Renato Bombelli

Osteoarthritis of the Hip

Pathogenesis and Consequent Therapy

With a Foreword by Maurice E. Müller

With 160 Figures,
70 in Color

Springer-Verlag
Berlin Heidelberg New York 1976

R. Bombelli, M.D., L.D. in Clinica Ortopedica – University of Milan,
Orthopaedic Consultant, Hospital of Busto Arsizio,
20025 Legnano/Italy, Via Lampugnani, 1

ISBN-13: 978-3-642-96358-2 e-ISBN-13: 978-3-642-96356-8
DOI: 10.1007/978-3-642-96356-8

Library of Congress Cataloging in Publication Data. Bombelli, Renato. Osteoarthritis of the hip. Bibliography: p. . Includes index. 1. Osteoarthritis—Surgery, 2. Hip joint—Diseases. 3. Femur—Surgery. I. Title. RD549.B65. 617′.58. 76-23191
ISBN-13: 978-3-642-96358-2

To my wife

Foreword

Osteoarthrosis of the hip is one of the most incapacitating diseases of the locomotor system and in the last forty years it has been a source of continuous interest to research workers and to the general public. In spite of numerous studies, however, the pathogenesis of the disease is still uncertain, and in particular the aetiology of "primary" osteoarthrosis is unknown.

Over the last 10 years the treatment of osteoarthrosis by joint replacement has become steadily more widespread, and the operations of osteotomy and arthrodesis have gone more and more out of favour. On the other hand, hip replacement is certainly not indicated in young adults, especially those engaged in sport, because of the twin dangers of late infection and of loosening.

Professor BOMBELLI has been a friend of Professor PAUWELS for 13 years. At first he accepted both Professor PAUWELS' theory and technique and with these he has had remarkable clinical successes leading to regeneration of the hip. On the other hand, Professor BOMBELLI has also had failures.

Professor BOMBELLI's aims in the present study have been twofold: to study the clinical failures and successes and to elucidate the natural history of the untreated disease over a period of years. He has found that in some patients pain diminishes as the years go by and that during this time a variety of changes can be demonstrated in the hip radiologically. In some cases the appearances suggested that the capacity of bone to remodel and to develop osteophytes was accompanied by a loss of pain; subjectively at least the disease in such hips had "healed".

On the basis of his observations both in untreated cases and in patients treated by intertrochanteric osteotomy, Professor BOMBELLI concluded that the natural "healing" process can be accelerated by surgery. He has embodied this concept in a mathematical analysis which rests upon the belief that good results can be explained by changes induced by surgery in the forces acting on the hip joint. Professor BOMBELLI has observed that, in more than 1000 cases, an extreme valgus osteotomy usually produces an excellent clinical result and that in particular it does so in secondary osteoarthrosis in young adults. He believes that the tendency to lateral subluxation of the femur in the osteoarthrotic hip is due to the presence of forces acting in a lateral direction. The objective of the BOMBELLI valgus osteotomy is therefore to subject the superior capsule of the hip to tension (by rotating the proximal fragment) in the expectation that this will induce osteophyte formation along the superior lip of the acetabulum: in other words, that a physiological "shelf" will be induced. Professor BOMBELLI believes that his good clinical results are due to the resultant increase in the weight-bearing area of the hip.

Although one might question the extent to which biological responses can be explained on the basis of mathematical analyses, the excellent objective results shown by an increase in the radiological joint space, the disappearance of cysts and the disappearance of sclerosis have to be accepted as such. The reader should therefore study this investigation with great care in he hope that Professor BOMBELLI's results can be reproduced by others: the best hip replacement has an unknown but certainly finite life whereas a hip healed after osteotomy will often last a lifetime.

Berne, October 1976 MAURICE E. MÜLLER

Preface

This work is the result of clinical, radiographic, and surgical experience gained in 13 years of treating 1450 cases of primary or secondary osteoarthritis of the hip by intertrochanteric femoral osteotomy.

The study of "Über den Schwerpunkt des menschlichen Körpers" (1889) and "Der Gang des Menschen" (1899) by FISCHER, the "Gesammelte Abhandlungen zur funktionellen Anatomie des Bewegungsapparates" (1965) and the "Atlas zur Biomechanik der gesunden und kranken Hüfte" (1973) by PAUWELS, the precious teaching of this author, father of biomechanics, and the daily observation of X-rays of the hips of patients before and after osteotomy, have allowed me to set forth a hypothesis concerning the pathogenesis of osteoarthritis of the hip and its consequent therapy.

My hypothesis is not the result of inductive, but of deductive reasoning, obtained from clinical and radiographic observations.

The treatment I propose, is not new (though it has some technical alterations), nor is it an alternative to today's widespread total hip replacement. It is in my opinion a procedure which has a particular place in the treatment of secondary osteoarthritis of the hip in young people, although it may sometimes be used in cases of primary osteoarthritis of the hip, in older patients.

The indications for osteotomy, according to my experience, are more widespread than usually thought, because bone and cartilage have an unexpected capacity for recovery if we remove damaging biomechanical forces and create new more favorable ones.

The aim of the operation is to create a healthy ecology in the hip. Nature itself is constantly engaged in counteracting the decaying effect due to causes not yet fully understood, by means of new bone formation: the osteophytes.

But nature proceeds slowly: "Natura non facit saltus"; natural healing occurs only after decades.

Man, the victim of the pathologic process, has too limited a period of life, nor does he readily agree to suffer for an extended period of time.

