

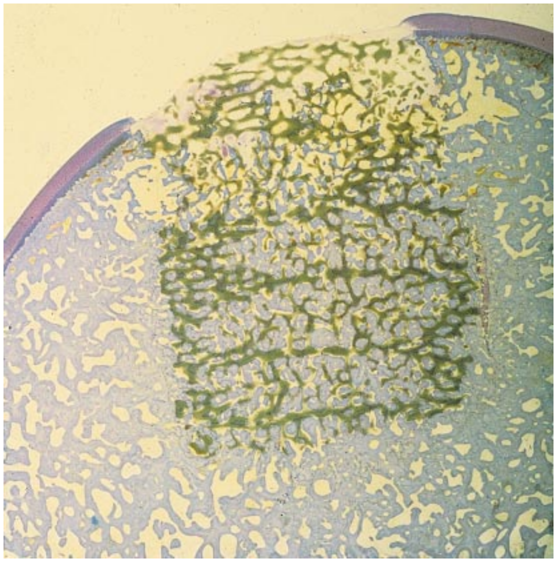


Fig. S28J: Transverse section of the distal condyle of MC3 6 months after intra-articular implantation of a coralline HA block. The scaffold character is easily visible (dark) throughout the block. The portion of the block exposed to synovial fluid is void of osseous ingrowth, whereas the deeper zones are fully filled out with bone.

28.5.2 Tricalcium phosphate (TCP)

In contrast to HA, **TCP is a rapidly biodegradable product.** According to researchers it is truly substituted by bone, starting with osteoclastic implant resorption followed by bone formation, a process called creeping substitution [13]. TCP is well accepted in biological tissues as well as in bone. It has osteoconductive abilities and seems to work faster than HA. **TCP shows very little resistance to pressure and is best incorporated into a relatively protected recipient site.**

Tricalcium phosphate (TCP) is rapidly resorbed.

TCP is best used in relatively protected sites.

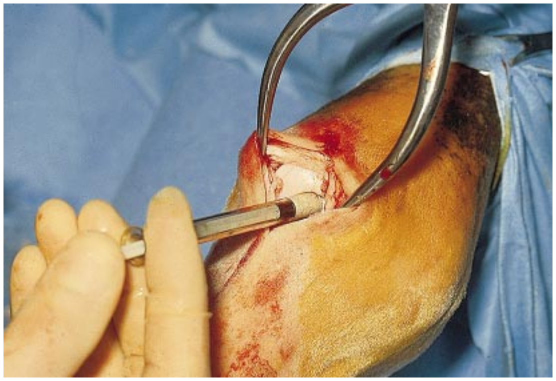


Fig. S28K: Implantation of Ossgraft into an artificially created articular defect in the distal MC3.

Two different types of TCP have been studied in the horse: Ossgraft and Ceros–82. Ossgraft is supplied in powder form in a small syringe, into which water is drawn up for mixing purposes. The slurry is subsequently applied to the recipient site (**Fig. S28K**) and slightly impacted to assure that the bone substitute remains in place. In a 1-year study, where this material was implanted into the weight bearing articular surface of the distal MC3 in horses, no improvement in incorporation or ossification speed (**Fig. S28L**) could be noted compared with control defects created in the same animals [18, 19]. In two cases, cystic type lesions developed having no apparent connection with the articular space.

In the Ceros–82 study, TCP cylinders of 25 mm length and 11 mm diameter (**Fig. S28M**) were incorporated into the weight bearing articular surface of the distal MC3, as well as in the dorsal cortex of the distal MC3 (**Fig. X28A**) [18, 20–22]. Identical defects were created in the opposite forelimb, but nothing was implanted to serve as controls (**Fig. X28A**). The implants were well accepted and partially resorbed within 1 year (**Fig. X28B**). The control defect in the dorsal cortex healed well within the same time-frame, displaying only a small scar (**Fig. X28B**). In some control defects in the articular surface, however, cyst-like lesions persisted throughout the evaluation period (**Fig. X28B**). It could be shown that in the previous medullary cavity, which the cylinder penetrated, large cavities developed, resembling somewhat the cancellous bone located in the region surrounding this cylinder (**Fig. S28N**). In the cavities large cells containing TCP particles could be noted (**Fig. S28N**). In the part of the cylinder that was adjacent to the cortical region of the distal MC3, only small cavities were seen, which again resembled the

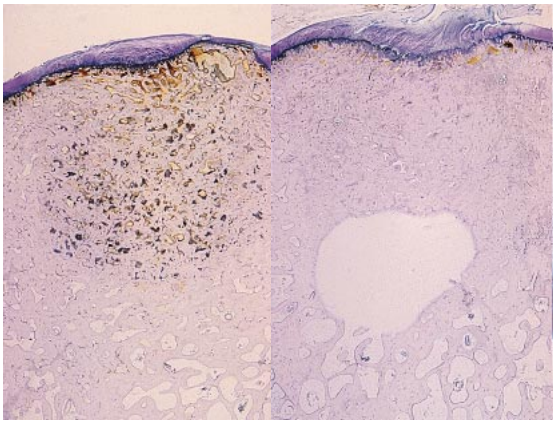


Fig. S28L: Transverse section of the distal condyle of MC3 12 months after intra-articular implantation of an Ossgraft bone substitute (left) and its control (right). Both defects filled in satisfactorily. The Ossgraft (mostly TCP) biotransformed almost completely to bone. Only some HA granules which were present persist (dark granules). The unfilled control defect filled in substantially, however a relatively large cystic lesion is clearly visible. Both articular sufaces have healed to a certain extent, even acquiring some proteoglycan staining.

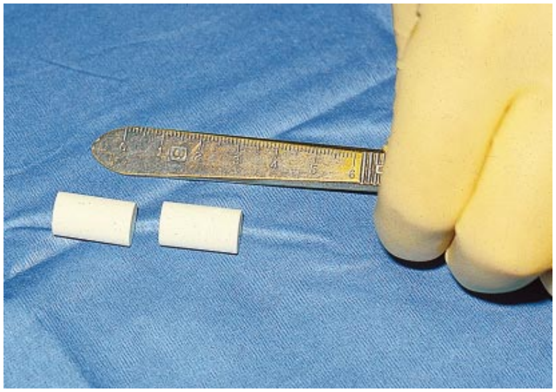


Fig. S28M: TCP cylinders (Ceros-82) measuring 11 x 25 mm which were implanted into osseous defects.

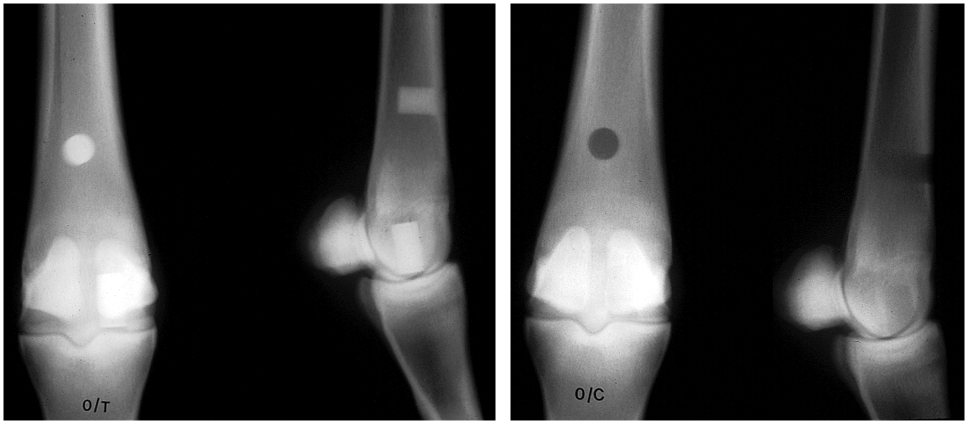


Fig. X28A: Immediate postoperative lateromedial and dorsopalmar radiographs of the metacarpophalangeal region of a research horse. Left: osseous defects in the articular suface of the medial condyle and the dorsal cortex of the distal third of MC3 are filled with a TCP cylinder each.
Right: identical defects were left unfilled as controls.

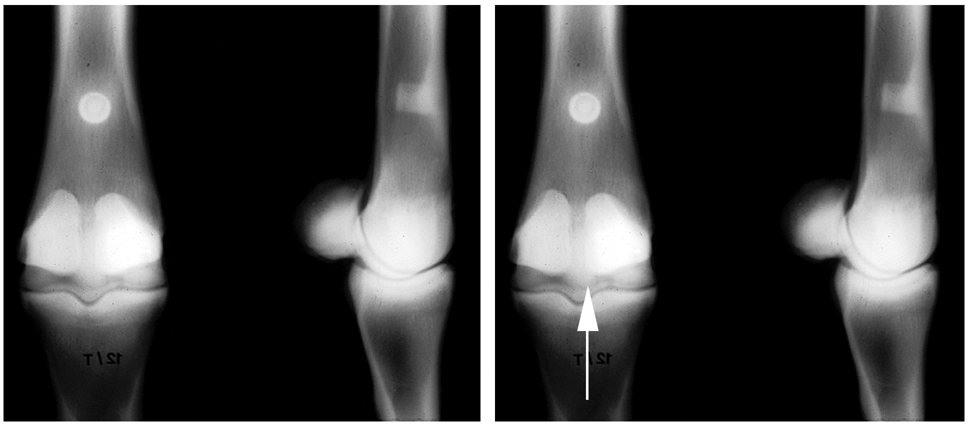


Fig. X28B: One year follow-up radiographs of the same animal as in **Fig. X28A**. The TCP cylinders (left) are well incorporated and partially substituted by bone (the contours are not as sharp as at the time of implantation). The control defects (right) have filled in almost completely, however, a cystic lesion (arrow) persists in the articular suface.

TCP may be mixed with autogenous grafting material.

surrounding cortical bone (**Fig. S28O**). The implant located in the cortex was well penetrated with osteons (**Fig. S28O**). It is an interesting phenomenon and reflects the influence of the physical environment on the final structural characteristics of the resultant bone. The articular surface covering the implant exhibited a smooth surface, and in certain areas proteoglycan deposition could be noted (**Fig. S28O**, right). TCP may therefore also be a viable implant to be used in articular defects, such as subchondral cystic lesions. **This author (JAA) has used TCP granules in conjunction with cancellous bone grafts in a wide variety of clinical applications with quite satisfactory results**. Possibly the addition of a bone marrow aspirate to TCP similar to that shown effective with demineralized bone matrix [**23**] may enhance incorporation of the graft into the parent tissue [**24**, **25**].

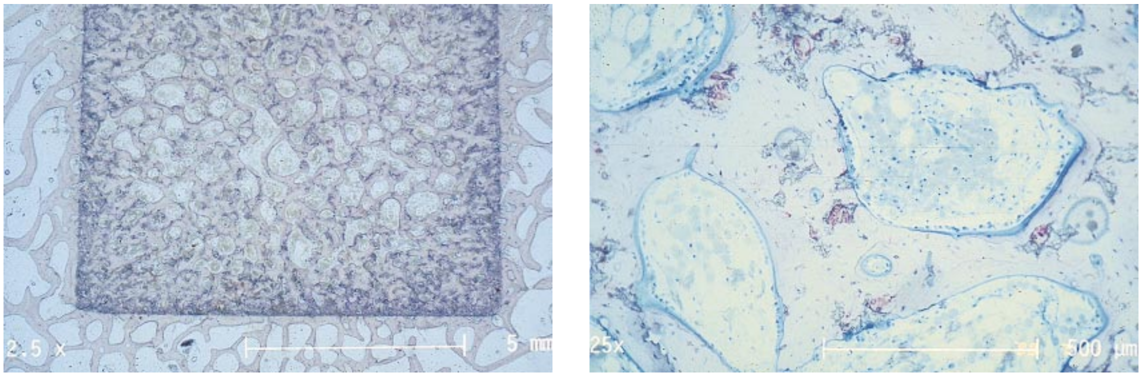


Fig. S28N: Transverse histologic section of the dorsal cortex defect filled with a TCP cylinder. Note the pefect incorporation of the cylinder in the medullary region (left). A close-up view depicts giant cells filled with HA granules (right).