The operation helps nature to produce in less than an hour what would normally take years.

I feel a deep gratitude to Prof. FRIEDRICH PAUWELS for his warm and generous teaching, to Dr. ROBERT SCHNEIDER, ASIF's President, for his inspiring suggestions, to Prof. MAURICE E. MÜLLER, Director of Orthopedics in Bern University, for his ingenious criticism, to Dr. ROBERT MATHYS and the other members of the committee of SYNTHES for their generous support.

Special thanks are merited by my colleagues in Busto Arsizio General Hospital; doctors, technicians, theatre and ward nurses, who have always given their friendly collaboration.

My thankfulness to my confident and affectionate patients, who are not the object, but the subject of the treatment.

The architects, MARCO TURRI, at the same time artist and technician, and ROBERTO PORETTI, precise and attentive, have ingeniously illustrated my thinking.

To Dr. GÖTZE and to the efficient staff of Springer-Verlag many thanks for their friendly and invaluable understanding.

Legnano, October 1976 RENATO BOMBELLI

Contents

The radiographical study of cases affected by Osteoarthritis of the Hip, before and after Intertrochanteric Osteotomy, suggests a *Pathogenesis* of the disease both in cases of primary and of secondary Osteoarthritis*. From a knowledge of the pathogenesis we can deduce a *Consequent Therapy*.

*Primary osteoarthritis:	Defect in material, that modifies the shape
Secondary osteoarthritis:	Defect in shape, that modifies the material

A. Introduction

Bone and cartilage are sensitive structures. Their qualitative and quantitative components depend not only on hormones, enzymes, vitamins, minerals, and proteins, but also on the stress put upon them when functioning.

The varus or valgus osteotomies aim at reducing the stress and strain by increasing the area of the weight-bearing joint surface.

Reduced function decreases the activity of the osteoblasts and, as a consequence, osteoporosis appears.

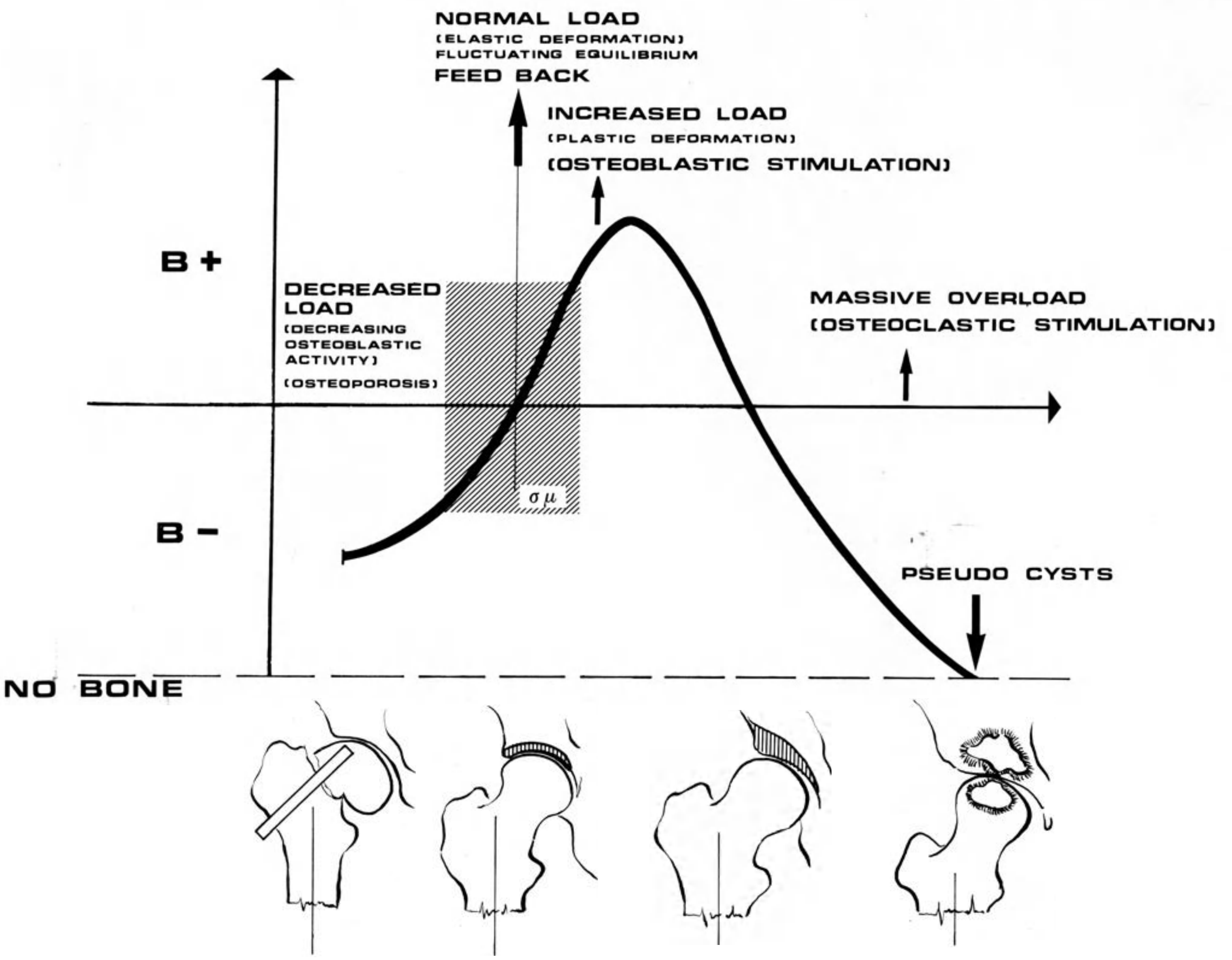
Increased function is responsible for a plastic bone deformation, which stimulates the activity of osteoblasts. As a result osteosclerosis appears.

Massive function produces microfractures and an increased activity of the osteoclasts. Pseudocysts appear.

Normal function produces an elastic bone deformation, which is responsible for a fluctuating equilibrium of the activity of the osteoblasts and of the osteoclasts.

Bone, in the majority of cases, is prepared to heal itself if pathologic forces acting upon it are removed.

BONE APPOSITION AND DEMOLITION ARE DUE TO STRAIN (σ) ELICITED BY FUNCTION (PAUWELS)

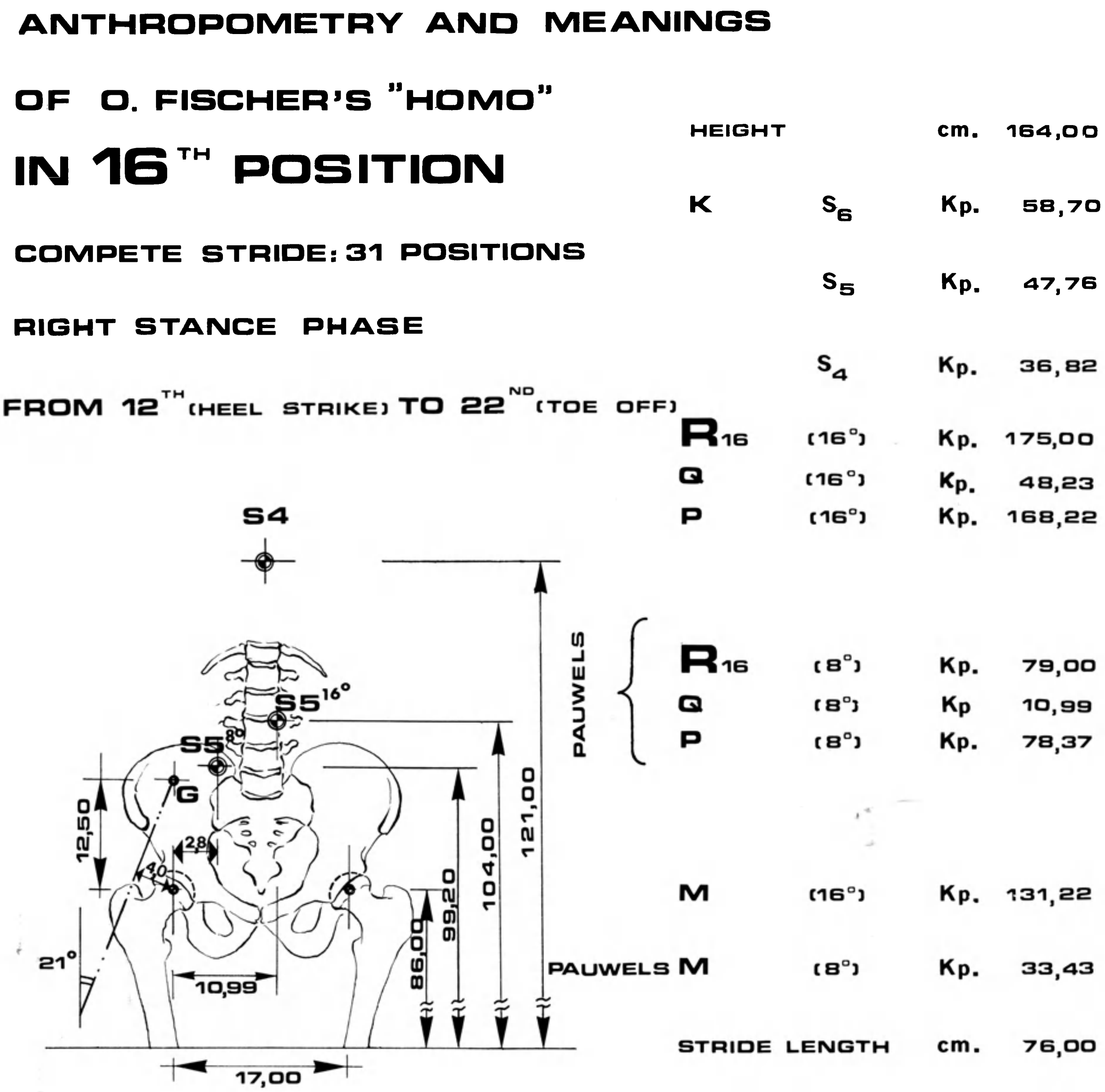


O. FISCHER (1899) studied man's gait, considered in 31 different lower limb positions, on a subject 58.7 kp body weight and 164 cm height.

When the subject is in monopodal support the force acting on the supporting femoral head is a resultant force R_{16} (175 kp) due to the body weight less the weight of the supporting limb S_5 (47.76 kp) and the force of abductors M (131.22 kp) acting to maintain the pelvis level.