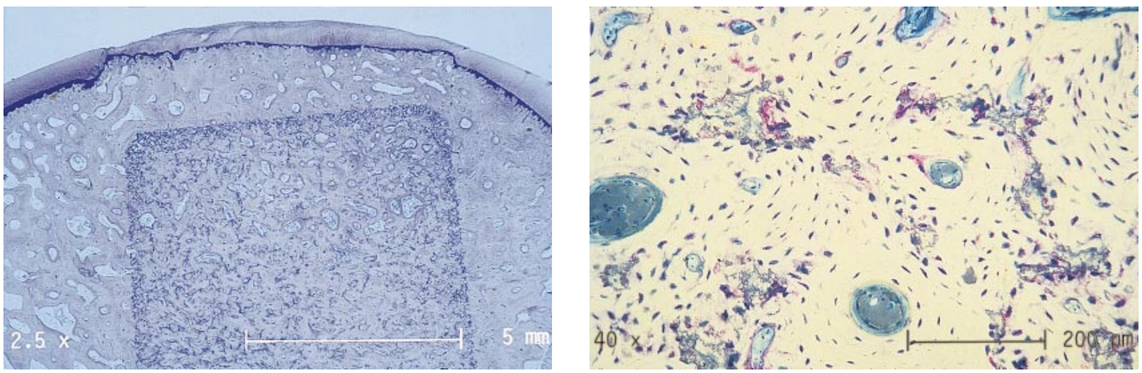


Fig. S28O: Transverse histologic section of the articular defect filled with a HA cylinder. Note the perfect incorporation of the cylinder in the cortex and subchondral zone, as well as the articular cartilage coverage (left). A cross-section shows the osteonal remodeling of the defect and the TCP granules accumulated in the central osteonal canal (right).

The fact that TCP can be impregnated with medications and serve as a storage and transport system for drugs may be looked upon as an additional benefit [12]. The bonding of the gentamicin to the surface of TCP allows slow release of the antibiotic over a period of 3 months. The combination is used mainly in the treatment of osteomyelitis and has shown promise. A case of septic physitis in a foal was successfully treated with curettage, application of a mixed cancellous-gentamicin impregnated TCP graft, and external coaptation (**Fig. S28P**, **Fig. S28Q**, **Fig. X28C**, **Fig. S28R**, **Fig. X28D**). The infection could be cured, but a partial collapse of the former

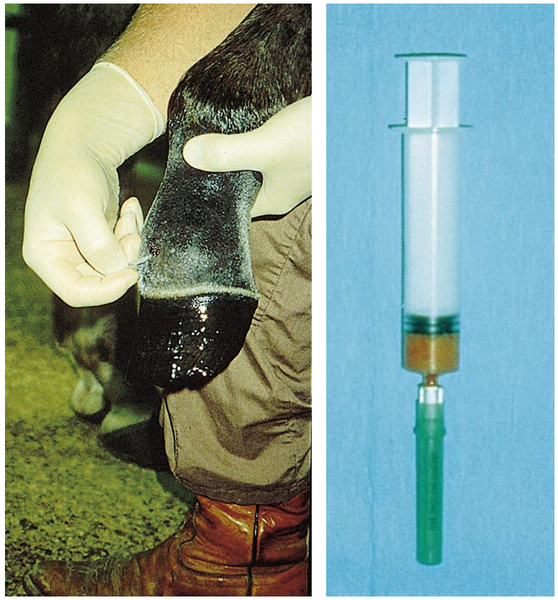


Fig. S28Q: An arthrocentesis of the proximal interphalangeal joint (left) reveals purulent synovial fluid (right).

Fig. S28P: A 7-month-old Arabian foal with septic physitis in the left middle phalanx: overview (left) and close-up (right). Note the marked swelling in the phalangeal region of the left forelimb.

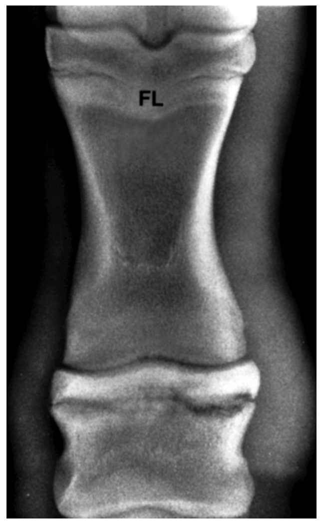


Fig. X28C: Dorsopalmar radiographic view of the involved region, depicting the abnormal widening of the proximal physis of the middle phalanx.

Fig. S28R: The infected physis was curetted (left). A cancellous bone graft was harvested and mixed with gentamicin-impregnated TCP granules (middle). The graft was subsequently implanted into the host site (right).

Fig. X28D: Immediate postoperative dorsopalmar (left) and lateromedial (right) radiographs of the patient shown in Fig. S28P, depicting the implant material clearly.

Gentamycin-impregnated TCP can be used in the treatment of bone infection.

TCP does not withstand loading.

joint had to be accepted during the process of proximal interphalangeal joint ankylosis, resulting in a valgus deformity (Fig. S28S, Fig. X28E). Also, **gentamicin- impregnated TCP was successfully applied in the treatment of open fractures in horses and prevented development of osteomyelitis** despite fracture treatment by means of internal fixation.

TCP granules are most frequently applied in animals during surgical fracture management or in arthrodesis. TCP blocks are used infrequently. If such a block is used, proper stabilization by means of internal fixation implants is important. **TCP is very brittle and does not tolerate drilling or fixation by means of screws** [12]. Screws could possibly cross the implant, but no holding power is exhibited. This is somewhat different from HA where minimal holding power could be expected.

Two month follow-up of the patient shown in **Fig. S28P**:

Fig. S28S (left): Note that the swelling is markedly reduced and the wound that developed postoperatively has healed.

Fig. X28E (right): Note the fusion which occurred in the proximal interphalangeal joint and the marked angular deformity which developed postoperatively. The animal was able to bear full weight on the limb.

Fig. S28T: Overview of a cortical Bio-Oss® specimen (left) and a close-up view of an osteonal vessel canal (right).

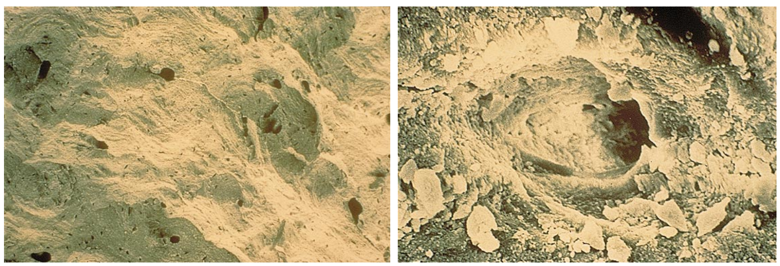
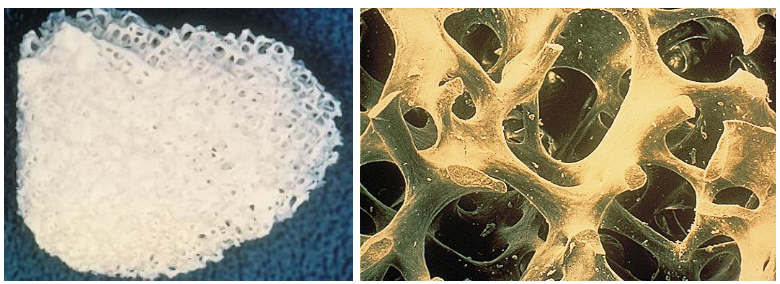


Fig. S28U: Overview of a porous cancellous Bio-Oss® block (left) and a close-up view, depicting the trabecular pattern of the sample (right).



28.5.3 Inorganic bovine bone

Inorganic bovine bone represents a type of apatite that is natural and unchanged [14]. The bone is harvested, thoroughly cleaned, defatted, and the collagen which is contained within the bone is digested. Several types of this material can be applied, cortical bone (**Fig. S28T**) as well as cancellous bone (**Fig. S28U**), either in blocks or in granules. Recently, collagen-covered blocks were introduced that differ from the synthetic calcium phosphates in that the material receives less heat treatment during its final preparation [14]. As a result, the fine crystalline nature of the bone, detectable with chemical analyses as well as radiography, is preserved. The crystals, which have the shape of small platelets, have a density of a maximum 100 Ångstrom units and contain about 38% calcium [12, 14]. **The phosphor percentage is 17% and the substance is almost entirely free of organic materials.** The stability of the material depends upon its preparation and ranges from very little in a cancellous blocks to considerable in cortical blocks. These materials show a better osteoconductivity than the synthetic materials since they already contain on the surface a biologically active apatite layer [12]. The material is used extensively in orthopedic and maxillofacial surgery to fill defects. Good results and good incorporation by the host tissue could be shown in a large number of cases (**Fig. S28V**) [26]. In veterinary surgery some studies are presently being pursued. It is being used, especially in osteomyelitis cases where the Bio-Oss® can be combined with the antibiotic Taurolin® (**Fig. S28W**). To date, good results could be achieved and this material warrants further investigation and wider application by veterinary surgeons.

Bio-Oss® is almost entirely free of organic material.

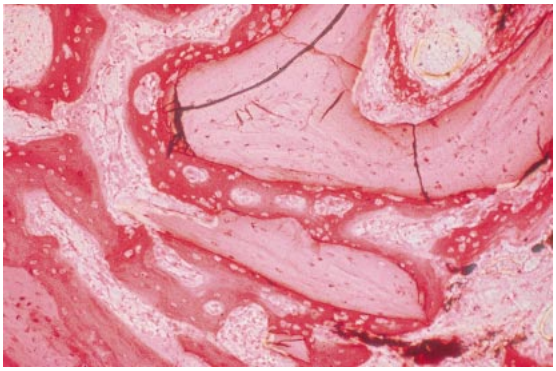


Fig. S28V: Histologic section of bone that developed around a cancellous Bio-Oss® implant.

Fig. S28W: Sterile wrapped Bio-Oss® bone substitute with a package of Taurolin® gel antibiotic.

28.6 General considerations

If blocks are applied as bone substitutes, a good press-fit needs to be established between the parent bone and the substitute because gaps greater than 1 mm cannot be bridged as easily as smaller ones [14]. Additionally, absolute stability between the parent bone and the implant needs to be present if blocks are expected to be incorporated. Should granules be applied to a recipient bed, the stability is not of great importance. Generally, the granules will be surrounded by a blood clot containing pluripotent cells that develop into osteoblasts. The addition of a cancellous bone graft to a bone substitute may be beneficial, because it allows filling of a greater defect with a relatively small amount of fresh graft. **The autogenous cancellous bone supplies pluripotent cells facilitating rapid ingrowth.** A similar sequence should follow introduction of a bone marrow aspirate.

28.7 Complications

28.7.1 Granules

Granules, if placed in an infected area, may not be incorporated but rather sequestered and flushed out, especially with so-called ingress/egress drainage systems. This may be minimized if substitutes impregnated with an antibiotic are used, since resolution of the infection may be accelerated.

28.7.2 Blocks

If a block is being applied to a fracture or as a space filler with insufficient protection, disintegration of the block may occur resulting in an unstable fixation predisposed to breakdown. Infection may result in sequestration of the implant, followed by disintegration and extrusion.

Protect blocks used as fillers from full physiologic loading.

Materials grafted as blocks must be in intimate contact with the host "bed".

Addition of an autogenous graft provides pluripotential cells and speeds up ingrowth.

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28.8.1 Online references

See online references on the PEOS internet home page for this chapter:
http://www.aopublishing.org/PEOS/28.htm

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29 Fracture documentation

Gustave E. Fackelman, Jörg A. Auer,
Joffrey C. Norris

AO equine fracture documentation system

Version 4.0

29.1 AO EqFx 4.0 user guide

AO Equine Fracture Documentation System for Microsoft Windows and Apple Macintosh Computers.