When the subject stands on both limbs the weight on the supporting femoral heads S_4 is 36.82 kp and on each supporting femoral head 18.41 kp. From FISCHER's study one can see how amazing is the difference of weight acting on the femoral head when the subject is standing on both limbs or on one limb. In the case of a painful hip the patient, when on monopodal support, shifts his body weight toward the supporting limb. By this pain-reflex movement, the weight on the hip is reduced from 175 kp $S_5(16°)$ to 79 kp $S_5(8°)$ (PAUWELS). In the frontal plane the caudolateral direction of force R in a non-painful hip is 16°; in a painful hip it is 8° or sometimes less, according to the intensity of pain.

The diagram shows the values of the distances from the body's centers of gravity S_4 (121 cm) – S_5 (104 cm) in position 16°, S_5 (99.20 cm) in position 8° to the ground, the distance between the centers of rotation of the femoral heads (17 cm) and the craniomedial direction of force M (21°).



B. Biomechanics of a Normal Hip

In order to understand the biomechanical situation in a pathologic hip joint and to realize its implications, a knowledge of the biomechanical forces acting in a normal hip during gait is required.

FISCHER (1889, 1899a and b), WEBER and WEBER (1895), CROSKEY et al. (1922), SAUNDERS et al. (1953), SCHWARTZ et al. (1964), MURRAY et al. (1964), PAUWELS (1965b), and others have contributed greatly to our knowledge of the biomechanics of the hip during normal gait. We base our study on the work of FISCHER (1889) and of PAUWELS (1965, 1973).

FISCHER considers 31 different lower limb positions in a complete cycle of a man walking in a straight line on a flat surface. According to FISCHER, the phase of the right or left monopodal support (stance phase) consists of 11 positions.

In considering the right stance phase from positions 12 to 22, we will simplify our study by choosing three representative positions: the 12th, the 16th, and the 22nd.

At the 12th position the right heel comes into contact with the ground (heel-strike), at the 16th position the whole foot presses on the ground (foot-to-ground contact), and at the 22nd position the big toe leaves the ground (toe-off) (Fig. 1).

The resultant force R of the two lines M and K, and passing through the center of the femoral head (CR), changes direction during gait. This is attributable to the displacement of the body's center of gravity (S_5) (Fig. 2).

In fact, the resultant force R has, in position 12, an anterolaterocaudal direction; in position 16, a laterocaudal direction; in position 22, a posterolaterocaudal direction.

The counter resultant force R_1 has on opposite direction to the force R in each position.

According to PAUWELS, the counter-resultant force R_1 may be resolved into two components: the force P, perpendicular to the weight-bearing surface, which has a verticocranial direction; and the force Q, parallel to the weight-bearing surface, which has a medial direction in the horizontal plane (Fig. 3).

To clearly understand the direction of the component forces P and Q of the counter-resultant force R_1 during gait, we try to schematize, following accepted mechanical principles. The head of the femur is presented as a hemisphere with its center CR (the point on which all the effective forces act). The acetabulum (socket) is presented as a slightly concave surface tangential to the head and in contact at a point T. This surface, which may be broken down into three cartesian axes (Y=frontal; X=sagittal; Z=vertical), is horizontal and parallel to the axes X-Y. The vertical axis Z passes through the theoretical tangential point T and through CR.

In normal anatomical conditions, the functional biomechanics are relatively simple. The CR of the spherical head is situated in the center of its greatest circle; the bearing surface (acetabulum) is horizontal and parallel to the axes X-Y; the vertical axis Z passes through the theoretical tangenitial point T and through the CR. The resultant force R, inclined at 16° in the frontal plane (during the 16th position), passes through the bearing surface at the point H and through CR (Fig. 4). During gait the force R changes direction in the sagittal plane X. In fact, the position of the body's center of gravity S_5 changes at each instant in the frontal plane (lateral oscillations) and in the sagittal plane (vertical oscillations). During position 12 the body is in backward balance (Fig. 5), during position 16 in frontal balance (Fig. 6), and during position 22 in forward balance (Fig. 7).

To simplify, we can imagine the displacement of the body's center of gravity S_5 in the plane parallel to the plane Z-X and along a straight line parallel to X.

We resolve the counter-resultant force R_1 into two forces: Q and P. The force Q is parallel to a line which joints the point T to the point H; the force P is parallel to a line joining the point CR to the point T.

From the drawings we can see that during gait the compressive force P is always vertical. The force Q, which is always directed medially in the horizontal plane, changes direction: namely, during the 12th position it is also directed posteriorly, during the 16th position only medially, during the 22nd position also anteriorly. As a consequence of this, the femoral head is stressed from every direction in the horizontal plane.

A long stride increases the force Q and decreases the force P; on the other hand, a short stride decreases the force Q and increases the force P.

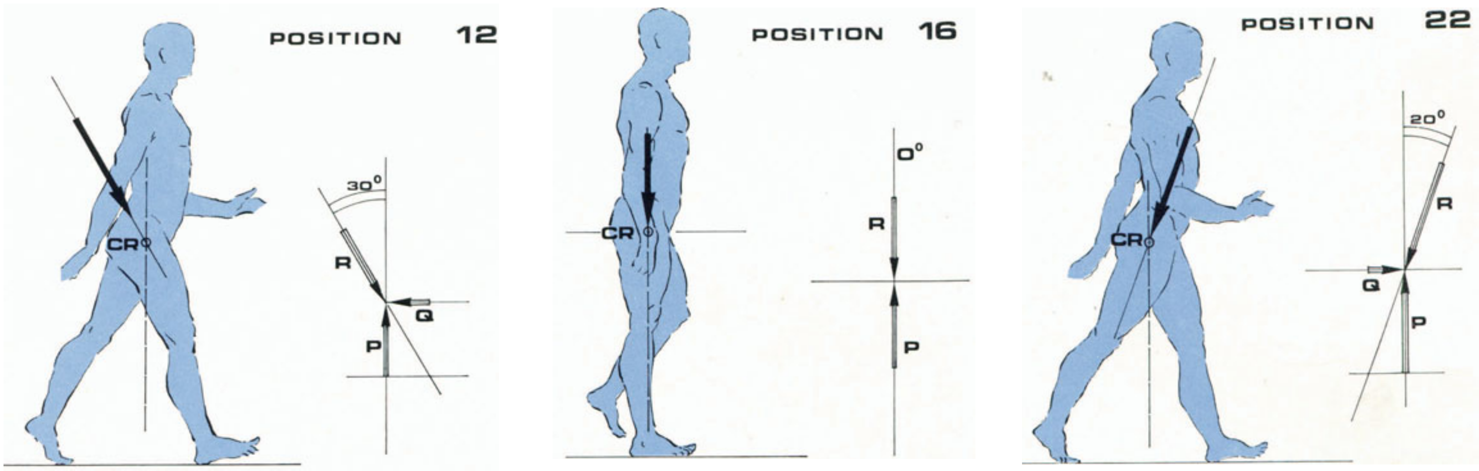


Fig. 1. Three fundamental positions of right limb during stance phase: *position 12* heel-strike, *position 16* foot-to-ground contact, *position 22* toe-off. According to FISCHER, complete stride of man walking on flat ground may be divided into 31 positions. The right stance phase is divided into 11 positions from 12 to 22

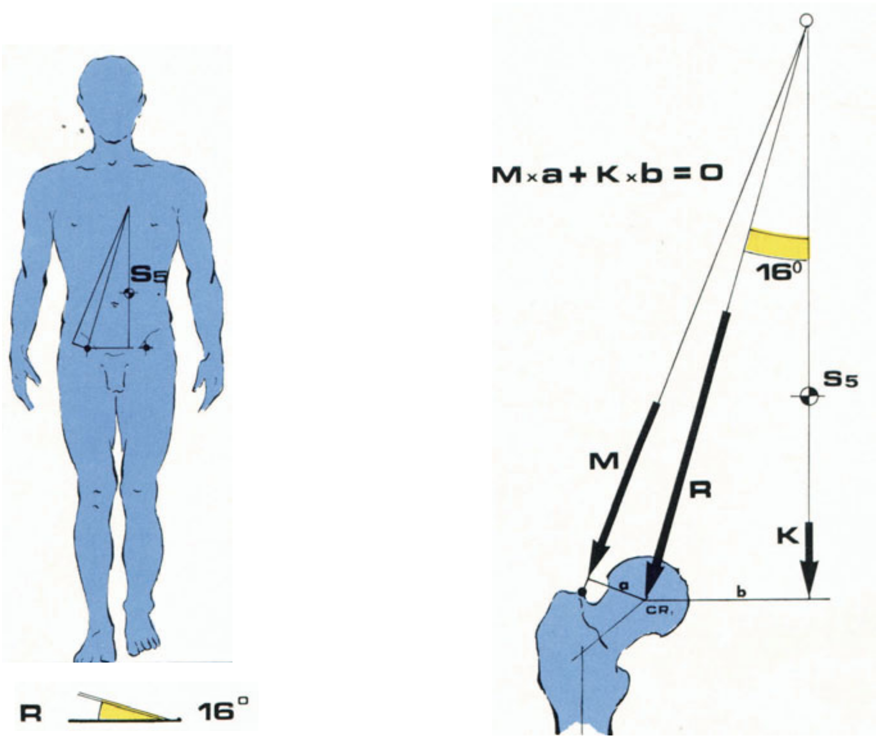


Fig. 2. Line M is the prolongation of direction of abductors. Line K is a vertical line, passing through the body's center of gravity S_5. K=Weight of body less weight of supporting limb in monopodal support. M=Abductors (gluteus medius—gluteus minimus—piriformis—tensor fasciae latae—sartorius—rectus anterior). CR=Center of rotation of spherical head. b=lever arm of body weight. a=lever arm of abductors

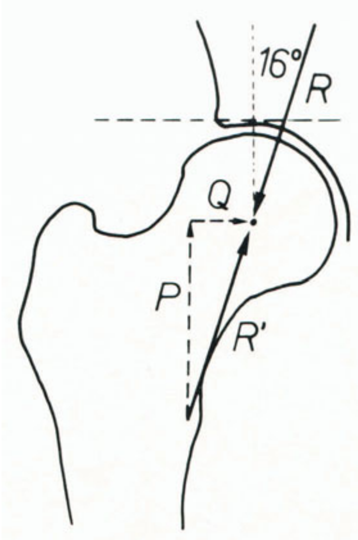
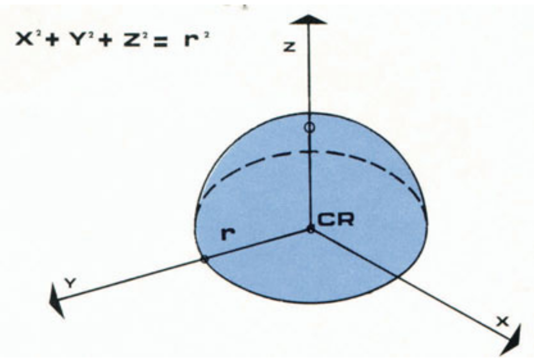
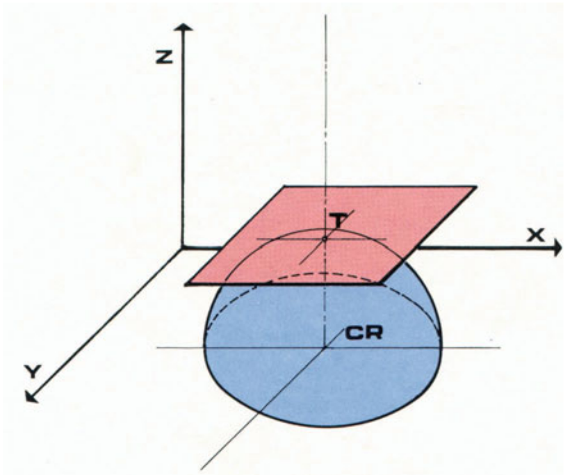