29.1.1 Installation

The AO Equine Fracture program must be installed on your hard disk using the supplied installation floppies. Two different versions of the program are available—Microsoft Windows (including Windows 95 and Windows NT) and Macintosh (including 680X0 and PowerPC)—so be sure you have the correct version for your platform. **EqFx requires four to eight megabytes of disk space, depending on your platform**.

To install the EqFx application, run the self-extracting archive “AO EqFx v4.sea” (Macintosh) or the installation program “a:\setup.exe” (Windows) found on the EqFx Disk1.

29.1.2 Starting the application

The EqFx application—AO Equine Fracture—can be launched from the Windows Start Menu or the Macintosh Finder.

29.1.3 Setting preferences

The preferences dialog (**Fig. F29A**)can be accessed at any time by using the “Settings ...” command in the “Script” menu. This dialog appears automatically when the program is launched for the first time or when no user name has been entered. The “Default Doctor Code” pre-enters a doctor’s name in any new case (although this entry can be edited at any time).

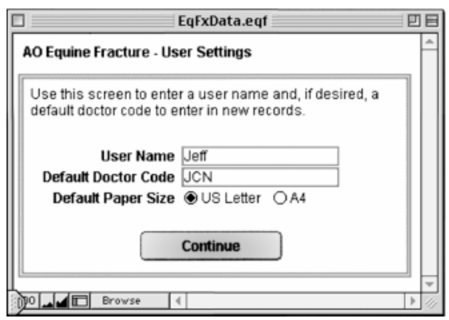

Fig. F29A: Preferences dialog.

EqFx requires 4–8 MB free hard disk space, depending on the platform being used.

29.1.4 EqFx “pages”

Each case in the current data set contains dozens of data “fields”. Because there are too many fields to display on your computer screen, these fields are organized into “pages”. A typical page is shown in **Fig. F29B**:

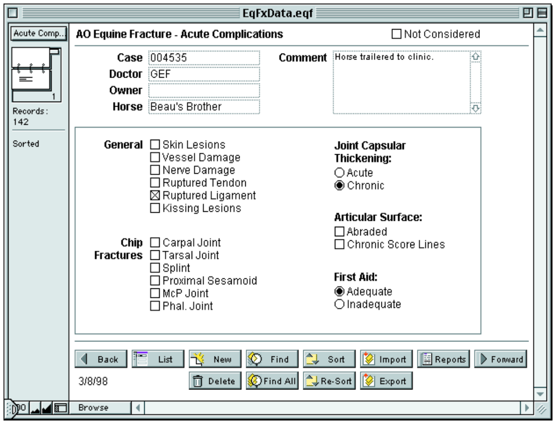

Fig. F29B: EqFx page.

Data is entered on pages using the mouse and/or keyboard to click on and/or type in radio buttons, checkboxes, pop-up menus, or text fields.

If there is a page which is not relevant or for which there is no data for the current case, you may wish to mark the “Not Considered” checkbox for that page. This option is available on every page except “Biographical Data” and “Fracture Classification”.

Each page contains a “Comment” field which can contain any amount of text providing additional information relevant to the current case and page.

Enter any amount of text in the comment field, to provide additional information.

29.1.5 Navigating among EqFx pages

To move through the EqFx pages you can click on the page navigation buttons located on every page (**Fig. F29C**):

Fig. F29C: Navigation buttons on each page.

You can also click on the “PageList” menu to skip quickly to any page (**Fig. F29D**):

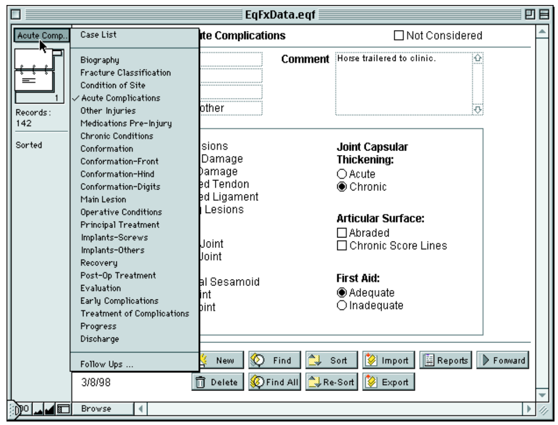

Fig. F29D: “Page List” allows you to skip to any page.

Page navigation commands with their keyboard shortcuts are also located in the “Script” menu.

29.1.6 Page 2: The fracture classification page

Central to the documentation of an equine fracture case is the classification of the fracture itself. The fracture classification page (**Fig. F29E**) is designed to assist you in making this classification.

Here you are guided through the classification system one level (or optionally two or three levels) at a time. When the classification is fully detailed, you are returned to the fracture classification page where the corresponding code is automatically entered. If, while using the fracture classifier you do not want to further subclassify the current code, simply click the "Done" button.

Use the fracture classifier as a guide to the levels of the classification system.

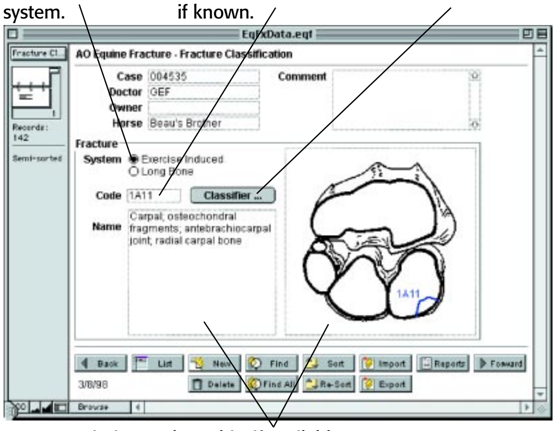

Fig. F29E: Fracture classification page.

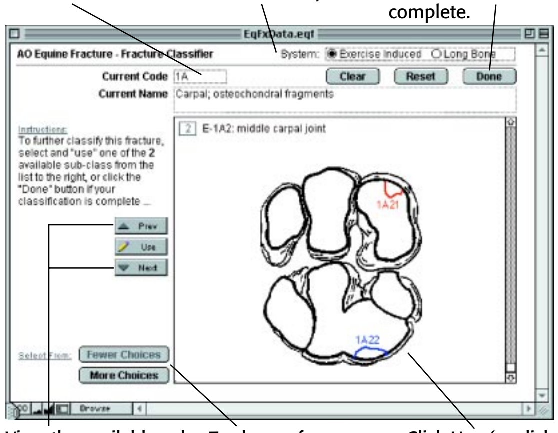

Fig. F29F: Fracture classifier.

EqFx 4.0 supports two fracture classification systems, "Exercise Induced" and "Long Bone". The applicable system must be selected before a classification can proceed.

If a fracture code (or a portion of the code) is known, this code can be entered directly into the "Code" field. If the code is not known, classification can nevertheless be made by clicking the "Classifier…" button and utilizing the fracture classifier (**Fig. F29F**):

29.1.7 Follow-up records

Each case in the database can include multiple follow-up records as the patient's recovery progresses. The initial follow-up screen (**Fig. F29G**) presents a list of existing follow-ups, which can be edited by clicking in the list, along with a button to create a new follow-up for the current case:

Use as many follow-up pages as necessary to fully describe the healing process.

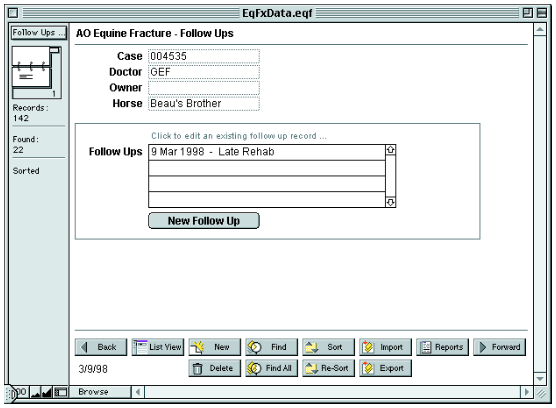

Fig. F29G: Follow-up record.

In the follow-up data entry screen (**Fig. F29H**) you should be aware that **the case code entered links the follow-up record to its respective case record**. Therefore, altering the case codes of records which include follow-ups may result in these follow-up records becoming detached from their cases! To return to the regular case pages from the follow-up data entry page, click the "Back" button.

The case code entered with biographical data serves to link a case to its follow-ups.

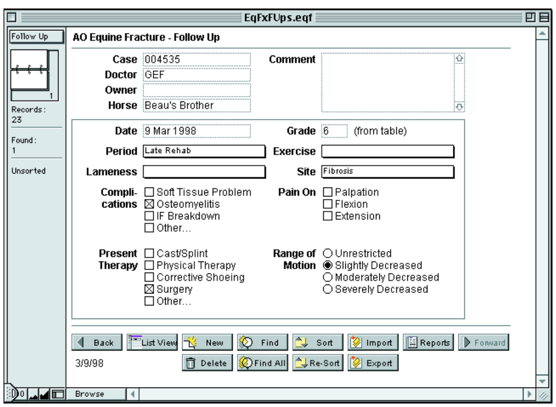

Fig. F29H: Follow-up data entry.

29.1.8 Adding and deleting cases

The number of cases that an EqFx data set can contain is limited only by the amount of disk space on the user's computer. To add or delete a case from the current data set, use the "New" or "Delete" buttons. Adding a new case always resets the current page to the first page: "Biographical Data". Note that you are required to enter a new and unique case code for each case.

29.1.9 Navigating among cases

To move through the cases in the current data set you can click on the case navigation buttons located on every page (**Fig. F29I**):

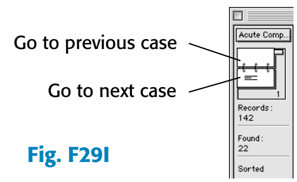

Fig. F29I

You can also click on the "Case List" button to view and scroll through a table of key fields for each case in the current data set (**Fig. F29J**):

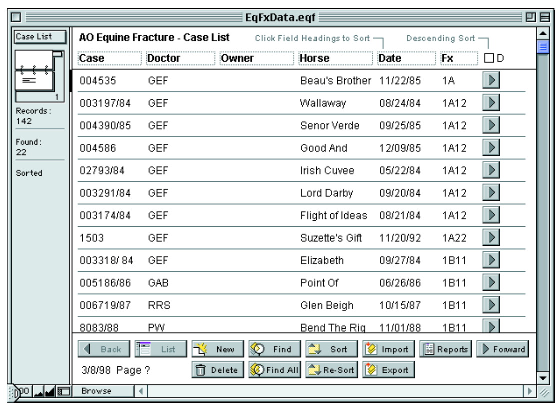

Fig. F29J: Case list with key fields for each case.

29.1.10 Organizing EqFx cases

Cases appear in the order that they are added to the data set unless they are sorted. To sort cases according to data in key fields, such as “Patient Name”, “Owner Name”, etc., click on the appropriate headings in the list view. Otherwise, click the “Sort” button and use the sort dialog to sort by any specified data field(s).

As the number of cases in a data set grows, it may also become useful to work with a subset of the cases, temporarily hiding other cases. To accomplish this use the “Find” and “Find All” buttons.

After clicking the “Find” button you will see an empty form with the “Omit” checkbox and “Find” button in the status area. Simply enter an example of the kind of data you want to find (you may move to other pages while in find mode, if necessary) and click the “Find” button. All records matching your example will be shown or, if you checked “Omit”, hidden. The number of matching records will be reported as “Found” in the status area (**Fig. F29K**). Any subsequent actions—e.g., listing, sorting, and reporting—will only include this found set of records.

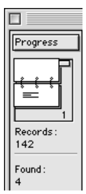

Fig. F29K: Status area indicating subsets.

To work with all of your records again, simply click the “Find All” button.