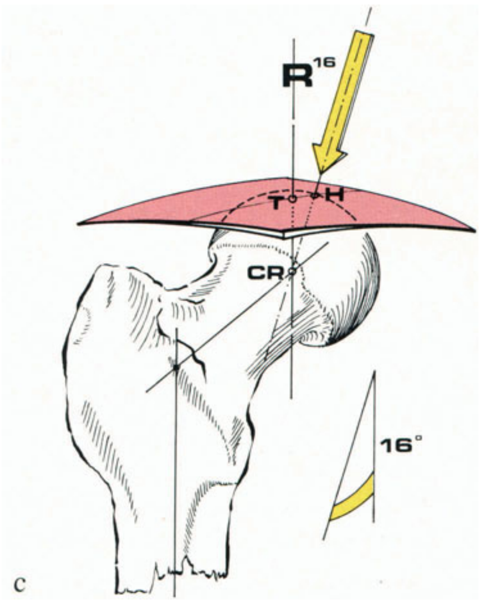
Fig. 3. Normal hip has horizontal weight-bearing joint surface. We are able to resolve counter-resultant force R_1 into two components: force P and force Q. Force P has a cranial direction; force Q has a horizontal direction and pushes femoral head into acetabulum (PAUWELS) (Phase 16 of man's gait, according to FISCHER)



a



b



c

Fig. 4a–c. Diagram shows: (a) Hemisphere with three Cartesian axes passing through its CR. (b) Hemisphere in contact at point T with tangential horizontal surface. (c) Head of femur presented as a hemisphere and acetabulum presented as slight concave surface in contact at point T with the head. The force R in frontal plane passes through acetabulum at point H and is directed to center CR and has an inclination of 16°