29.1.11 Reporting EqFx data

EqFx can produce both a case chart and case list report. To print or preview a report, click the “Reports” button and specify whether you would like a case chart for the current case or a case list of all cases in the current “found set” (**Fig. F29L**):

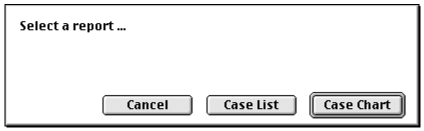

Fig. F29L

Note that **follow-up reports must be printed separately from the follow-up data entry screen.**

Additionally, a text version of the current case chart can be placed into the system clipboard by choosing the “Copy Report to Clipboard” command from the “Script” menu. You may then paste the report into a word processing or e-mail application. If the fracture classification of the current case includes a graphic, **this graphic can also be placed into the system clipboard by choosing the “Copy Graphic to Clipboard” command from the “Script” menu.**

29.1.12 Exporting and importing EqFx cases

Use the “Export” and “Import” buttons to move data into and out of EqFx 4.0. A “Standard” export includes all data fields and outputs a comma-delimited text field with field headings. This export file can be directly imported into another EqFx 4.0 file by clicking the “Import”

It may be useful to create “subsets” of cases as the number documented grows.

Follow-up reports must be generated separately.

Graphics associated with fracture classification are easily included in case reports.

button, selecting the text file, and clicking the "Import" button again in the import dialog window. Custom exports and imports can also be accomplished by using the options available in the dialog windows. When importing cases, make sure that the included case codes are all unique!

29.2 Appendix A: Keyboard shortcuts

NOTE: On Macintosh systems, substitute the Command key (⌘) for the Ctrl key in the shortcuts described below.

To do this...	Type this...
Move forward one field on a page	Tab
Move backward one field on a page	Shift + Tab
Move between options in a radio button group	Up & down arrows
Mark/unmark selected check box or radio button	Spacebar
Unselect option from a pop-up menu or list	Shift + Click

Navigating fields and controls
Navigating pages

To do this...	Type this...
Move backward one page	Ctrl + 1
Move forward one page	Ctrl + 2

Navigating cases

To do this...	Type this...
Move backward one case	Ctrl + down arrow (Windows) Cmd + Tab (Macintosh)
Move forward one case	Ctrl + up arrow (Windows) Cmd + Shift + Tab (Macintosh)

29.3 Appendix B: Exercise induced fracture codes

Code	Description
1	Carpal
1A	Carpal; osteochondral fragments
1A1	Carpal; osteochondral fragments; antebrachiocarpal joint
1A11	Carpal; osteochondral fragments; antebrachiocarpal joint; radial carpal bone
1A12	Carpal; osteochondral fragments; antebrachiocarpal joint; distal radius
1A13	Carpal; osteochondral fragments; antebrachiocarpal joint; other
1A2	Carpal; osteochondral fragments; middle carpal joint
1A21	Carpal; osteochondral fragments; middle carpal joint; radial carpal bone
1A22	Carpal; osteochondral fragments; middle carpal joint; third carpal bone
1A23	Carpal; osteochondral fragments; middle carpal joint; other
1B	Carpal; slab fracture
1B1	Carpal; slab fracture; dorsomedial C3 fx
1B11	Carpal; slab fracture; dorsomedial C3 fx
1B12	Carpal; slab fracture; dorsomedial C3 fx
1B13	Carpal; slab fracture; dorsomedial C3 fx
1B14	Carpal; slab fracture; dorsomedial C3 fx; comminuted
1B2	Carpal; slab fracture; dorsolateral sagittal C3 fx
1B21	Carpal; slab fracture; dorsolateral sagittal C3 fx
1B22	Carpal; slab fracture; dorsolateral sagittal C3 fx
1B23	Carpal; slab fracture; dorsolateral sagittal C3 fx
1B3	Carpal; slab fracture; other
1B31	Carpal; slab fracture; other; radial carpal bone
1B32	Carpal; slab fracture; other; intermediate carpal bone
1B33	Carpal; slab fracture; other; other
1C	Carpal; accessory carpal bone
1C1	Carpal; accessory carpal bone; proximal rim avulsion(s)
1C2	Carpal; accessory carpal bone; body
1C21	Carpal; accessory carpal bone; body; simple axial fx
1C22	Carpal; accessory carpal bone; body; comminuted

Code	Description
2	Articular tarsal
2A	Articular tarsal; osteochondrosis dissecans lesions
2A1	Articular tarsal; osteochondrosis dissecans lesions; intermediate ridge of distal tibia
2A2	Articular tarsal; osteochondrosis dissecans lesions; lateral trochlear ridge of tibial tarsalbone
2A3	Articular tarsal; osteochondrosis dissecans lesions; medial trochlear ridge of tibial tarsalbone
2B	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx
2B1	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; articular osteochonral fragments (chip fx)
2B11	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; articular osteochonral fragments (chip fx); origin unclear
2B12	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; articular osteochonral fragments (chip fx); distal tibia
2B13	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; articular osteochonral fragments (chip fx); tibial tarsal bone
2B2	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; fibulotarsal bone fx
2B21	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; fibulotarsal bone fx; calcaneus fx
2B22	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; fibulotarsal bone fx; body fx
2B23	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; fibulotarsal bone fx; avulsion fx of plantar aspect
2B3	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; tibiotarsal bone fx
2B31	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; tibiotarsal bone fx; lateraltrochlear ridge
2B32	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; tibiotarsal bone fx; medialtrochlear ridge
2B33	Articular tarsal; distal tibial-, tibio-, fibulotarsal fx; tibiotarsal bone fx; body fx
2C	Articular tarsal; distal intertarsal, tarso metatarsal joints
2C1	Articular tarsal; distal intertarsal, tarso metatarsal joints; osteochondral fragments (chip fx)
2C11	Articular tarsal; distal intertarsal, tarso metatarsal joints; osteochondral fragments (chip fx); origin unclear

Code	Description
2C12	Articular tarsal; distal intertarsal, tarso metatarsal joints; osteochondral fragments (chip fx); small tarsal bones
2C13	Articular tarsal; distal intertarsal, tarso metatarsal joints; osteochondral fragments (chip fx); metatarsal bones
2C2	Articular tarsal; distal intertarsal, tarso metatarsal joints; central tarsal bone slab fx
2C3	Articular tarsal; distal intertarsal, tarso metatarsal joints; distal row slab fx
2C31	Articular tarsal; distal intertarsal, tarso metatarsal joints; distal row slab fx; first, second tarsal bone
2C32	Articular tarsal; distal intertarsal, tarso metatarsal joints; distal row slab fx; third tarsal bone
2C33	Articular tarsal; distal intertarsal, tarso metatarsal joints; distal row slab fx; fourth tarsal bone
3	Metacarpal
3A	Metacarpal; complete fx of MC2, MC4
3A1	Metacarpal; complete fx of MC2, MC4; second metacarpal (MC2)
3A11	Metacarpal; complete fx of MC2, MC4; second metacarpal (MC2); proximal third
3A12	Metacarpal; complete fx of MC2, MC4; second metacarpal (MC2); middle third
3A13	Metacarpal; complete fx of MC2, MC4; second metacarpal (MC2); fistal third
3A2	Metacarpal; complete fx of MC2, MC4; fourth metacarpal (MC4)
3A21	Metacarpal; complete fx of MC2, MC4; fourth metacarpal (MC4); proximal third
3A22	Metacarpal; complete fx of MC2, MC4; fourth metacarpal (MC4); middle third
3A23	Metacarpal; complete fx of MC2, MC4; fourth metacarpal (MC4); distal third
3B	Metacarpal; incomplete MC3 shaft fx (“stress” fx)
3B1	Metacarpal; incomplete MC3 shaft fx (“stress” fx); proximal third of MC3
3B11	Metacarpal; incomplete MC3 shaft fx (“stress” fx); proximal third of MC3; dorsomedial
3B12	Metacarpal; incomplete MC3 shaft fx (“stress” fx); proximal third of MC3; dorsal
3B13	Metacarpal; incomplete MC3 shaft fx (“stress” fx); proximal third of MC3; dorsolateral

Code	Description
3B2	Metacarpal; incomplete MC3 shaft fx (“stress” fx); middle third of MC3
3B21	Metacarpal; incomplete MC3 shaft fx (“stress” fx); middle third of MC3; dorsomedial
3B22	Metacarpal; incomplete MC3 shaft fx (“stress” fx); middle third of MC3; dorsal
3B23	Metacarpal; incomplete MC3 shaft fx (“stress” fx); middle third of MC3; dorsolateral
3B3	Metacarpal; incomplete MC3 shaft fx (“stress” fx); distal third of MC3
3B31	Metacarpal; incomplete MC3 shaft fx (“stress” fx); distal third of MC3; dorsomedial
3B32	Metacarpal; incomplete MC3 shaft fx (“stress” fx); distal third of MC3; dorsal
3B33	Metacarpal; incomplete MC3 shaft fx (“stress” fx); distal third of MC3; dorsolateral
3C	Metacarpal; intra-articular fx of distal MC3
3C1	Metacarpal; intra-articular fx of distal MC3; osteochondral fragments
3C11	Metacarpal; intra-articular fx of distal MC3; osteochondral fragments; OCD
3C12	Metacarpal; intra-articular fx of distal MC3; osteochondral fragments; osteochondral fragments
3C2	Metacarpal; intra-articular fx of distal MC3; lateral condylar fx
3C21	Metacarpal; intra-articular fx of distal MC3; lateral condylar fx
3C22	Metacarpal; intra-articular fx of distal MC3; lateral condylar fx
3C23	Metacarpal; intra-articular fx of distal MC3; lateral condylar fx
3C3	Metacarpal; intra-articular fx of distal MC3; medial condylar fx
3C31	Metacarpal; intra-articular fx of distal MC3; medial condylar fx
3C32	Metacarpal; intra-articular fx of distal MC3; medial condylar fx
3C33	Metacarpal; intra-articular fx of distal MC3; medial condylar fx
4	Metatarsal
4A	Metatarsal; complete fx of MT2, MT4
4A1	Metatarsal; complete fx of MT2, MT4; second metatarsal (MT2)
4A11	Metatarsal; complete fx of MT2, MT4; second metatarsal (MT2); proximal third
4A12	Metatarsal; complete fx of MT2, MT4; second metatarsal (MT2); middle third
4A13	Metatarsal; complete fx of MT2, MT4; second metatarsal (MT2); distal third

Code	Description
4A2	Metatarsal; complete fx of MT2, MT4; fourth metatarsal (MT4)
4A21	Metatarsal; complete fx of MT2, MT4; fourth metatarsal (MT4); proximal third
4A22	Metatarsal; complete fx of MT2, MT4; fourth metatarsal (MT4); middle third
4A23	Metatarsal; complete fx of MT2, MT4; fourth metatarsal (MT4); distal third
4B	Metatarsal; intra-articular distal MT3 fx
4B1	Metatarsal; intra-articular distal MT3 fx; osteochondral fragments
4B11	Metatarsal; intra-articular distal MT3 fx; osteochondral fragments; OCD
4B12	Metatarsal; intra-articular distal MT3 fx; osteochondral fragments; osteochondral fragments
4B2	Metatarsal; intra-articular distal MT3 fx; lateral condylar fx
4B21	Metatarsal; intra-articular distal MT3 fx; lateral condylar fx; small fissure fx
4B22	Metatarsal; intra-articular distal MT3 fx; lateral condylar fx; complete undisplaced fx
4B23	Metatarsal; intra-articular distal MT3 fx; lateral condylar fx; complete displaced fx
4B3	Metatarsal; intra-articular distal MT3 fx; medial condylar fx
4B31	Metatarsal; intra-articular distal MT3 fx; medial condylar fx; small fissure fx
4B32	Metatarsal; intra-articular distal MT3 fx; medial condylar fx; complete undisplaced fx
4B33	Metatarsal; intra-articular distal MT3 fx; medial condylar fx; incomplete condylar-shaft fx
5	Proximal phalanx
5A	Proximal phalanx; osteochondral fragments (chip fx), condylar fx
5A1	Proximal phalanx; osteochondral fragments (chip fx), condylar fx; metacarpophalangeal joint
5A11	Proximal phalanx; osteochondral fragments (chip fx), condylar fx; metacarpophalangeal joint; palmar eminence
5A12	Proximal phalanx; osteochondral fragments (chip fx), condylar fx; metacarpophalangeal joint; dorso-(medial) fragment
5A2	Proximal phalanx; osteochondral fragments (chip fx), condylar fx; proximal interphalangeal joint (condylar fx)
5A21	Proximal phalanx; osteochondral fragments (chip fx), condylar fx; proximal interphalangeal joint (condylar fx); medial condyle
5A22	Proximal phalanx; osteochondral fragments (chip fx), condylar fx; proximal interphalangeal joint (condylar fx); lateral condyle

Code	Description
5B	Proximal phalanx; intra-articular fx
5B1	Proximal phalanx; intra-articular fx; midsagittal monoarticular (“screwdriver”) fx
5B11	Proximal phalanx; intra-articular fx; midsagittal monoarticular (“screwdriver”) fx; short fissure fx
5B12	Proximal phalanx; intra-articular fx; midsagittal monoarticular (“screwdriver”) fx; incomplete fx
5B13	Proximal phalanx; intra-articular fx; midsagittal monoarticular (“screwdriver”) fx; complete fx
5B2	Proximal phalanx; intra-articular fx; midsagittal biarticular (“screwdriver”) fx
5B21	Proximal phalanx; intra-articular fx; midsagittal biarticular (“screwdriver”) fx; sagittal, nondisplaced
5B22	Proximal phalanx; intra-articular fx; midsagittal biarticular (“screwdriver”) fx; sagittal displaced fx
5B3	Proximal phalanx; intra-articular fx; other
5B31	Proximal phalanx; intra-articular fx; other; frontal
5B32	Proximal phalanx; intra-articular fx; other; wing
5B33	Proximal phalanx; intra-articular fx; other; comminuted
5C	Proximal phalanx; extra-articular fx
5C1	Proximal phalanx; extra-articular fx; transverse fx
6	Middle phalanx
6A	Middle phalanx; osteochondral fragments
6A1	Middle phalanx; osteochondral fragments; proximal interphalangeal joint
6A2	Middle phalanx; osteochondral fragments; distal interphalangeal joint
6B	Middle phalanx; intra-articular fx
6B1	Middle phalanx; intra-articular fx; sagittal, frontal wing, monoarticular fx
6B11	Middle phalanx; intra-articular fx; sagittal, frontal wing, monoarticular fx; simple
6B12	Middle phalanx; intra-articular fx; sagittal, frontal wing, monoarticular fx; bilateral
6B13	Middle phalanx; intra-articular fx; sagittal, frontal wing, monoarticular fx; wing
6B2	Middle phalanx; intra-articular fx; comminuted monoarticular fx
6B3	Middle phalanx; intra-articular fx; simple, comminuted, biarticular fx
6B31	Middle phalanx; intra-articular fx; simple, comminuted, biarticular fx; oblique
6B32	Middle phalanx; intra-articular fx; simple, comminuted, biarticular fx; comminuted

Code	Description
6C	Middle phalanx; extra-articular fx
6C1	Middle phalanx; extra-articular fx; transverse fx
7	Distal phalanx
7A	Distal phalanx; osteochondral fragments (chip fx)
7A1	Distal phalanx; osteochondral fragments (chip fx); osteochondral framents (chip fx)
7A2	Distal phalanx; osteochondral fragments (chip fx); extensor process fx
7B	Distal phalanx; intra-articular fx
7B1	Distal phalanx; intra-articular fx; midsagittal
7B2	Distal phalanx; intra-articular fx; asymmetric sagittal
7B21	Distal phalanx; intra-articular fx; asymmetric sagittal; lateral
7B22	Distal phalanx; intra-articular fx; asymmetric sagittal; medial
7B3	Distal phalanx; intra-articular fx; frontal, comminuted
7B31	Distal phalanx; intra-articular fx; frontal, comminuted; frontal
7B32	Distal phalanx; intra-articular fx; frontal, comminuted; comminuted
7C	Distal phalanx; extra-articular fx
7C1	Distal phalanx; extra-articular fx; wing
7C11	Distal phalanx; extra-articular fx; wing; lateral
7C12	Distal phalanx; extra-articular fx; wing; medial
7C2	Distal phalanx; extra-articular fx; solar rim, border
8	Proximal sesamoid
8A	Proximal sesamoid; lateral proximal sesamoid chip fx
8A1	Proximal sesamoid; lateral proximal sesamoid chip fx; chip fx
8A11	Proximal sesamoid; lateral proximal sesamoid chip fx; chip fx; abaxial, extra-articular
8A12	Proximal sesamoid; lateral proximal sesamoid chip fx; chip fx; apical chip
8A13	Proximal sesamoid; lateral proximal sesamoid chip fx; chip fx; basilar chip
8A2	Proximal sesamoid; lateral proximal sesamoid chip fx; body fx
8A21	Proximal sesamoid; lateral proximal sesamoid chip fx; body fx; apical (proximal third)
8A22	Proximal sesamoid; lateral proximal sesamoid chip fx; body fx; midbody (middle third)
8A23	Proximal sesamoid; lateral proximal sesamoid chip fx; body fx; axial

Code	Description
8A3	Proximal sesamoid; lateral proximal sesamoid chip fx; basilar fx
8A31	Proximal sesamoid; lateral proximal sesamoid chip fx; basilar fx; simple
8A32	Proximal sesamoid; lateral proximal sesamoid chip fx; basilar fx; T-fx
8A33	Proximal sesamoid; lateral proximal sesamoid chip fx; basilar fx; comminuted fx
8B	Proximal sesamoid; medial proximal sesamoid chip fx
8B1	Proximal sesamoid; medial proximal sesamoid chip fx; chip fx
8B11	Proximal sesamoid; medial proximal sesamoid chip fx; chip fx; abaxial, extra-articular
8B12	Proximal sesamoid; medial proximal sesamoid chip fx; chip fx; apical chip
8B13	Proximal sesamoid; medial proximal sesamoid chip fx; chip fx; basilar chip
8B2	Proximal sesamoid; medial proximal sesamoid chip fx; body fx
8B21	Proximal sesamoid; medial proximal sesamoid chip fx; body fx; apical (proximal third)
8B22	Proximal sesamoid; medial proximal sesamoid chip fx; body fx; midbody (middle third)
8B23	Proximal sesamoid; medial proximal sesamoid chip fx; body fx; axial
8B3	Proximal sesamoid; medial proximal sesamoid chip fx; basilar fx
8B31	Proximal sesamoid; medial proximal sesamoid chip fx; basilar fx; simple
8B32	Proximal sesamoid; medial proximal sesamoid chip fx; basilar fx; T-fx
8B33	Proximal sesamoid; medial proximal sesamoid chip fx; basilar fx; comminuted fx
8C	Proximal sesamoid; distal sesamoid (navicular bone) fx
8C1	Proximal sesamoid; distal sesamoid (navicular bone) fx; chip fx
8C11	Proximal sesamoid; distal sesamoid (navicular bone) fx; chip fx; proximal rim
8C12	Proximal sesamoid; distal sesamoid (navicular bone) fx; chip fx; distal rim
8C13	Proximal sesamoid; distal sesamoid (navicular bone) fx; chip fx; multiple fx
8C2	Proximal sesamoid; distal sesamoid (navicular bone) fx; body fx
8C21	Proximal sesamoid; distal sesamoid (navicular bone) fx; body fx; wing
8C22	Proximal sesamoid; distal sesamoid (navicular bone) fx; body fx; sagittal
8C23	Proximal sesamoid; distal sesamoid (navicular bone) fx; body fx; abaxial
8C3	Proximal sesamoid; distal sesamoid (navicular bone) fx; fx through cyst

29.4 Appendix C: Long bone fracture codes

Code	Description
01	Humerus
011	Humerus; proximal metaphysis
011A	Humerus; proximal metaphysis; simple
011A1	Humerus; proximal metaphysis; simple; simple fx
011A2	Humerus; proximal metaphysis; simple; tuberculum fx
011A3	Humerus; proximal metaphysis; simple; complete fx
011B	Humerus; proximal metaphysis; reducible fragments
011B1	Humerus; proximal metaphysis; reducible fragments; 3 fragments
011B2	Humerus; proximal metaphysis; reducible fragments; >3 fragments
011C	Humerus; proximal metaphysis; complex
011C1	Humerus; proximal metaphysis; complex; humeral neck
011C1i	Humerus; proximal metaphysis; complex; humeral neck; S-H 1
011C1ii	Humerus; proximal metaphysis; complex; humeral neck; S-H 2
011C2	Humerus; proximal metaphysis; complex; humeral head
011C2iii	Humerus; proximal metaphysis; complex; humeral head; S-H 3
011C2iv	Humerus; proximal metaphysis; complex; humeral head; S-H 4
011C3	Humerus; proximal metaphysis; complex; multifragment articular
011C3iii	Humerus; proximal metaphysis; complex; multifragment articular; S-H 3
011C3iv	Humerus; proximal metaphysis; complex; multifragment articular; S-H 4
012	Humerus; diaphysis
012A	Humerus; diaphysis; simple
012A1	Humerus; diaphysis; simple; deltoid tuberosity
012A2	Humerus; diaphysis; simple; incomplete fissure
012A3	Humerus; diaphysis; simple; complete oblique
012B	Humerus; diaphysis; reducible fragments
012B1	Humerus; diaphysis; reducible fragments; complete transverse
012B2	Humerus; diaphysis; reducible fragments; 1 reducible fragment
012B3	Humerus; diaphysis; reducible fragments; >1 reducible fragments

Code	Description
012C	Humerus; diaphysis; complex
012C1	Humerus; diaphysis; complex; complex reducible fragments
012C3	Humerus; diaphysis; complex; nonreducible fragments
012C3	Humerus; diaphysis; complex; nonreducible fragments
013	Humerus; distal metaphysis
013A	Humerus; distal metaphysis; simple
013A1	Humerus; distal metaphysis; simple; incomplete fissure
013A2	Humerus; distal metaphysis; simple; complete fx medial epicondyle, extra-articular
013A2i	Humerus; distal metaphysis; simple; complete fx medial epicondyle, extra-articular; S-H1
013A2ii	Humerus; distal metaphysis; simple; complete fx medial epicondyle, extra-articular; S-H2
013B	Humerus; distal metaphysis; reducible fragments
013B1	Humerus; distal metaphysis; reducible fragments; lateral condyle, articular component
013B1iii	Humerus; distal metaphysis; reducible fragments; lateral condyle, articular component; S-H3
013B1iv	Humerus; distal metaphysis; reducible fragments; lateral condyle, articular component; S-H4
013B2	Humerus; distal metaphysis; reducible fragments; medial condyle, articular component
013B2i	Humerus; distal metaphysis; reducible fragments; medial condyle, articular component; S-H1
013B2ii	Humerus; distal metaphysis; reducible fragments; medial condyle, articular component; S-H2
013C	Humerus; distal metaphysis; complex
013C1	Humerus; distal metaphysis; complex; Y-fx, articular component
013C1iii	Humerus; distal metaphysis; complex; Y-fx, articular component; S-H 3
013C1iv	Humerus; distal metaphysis; complex; Y-fx, articular component; S-H 4
013C2	Humerus; distal metaphysis; complex; multifragment, articular component
013C2iii	Humerus; distal metaphysis; complex; multifragment, articular component; S-H 3
013C2iv	Humerus; distal metaphysis; complex; multifragment, articular component; S-H 4