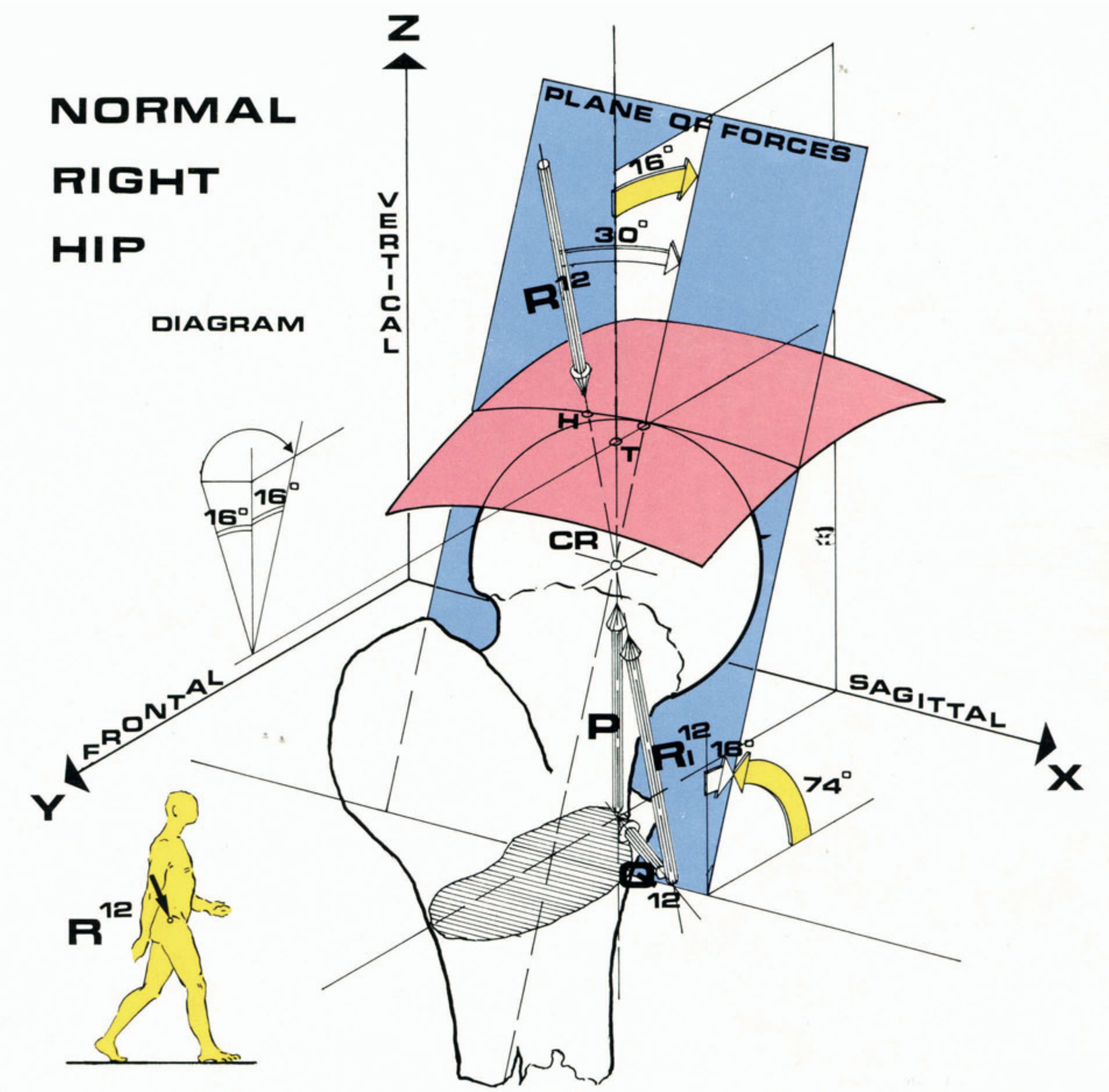


Fig. 5. In position 12 resultant force R has an inclination of 16° in the frontal plane and of 30° in the sagittal plane. Force R, passing through center of head CR, is directed inferolateroanteriorly, because body's center of gravity S_5 is located cranially, medially, and posteriorly to center of head of femur CR. Tangent point T is located laterally to point H (point on acetabular surface through which force R passes). Counter-resultant force R_1 has an opposite direction. Its component force Q has medialposterior direction in the horizontal plane and its component force P has a craniovertical direction

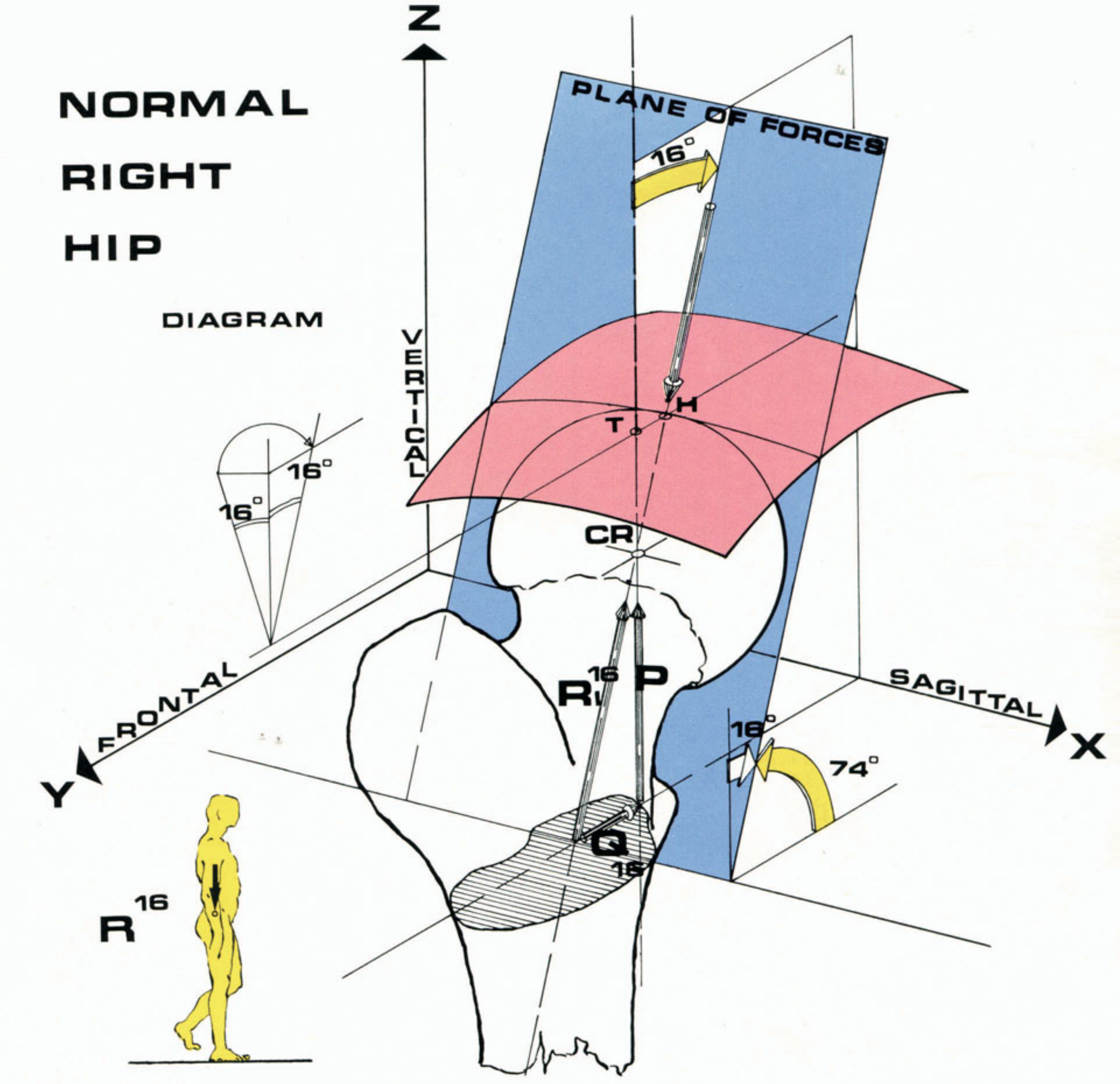


Fig. 6. In position 16 the body is in the frontal plane. Resultant force R, passing through CR, has an inclination of 16° in the frontal plane. Tangent point T is located laterally to point H (point on acetabular surface through which force R passes). Counter-resultant force R_1 has an opposite direction. Force Q has a medial direction in the horizontal plane. Force P has a verticocranial direction