Code	Description
013C3	Humerus; distal metaphysis; complex; multifragment, articular component, nonreducible
013C3iii	Humerus; distal metaphysis; complex; multifragment, articular component, nonreducible; S-H3
013C3iv	Humerus; distal metaphysis; complex; multifragment, articular component, nonreducible; S-H4
02	Radius, ulna
021	Radius, ulna; proximal metaphysis
021A	Radius, ulna; proximal metaphysis; simple
021A1	Radius, ulna; proximal metaphysis; simple; ulna non-articular
021A1a	Radius, ulna; proximal metaphysis; simple; ulna non-articular; distal to cubital joint level
021A1b	Radius, ulna; proximal metaphysis; simple; ulna non-articular; proximal to cubital joint
021A1i	Radius, ulna; proximal metaphysis; simple; ulna non-articular; S-H 1
021A1ii	Radius, ulna; proximal metaphysis; simple; ulna non-articular; S-H 2
021A2	Radius, ulna; proximal metaphysis; simple; radius non-articular
021A2i	Radius, ulna; proximal metaphysis; simple; radius non-articular; S-H 1
021A2ii	Radius, ulna; proximal metaphysis; simple; radius non-articular; S-H 2
021A3	Radius, ulna; proximal metaphysis; simple; radius & ulna
021A3i	Radius, ulna; proximal metaphysis; simple; radius & ulna; S-H 1
021A3ii	Radius, ulna; proximal metaphysis; simple; radius & ulna; S-H 2
021B	Radius, ulna; proximal metaphysis; reducible fragments
021B1	Radius, ulna; proximal metaphysis; reducible fragments; ulna, articular
021B1a	Radius, ulna; proximal metaphysis; reducible fragments; ulna, articular; distal to cubital joint level
021B1b	Radius, ulna; proximal metaphysis; reducible fragments; ulna, articular; ulnar notch
021B1iii	Radius, ulna; proximal metaphysis; reducible fragments; ulna, articular; S-H 3
021B2	Radius, ulna; proximal metaphysis; reducible fragments; radius, articular
021B2iii	Radius, ulna; proximal metaphysis; reducible fragments; radius, articular; S-H 3
021B2iv	Radius, ulna; proximal metaphysis; reducible fragments; radius, articular; S-H 4
021B3	Radius, ulna; proximal metaphysis; reducible fragments; complete, articular
021B3iii	Radius, ulna; proximal metaphysis; reducible fragments; complete, articular; S-H 3
021B3iv	Radius, ulna; proximal metaphysis; reducible fragments; complete, articular; S-H 4

Code	Description
021C	Radius, ulna; proximal metaphysis; complex
021C1	Radius, ulna; proximal metaphysis; complex; ulna, articular
021C1a	Radius, ulna; proximal metaphysis; complex; ulna, articular; distal to cubital joint level
021C1b	Radius, ulna; proximal metaphysis; complex; ulna, articular; ulnar notch
021C1ii	Radius, ulna; proximal metaphysis; complex; ulna, articular; S-H 2
021C2	Radius, ulna; proximal metaphysis; complex; radius, articular
021C2iii	Radius, ulna; proximal metaphysis; complex; radius, articular; S-H 3
021C2iv	Radius, ulna; proximal metaphysis; complex; radius, articular; S-H 4
021C3	Radius, ulna; proximal metaphysis; complex; complete, articular
021C3iii	Radius, ulna; proximal metaphysis; complex; complete, articular; S-H 3
021C3iv	Radius, ulna; proximal metaphysis; complex; complete, articular; S-H 4
022	Radius, ulna;diaphysis
022A	Radius, ulna; diaphysis; simple
022A1	Radius, ulna; diaphysis; simple; incomplete
022A2	Radius, ulna; diaphysis; simple; complete, oblique
022A3	Radius, ulna; diaphysis; simple; complete, transverse
022B	Radius, ulna; diaphysis; reducible fragments
022B1	Radius, ulna; diaphysis; reducible fragments; multifragment 1 reducible
022B2	Radius, ulna; diaphysis; reducible fragments; multifragment several reducible
022B3	Radius, ulna; diaphysis; reducible fragments; multifragment nonreducible
022C	Radius, ulna; diaphysis; complex
022C1	Radius, ulna; diaphysis; complex; multifragment reducible
022C2	Radius, ulna; diaphysis; complex; multifragment segmental
022C3	Radius, ulna; diaphysis; complex; complex multifragment nonreducible
023	Radius, ulna; distal metaphysis
023A	Radius, ulna; distal metaphysis; simple
023A1	Radius, ulna; distal metaphysis; simple; fissure fx, nonarticular
023A2	Radius, ulna; distal metaphysis; simple; fx medial condyle, nonarticular
023B	Radius, ulna; distal metaphysis; reducible fragments
023B1	Radius, ulna; distal metaphysis; reducible fragments; fissure fx, lateral
023B2	Radius, ulna; distal metaphysis; reducible fragments; fx medial condyle, articular

Code	Description
023C	Radius, ulna; distal metaphysis; complex
023C1	Radius, ulna; distal metaphysis; complex; Y-fx, articular component
023C1iii	Radius, ulna; distal metaphysis; complex; Y-fx, articular component; S-H 3
023C1iv	Radius, ulna; distal metaphysis; complex; Y-fx, articular component; S-H 4
023C2	Radius, ulna; distal metaphysis; complex; multifragment, reducible
023C2iii	Radius, ulna; distal metaphysis; complex; multifragment, reducible; S-H 3
023C2iv	Radius, ulna; distal metaphysis; complex; multifragment, reducible; S-H 4
023C3	Radius, ulna; distal metaphysis; complex; multifragment, nonreducible
023C3iii	Radius, ulna; distal metaphysis; complex; multifragment, nonreducible; S-H 3
023C3iv	Radius, ulna; distal metaphysis; complex; multifragment, nonreducible; S-H 4
03	Femur
031	Femur; proximal metaphysis
031A	Femur; proximal metaphysis; simple
031A1	Femur; proximal metaphysis; simple; fx trochanter majus
031A2	Femur; proximal metaphysis; simple; fissure, nonarticular
031A3	Femur; proximal metaphysis; simple; transverse, nonarticular
031B	Femur; proximal metaphysis; reducible fragments
031B1	Femur; proximal metaphysis; reducible fragments; fissure fx femoral neck
031B2	Femur; proximal metaphysis; reducible fragments; femoral neck
031B2i	Femur; proximal metaphysis; reducible fragments; femoral neck; S-H 1
031B2ii	Femur; proximal metaphysis; reducible fragments; femoral neck; S-H 2
031C	Femur; proximal metaphysis; complex
031C1	Femur; proximal metaphysis; complex; femoral head, articular
031C1iii	Femur; proximal metaphysis; complex; femoral head, articular; S-H 3
031C1iv	Femur; proximal metaphysis; complex; femoral head, articular; S-H 4
031C2	Femur; proximal metaphysis; complex; articular, reducible
031C2iv	Femur; proximal metaphysis; complex; articular, reducible; S-H 4
031C3	Femur; proximal metaphysis; complex; articular, nonreducible
031C3iv	Femur; proximal metaphysis; complex; articular, nonreducible; S-H 4
032	Femur; diaphysis
032A	Femur; diaphysis; simple
032A1	Femur; diaphysis; simple; fx tronchanter tertius
032A2	Femur; diaphysis; simple; fissure
032A3	Femur; diaphysis; simple; oblique

Code	Description
032B	Femur; diaphysis; reducible fragments
032B1	Femur; diaphysis; reducible fragments; 1 reducible fragment
032B2	Femur; diaphysis; reducible fragments; >1 reducible fragments
032B3	Femur; diaphysis; reducible fragments; nonreducible fragments
032C	Femur; diaphysis; complex
032C1	Femur; diaphysis; complex; reducible
032C2	Femur; diaphysis; complex; segmental
032C3	Femur; diaphysis; complex; nonreducible
033	Femur; distal metaphysis
033A	Femur; distal metaphysis; simple
033A1	Femur; distal metaphysis; simple; lateral epicondyle nonarticular
033A2	Femur; distal metaphysis; simple; medial epicondyle nonarticular
033A3	Femur; distal metaphysis; simple; transverse
033A3i	Femur; distal metaphysis; simple; transverse; S-H 1
033A3ii	Femur; distal metaphysis; simple; transverse; S-H 2
033B	Femur; distal metaphysis; reducible fragments
033B1	Femur; distal metaphysis; reducible fragments; lateral trochlea, articular
033B1iii	Femur; distal metaphysis; reducible fragments; lateral trochlea, articular; S-H 3
033B1iv	Femur; distal metaphysis; reducible fragments; lateral trochlea, articular; S-H 4
033B2	Femur; distal metaphysis; reducible fragments; medial trochlea, articular
033B2iii	Femur; distal metaphysis; reducible fragments; medial trochlea, articular; S-H 3
033B2iv	Femur; distal metaphysis; reducible fragments; medial trochlea, articular; S-H 4
033B3	Femur; distal metaphysis; reducible fragments; caudal condyle in frontal plane, articular
033B3iii	Femur; distal metaphysis; reducible fragments; caudal condyle in frontal plane, articular; S-H 3
033B3iv	Femur; distal metaphysis; reducible fragments; caudal condyle in frontal plane, articular; S-H 4
033C	Femur; distal metaphysis; complex
033C1	Femur; distal metaphysis; complex; Y-fx, articular
033C1iii	Femur; distal metaphysis; complex; Y-fx, articular; S-H 3
033C1iv	Femur; distal metaphysis; complex; Y-fx, articular; S-H 4

Code	Description
033C2	Femur; distal metaphysis; complex; Y-fx, articular, reducible
033C2iii	Femur; distal metaphysis; complex; Y-fx, articular, reducible; S-H 3
033C2iv	Femur; distal metaphysis; complex; Y-fx, articular, reducible; S-H 4
033C3	Femur; distal metaphysis; complex; Y-fx, articular, nonreducible
033C3iii	Femur; distal metaphysis; complex; Y-fx, articular, nonreducible; S-H 3
033C3iv	Femur; distal metaphysis; complex; Y-fx, articular, nonreducible; S-H 4
04	Tibia
041	Tibia; proximal metaphysis
041A	Tibia; proximal metaphysis; simple
041A1	Tibia; proximal metaphysis; simple; tibial crest, nonarticular
041A1i	Tibia; proximal metaphysis; simple; tibial crest, nonarticular; S-H 1
041A1ii	Tibia; proximal metaphysis; simple; tibial crest, nonarticular; S-H 2
041A2	Tibia; proximal metaphysis; simple; fissure fx, nonarticular
041B	Tibia; proximal metaphysis; reducible fragments
041B1	Tibia; proximal metaphysis; reducible fragments; fissure fx, articular
041B2	Tibia; proximal metaphysis; reducible fragments; transverse, nonarticular
041B2i	Tibia; proximal metaphysis; reducible fragments; transverse, nonarticular; S-H 1
041B2ii	Tibia; proximal metaphysis; reducible fragments; transverse, nonarticular; S-H 2
041B3	Tibia; proximal metaphysis; reducible fragments; transverse, nonarticular, multifragment
041B3ii	Tibia; proximal metaphysis; reducible fragments; transverse, nonarticular, multifragment; S-H 2
041C	Tibia; proximal metaphysis; complex
041C1	Tibia; proximal metaphysis; complex; tibial crest, articular component
041C1iii	Tibia; proximal metaphysis; complex; tibial crest, articular component; S-H 3
041C2	Tibia; proximal metaphysis; complex; articular component
041C2iv	Tibia; proximal metaphysis; complex; articular component; S-H 4
041C3	Tibia; proximal metaphysis; complex; multifragment fx
041C3iii	Tibia; proximal metaphysis; complex; multifragment fx; S-H 3
041C3iv	Tibia; proximal metaphysis; complex; multifragment fx; S-H 4
042	Tibia; diaphysis
042A	Tibia; diaphysis; simple
042A1	Tibia; diaphysis; simple; fissure fx
042A2	Tibia; diaphysis; simple; oblique
042A3	Tibia; diaphysis; simple; transverse

Code	Description
042B	Tibia; diaphysis; reducible fragments
042B1	Tibia; diaphysis; reducible fragments; 1 reducible fragment
042B2	Tibia; diaphysis; reducible fragments; >1 reducible fragments
042B3	Tibia; diaphysis; reducible fragments; nonreducible fragments
042C	Tibia; diaphysis; complex
042C1	Tibia; diaphysis; complex; multifragment, reducible
042C2	Tibia; diaphysis; complex; multifragment, segmental
042C3	Tibia; diaphysis; complex; multifragment, nonreducible
043	Tibia; distal metaphysis
043A	Tibia; distal metaphysis; simple
043A1	Tibia; distal metaphysis; simple; fissure fx, nonarticular
043A2	Tibia; distal metaphysis; simple; lateral condyle, nonarticular
043A3	Tibia; distal metaphysis; simple; medial condyle, nonarticular
043B	Tibia; distal metaphysis; reducible fragments
043B1	Tibia; distal metaphysis; reducible fragments; transverse, nonarticular
043B1i	Tibia; distal metaphysis; reducible fragments; transverse, nonarticular; S-H 1
043B1ii	Tibia; distal metaphysis; reducible fragments; transverse, nonarticular; S-H 2
043B2	Tibia; distal metaphysis; reducible fragments; transverse, nonarticular, 1 reducible fragment
043B2i	Tibia; distal metaphysis; reducible fragments; transverse, nonarticular, 1 reducible fragment; S-H 1
043B2ii	Tibia; distal metaphysis; reducible fragments; transverse, nonarticular, 1 reducible fragment; S-H 2
043B3	Tibia; distal metaphysis; reducible fragments; transverse, nonarticular, nonreducible fragments
043B3i	Tibia; distal metaphysis; reducible fragments; transverse, nonarticular, nonreducible fragments; S-H 1
043B3ii	Tibia; distal metaphysis; reducible fragments; transverse, nonarticular, nonreducible fragments; S-H 2
043C	Tibia; distal metaphysis; complex
043C1	Tibia; distal metaphysis; complex; fissure fx, articular
043C2	Tibia; distal metaphysis; complex; articular
043C2iii	Tibia; distal metaphysis; complex; articular; S-H 3
043C2iv	Tibia; distal metaphysis; complex; articular; S-H 4
043C3	Tibia; distal metaphysis; complex; multifragment, articular
043C3iii	Tibia; distal metaphysis; complex; multifragment, articular; S-H 3
043C3iv	Tibia; distal metaphysis; complex; multifragment, articular; S-H 4

Code	Description
05	MC3, MT3
051	MC3, MT3; proximal metaphysis
051A	MC3, MT3; proximal metaphysis; simple
051A1	MC3, MT3; proximal metaphysis; simple; fissure fx, nonarticular
051A2	MC3, MT3; proximal metaphysis; simple; avulsion fx extensor carpi radialis tendon, nonarticular
051A3	MC3, MT3; proximal metaphysis; simple; avulsion fx origin of interosseus, nonarticular
051B	MC3, MT3; proximal metaphysis; reducible fragments
051B1	MC3, MT3; proximal metaphysis; reducible fragments; fissure fx, articular
051B2	MC3, MT3; proximal metaphysis; reducible fragments; articular
051B3	MC3, MT3; proximal metaphysis; reducible fragments; multifragment fx, articular, reducible
051C	MC3, MT3; proximal metaphysis; complex
051C1	MC3, MT3; proximal metaphysis; complex; multifragment, reducible
051C2	MC3, MT3; proximal metaphysis; complex; multifragment, articular defect
051C3	MC3, MT3; proximal metaphysis; complex; multifragment, nonreducible
052	MC3, MT3; diaphysis
052A	MC3, MT3; diaphysis; simple
052A1	MC3, MT3; diaphysis; simple; fissure fx
052A2	MC3, MT3; diaphysis; simple; oblique
052A3	MC3, MT3; diaphysis; simple; transverse
052B	MC3, MT3; diaphysis; reducible fragments
052B1	MC3, MT3; diaphysis; reducible fragments; 1 reducible fragment
052B2	MC3, MT3; diaphysis; reducible fragments; >1 reducible fragments
052B3	MC3, MT3; diaphysis; reducible fragments; nonreducible fragments
052C	MC3, MT3; diaphysis; complex
052C1	MC3, MT3; diaphysis; complex; multifragment, reducible
052C2	MC3, MT3; diaphysis; complex; multifragment, segmental
052C3	MC3, MT3; diaphysis; complex; multifragment, nonreducible
053	MC3, MT3; distal metaphysis
053A	MC3, MT3; distal metaphysis; simple
053A1	MC3, MT3; distal metaphysis; simple; fissure fx, nonarticular
053A2	MC3, MT3; distal metaphysis; simple; oblique, nonarticular

Code	Description
053A3	MC3, MT3; distal metaphysis; simple; transverse, nonarticular
053A3i	MC3, MT3;distal metaphysis; simple; transverse, nonarticular; S-H 1
053A3ii	MC3, MT3;distal metaphysis; simple; transverse, nonarticular; S-H 2
06	Scapula
061	Scapula; proximal metaphysis
061A	Scapula; proximal metaphysis; simple
061A1	Scapula; proximal metaphysis; simple; fx proximal margin
061B	Scapula; proximal metaphysis; reducible fragments
061B1	Scapula; proximal metaphysis; reducible fragments; body fx
061C	Scapula; proximal metaphysis; complex
061C1	Scapula; proximal metaphysis; complex; multifragment fx
062	Scapula; diaphysis
062A	Scapula; diaphysis; simple
062A1	Scapula; diaphysis; simple; spine fx
062B	Scapula; diaphysis; reducible fragments
062B1	Scapula; diaphysis; reducible fragments; neck fx
062C	Scapula; diaphysis; complex
062C1	Scapula; diaphysis; complex; multifragment fx
063	Scapula; distal metaphysis
063A	Scapula; distal metaphysis; simple
063A1	Scapula; distal metaphysis; simple; avulsion fx of supraglenoid tubercle, nonarticular
063A1i	Scapula; distal metaphysis; simple; S-H 1; avulsion fx of supraglenoid tubercle, nonarticular
063A1ii	Scapula; distal metaphysis; simple; S-H 2; avulsion fx of supraglenoid tubercle, nonarticular
063B	Scapula; distal metaphysis; reducible fragments
063B1	Scapula; distal metaphysis; reducible fragments; small fragment articular rim
063B2	Scapula; distal metaphysis; reducible fragments; avulsion fx of supraglenoid tubercle, articular
063B2i	Scapula; distal metaphysis; reducible fragments; S-H 1; avulsion fx of supraglenoid tubercle, articular
063B2ii	Scapula; distal metaphysis; reducible fragments; S-H 2; avulsion fx of supraglenoid tubercle, articular
063B3	Scapula; distal metaphysis; reducible fragments; scapula, articular

Code	Description
063C	Scapula; distal metaphysis; complex
063C1	Scapula; distal metaphysis; complex; multifragment fx
063C1ii	Scapula; distal metaphysis; complex; multifragment fx; S-H 2
063C1iii	Scapula; distal metaphysis; complex; multifragment fx; S-H 3
07	Mandible
071	Mandible; proximal metaphysis
071A	Mandible; proximal metaphysis; simple
071A1	Mandible; proximal metaphysis; simple; avulsion fx 1–2 incisors
071A2	Mandible; proximal metaphysis; simple; avulsion fx 3–4 incisors (left & right I1&2)
071A3	Mandible; proximal metaphysis; simple; avulsion fx of incisors (incl I3)
071B	Mandible; proximal metaphysis; reducible fragments
071B1	Mandible; proximal metaphysis; reducible fragments; symphysis
071B2	Mandible; proximal metaphysis; reducible fragments; involving incisors & part of rostral mandibula
071B3	Mandible; proximal metaphysis; reducible fragments; unilateral fx in diastema
071C	Mandible; proximal metaphysis; complex
071C1	Mandible; proximal metaphysis; complex; transverse fx in diastema
071C2	Mandible; proximal metaphysis; complex; bilateral ramus fx in diastema
071C3	Mandible; proximal metaphysis; complex; complex bilateral ramus fx in diastema
071C3a	Mandible; proximal metaphysis; complex; complex bilateral ramus fx in diastema; 1 simple, 1 complex
071C3b	Mandible; proximal metaphysis; complex; complex bilateral ramus fx in diastema; both complex
072	Mandible; diaphysis
072A	Mandible; diaphysis; simple
072A1	Mandible; diaphysis; simple; marginal fx ramus
072A2	Mandible; diaphysis; simple; simple, unilateral, interdental fx ramus
072B	Mandible; diaphysis; reducible fragments
072B1	Mandible; diaphysis; reducible fragments; complex unilateral intradental fx ramus
072B2	Mandible; diaphysis; reducible fragments; segmental unilateral intradental fx ramus
072C	Mandible; diaphysis; complex
072C1	Mandible; diaphysis; complex; simple bilateral intradental fx ramus

Code	Description
072C2	Mandible; diaphysis; complex; segmental bilateral intradental fx ramus
072C2a	Mandible; diaphysis; complex; segmental bilateral intradental fx ramus; 1 simple, 1 complex
072C2b	Mandible; diaphysis; complex; segmental bilateral intradental fx ramus; both complex
072C3	Mandible; diaphysis; complex; complex bilateral intradental fx ramus
072C3a	Mandible; diaphysis; complex; complex bilateral intradental fx ramus; 1 simple, 1 complex
072C3b	Mandible; diaphysis; complex; complex bilateral intradental fx ramus; both complex
073	Mandible; distal metaphysis
073A	Mandible; distal metaphysis; simple
073A1	Mandible; distal metaphysis; simple; marginal fx angle of ramus
073A2	Mandible; distal metaphysis; simple; fissure fx vertical ramus
073A3	Mandible; distal metaphysis; simple; simple fx vertical ramus
073B	Mandible; distal metaphysis; reducible fragments
073B1	Mandible; distal metaphysis; reducible fragments; complex fx vertical ramus, unilateral
073B2	Mandible; distal metaphysis; reducible fragments; simple fx involving temporal jt
073C	Mandible; distal metaphysis; complex
073C1	Mandible; distal metaphysis; complex; bilateral simple fx vertical ramus
073C2	Mandible; distal metaphysis; complex; complex unilateral fx vertical ramus involving temporal jt
073C3	Mandible; distal metaphysis; complex; complex bilateral fx vertical ramus involving temporal jt
073C3a	Mandible; distal metaphysis; complex; complex bilateral fx vertical ramus involving temporal jt; 1 simple, 1 complex
073C3b	Mandible; distal metaphysis; complex; complex bilateral fx vertical ramus involving temporal jt; both complex
08	Skull & maxilla
081	Skull & maxilla; proximal metaphysis
081A	Skull & maxilla; proximal metaphysis; simple
081A1	Skull & maxilla; proximal metaphysis; simple; avulsion fx 2 incisors (left & right I1&2)
081A2	Skull & maxilla; proximal metaphysis; simple; avulsion fx 3–4 incisors (left & right I1&2)
081A3	Skull & maxilla; proximal metaphysis; simple; avulsion fx incisors (incl I3)

Code	Description
081B	Skull & maxilla; proximal metaphysis; reducible fragments
081B1	Skull & maxilla; proximal metaphysis; reducible fragments; fx of incisors and 1 canine
081B2	Skull & maxilla; proximal metaphysis; reducible fragments; fx rostral to canine
081B3	Skull & maxilla; proximal metaphysis; reducible fragments; simple fx in diastema
081C	Skull & maxilla; proximal metaphysis; complex
081C1	Skull & maxilla; proximal metaphysis; complex; complex fx of diastema
082	Skull & maxilla; diaphysis
082A	Skull & maxilla; diaphysis; simple
082A1	Skull & maxilla; diaphysis; simple; facial crest
082A2	Skull & maxilla; diaphysis; simple; simple depression fx frontal bone
082B	Skull & maxilla; diaphysis; reducible fragments
082B1	Skull & maxilla; diaphysis; reducible fragments; simple fx nasal bone
082B2	Skull & maxilla; diaphysis; reducible fragments; complex unilateral fx nasal/frontal bone
082C	Skull & maxilla; diaphysis; complex
082C1	Skull & maxilla; diaphysis; complex; complex bilateral fx nasal/frontal bone
083	Skull & maxilla; distal metaphysis
083A	Skull & maxilla; distal metaphysis; simple
083A1	Skull & maxilla; distal metaphysis; simple; simple fx zygomatic arch
083A2	Skull & maxilla; distal metaphysis; simple; simple fx occipital crest
083B	Skull & maxilla; distal metaphysis; reducible fragments
083B1	Skull & maxilla; distal metaphysis; reducible fragments; complex fx zygomatic arch with ocular involvement
083B2	Skull & maxilla; distal metaphysis; reducible fragments; simple depression fx frontal/occipital bone
083C	Skull & maxilla; distal metaphysis; complex
083C1	Skull & maxilla; distal metaphysis; complex; complex depression fx calvarium
083C2	Skull & maxilla; distal metaphysis; complex; complex fx occipital bone
083C3	Skull & maxilla; distal metaphysis; complex; sphenoid bone
09	Pelvis
091	Pelvis; proximal metaphysis
091A	Pelvis; proximal metaphysis; simple
091A1	Pelvis; proximal metaphysis; simple; tuber coxae

Code	Description
091B	Pelvis; proximal metaphysis; reducible fragments
091B1	Pelvis; proximal metaphysis; reducible fragments; wing of ilium
091C	Pelvis; proximal metaphysis; complex
091C1	Pelvis; proximal metaphysis; complex; unilateral complex ilium fx
091C2	Pelvis; proximal metaphysis; complex; bilateral simple wing ilium fx
091C3	Pelvis; proximal metaphysis; complex; bilateral complex ilium fx
092	Pelvis; diaphysis
092A	Pelvis; diaphysis; simple
092A1	Pelvis; diaphysis; simple; symphysis
092B	Pelvis; diaphysis; reducible fragments
092B1	Pelvis; diaphysis; reducible fragments; os pubis
092C	Pelvis; diaphysis; complex
092C1	Pelvis; diaphysis; complex; chip fx of acetabular rim
092C2	Pelvis; diaphysis; complex; simple acetabular fx
092C3	Pelvis; diaphysis; complex; complex acetabular fx
093	Pelvis; distal metaphysis
093A	Pelvis; distal metaphysis; simple
093A1	Pelvis; distal metaphysis; simple; tuber ischiadicum
093B	Pelvis; distal metaphysis; reducible fragments
093B1	Pelvis; distal metaphysis; reducible fragments; bilateral fx of ischium
093C	Pelvis; distal metaphysis; complex
093C1	Pelvis; distal metaphysis; complex; complex fx of pelvis floor
10	Patella
101	Patella; proximal metaphysis
101A	Patella; proximal metaphysis; simple
101A1	Patella; proximal metaphysis; simple; small fx proximal border
101C	Patella; proximal metaphysis; complex
101C2	Patella; proximal metaphysis; complex; multifragment fx proximal border
102	Patella; diaphysis
102A	Patella; diaphysis; simple
102A1	Patella; diaphysis; simple; chip fx cranial surface
102C	Patella; diaphysis; complex
102C2	Patella; diaphysis; complex; multiple chip fx cranial surface

Code	Description
103	Patella; distal metaphysis
103A	Patella; distal metaphysis; simple
103A1	Patella; distal metaphysis; simple; small articular fx distal border
103B	Patella; distal metaphysis; reducible fragments
103B1	Patella; distal metaphysis; reducible fragments; abaxial,articular
103B2	Patella; distal metaphysis; reducible fragments; sagittal, articular
103C	Patella; distal metaphysis; complex
103C1	Patella; distal metaphysis; complex; horizontal articular
103C2	Patella; distal metaphysis; complex; articular in frontal plane
103C3	Patella; distal metaphysis; complex; multifragment, articular
11	Atlas
11A	Atlas; simple
11A1	Atlas; simple; simplewing fx
11A2	Atlas; simple; complex wing fx
11B	Atlas; reducible fragments
11B1	Atlas; reducible fragments; simple fx dorsal arch
11B2	Atlas; reducible fragments; simple fx dorsal & ventral arch
11B3	Atlas; reducible fragments; complex fx
12	Axis
12A	Axis; simple
12A1	Axis; simple; transverse crest
12A2	Axis; simple; dorsal crest, nonarticular
12B	Axis; reducible fragments
12B1	Axis; reducible fragments; dens of C2
12B2	Axis; reducible fragments; body of C2
13	Cervical spine (C3–7)
13A	Cervical spine (C3–7); simple
13A1	Cervical spine (C3–7); simple; transverse process
13A2	Cervical spine (C3–7); simple; peripheral fx of body
13A3	Cervical spine (C3–7); simple; articular fx of body
14	Thoracic spine (T1–18)
14A	Thoracic spine (T1–18); simple
14A1	Thoracic spine (T1–18); simple; dorsal spinous process
14A2	Thoracic spine (T1–18); simple; peripheral fx of body
14A3	Thoracic spine (T1–18); simple; complex fx of body

Code	Description
15	Ribs
15B	Ribs; reducible fragments
15B1	Ribs; reducible fragments; simple
15B2	Ribs; reducible fragments; complex
16	Lumbar spine (L1–7)
16A	Lumbar spine (L1–7); simple
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29.5 Online references

See online references on the PEOS internet home page for this chapter:
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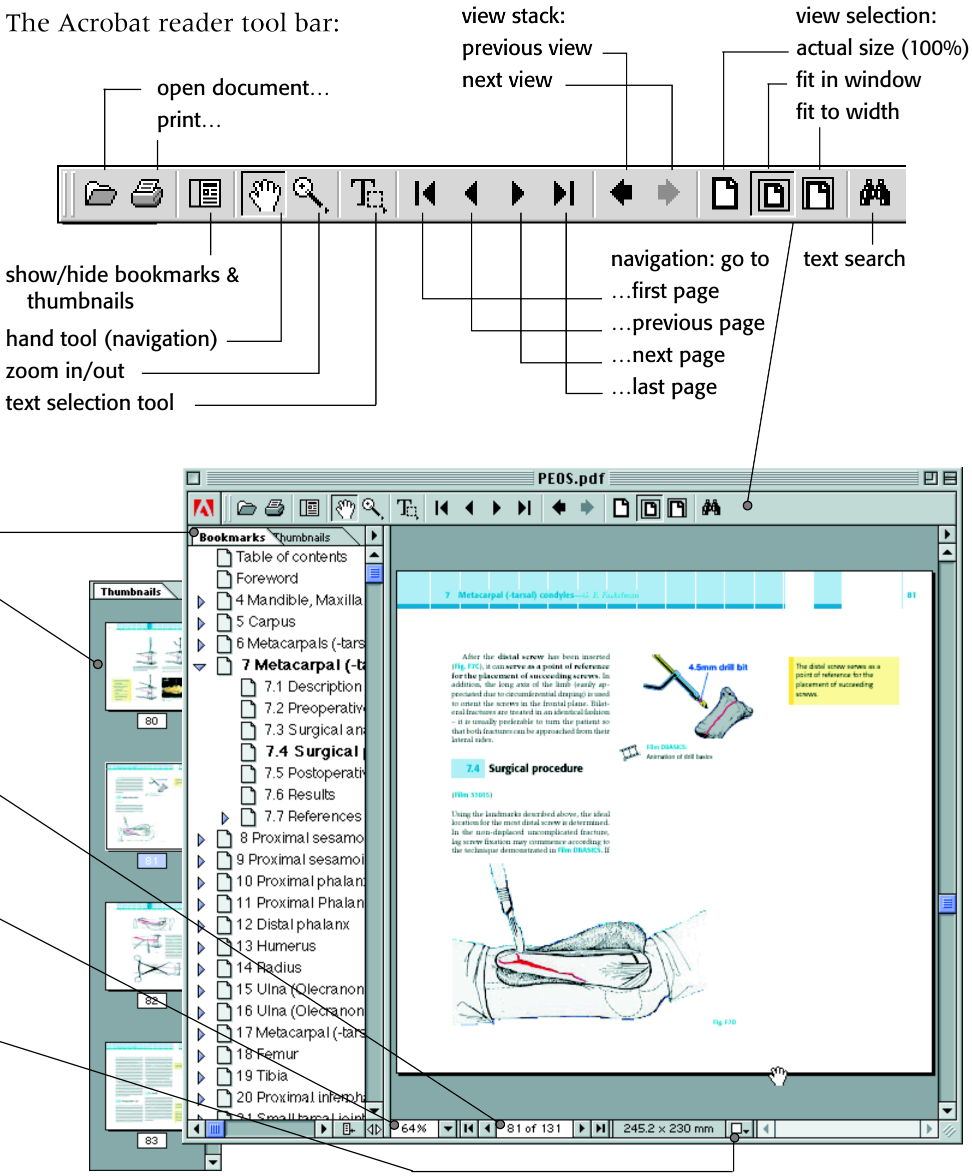

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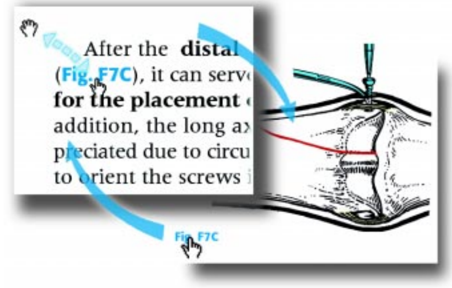

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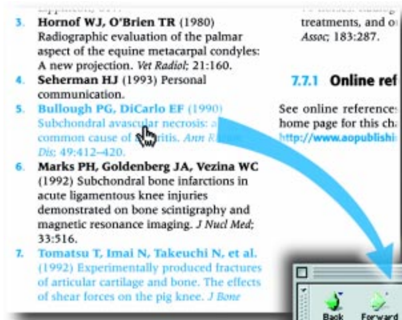

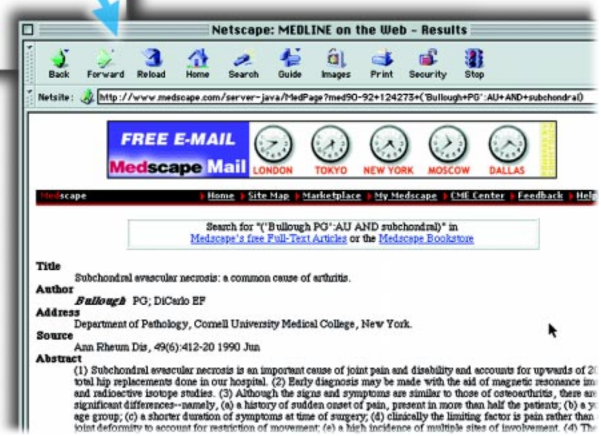

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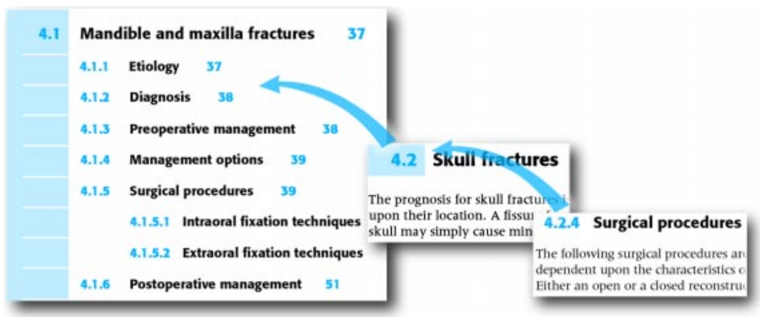

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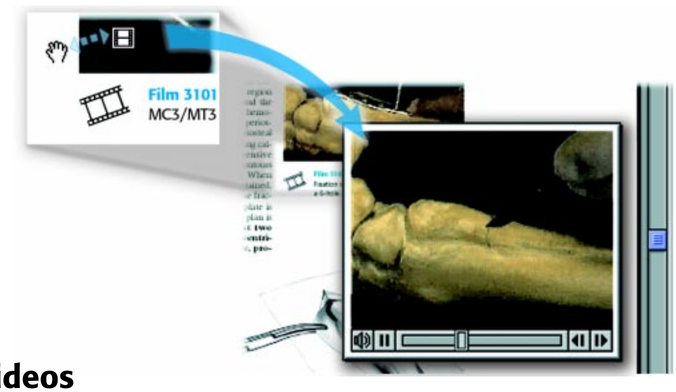

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