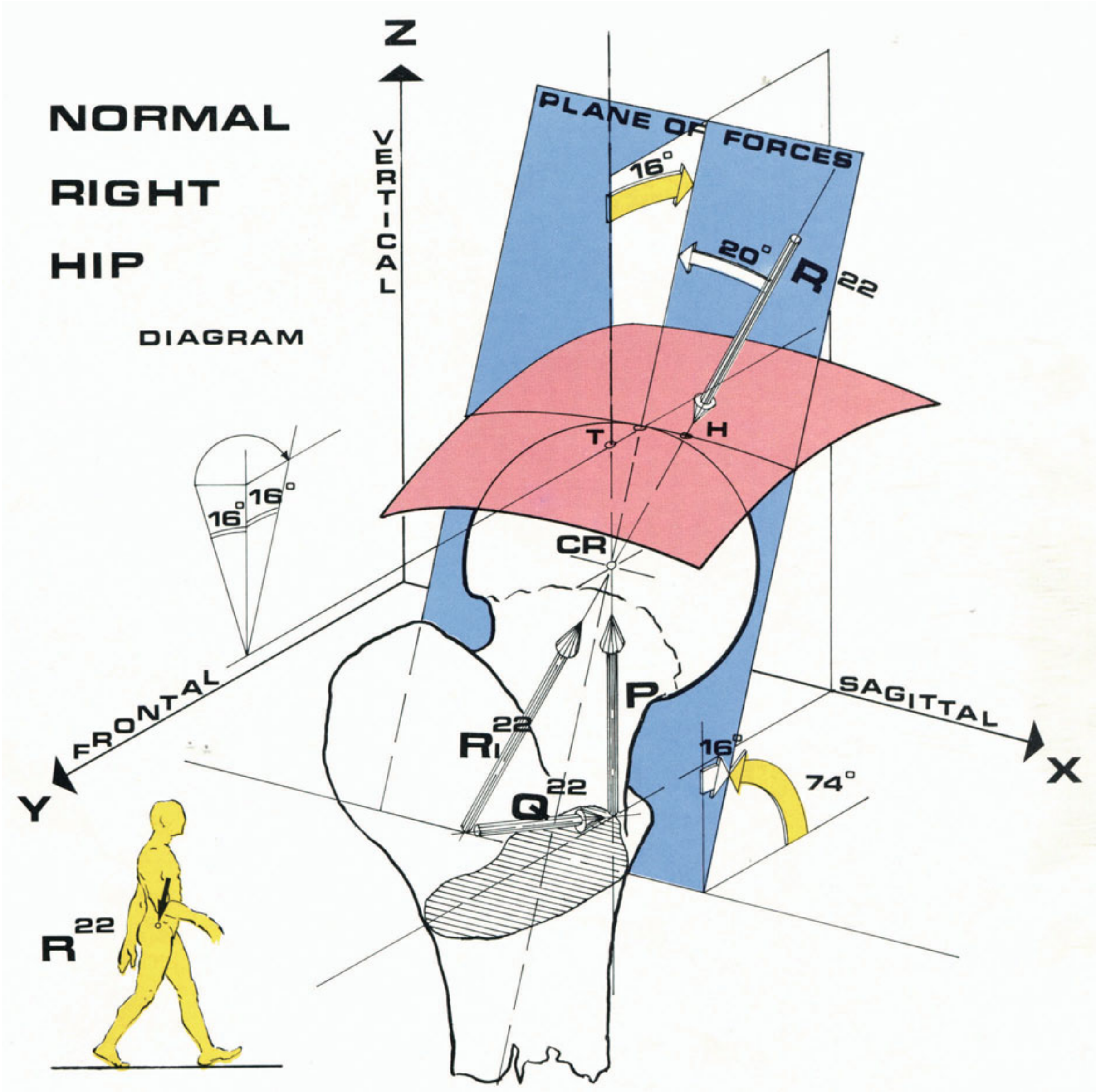


Fig. 7. In position 22 resultant force R is inclined at 16° in frontal plane and at 20° in sagittal plane. Body's center of gravity S_5 is located craniallymedially and anteriorly to center of head of femur CR; therefore, resultant force R has caudolateroposterior direction. Counter-resultant force R_1 has an opposite direction. Its component force Q has an anteromedial direction in horizontal plane; its component force P has verticocranial direction. Tangent point T is located laterally to point H

C. Biomechanics in Osteoarthritis of the Hip

We will now consider what now occurs in primary and secondary osteoarthritis of the hip.*

In osteoarthritis of the hip a pathologic condition both of the femoral head and of the acetabulum develops. As can be observed on X-rays, the head becomes progressively flattened in its anterocraniolateral quadrants, the weight-bearing surface of the acetabulum shifts anterocranially in the sagittal plane *X* and laterally in the frontal plane *Y* (Fig. 8a).

These two alterations occur over a long period of time. In young persons it takes many years, but sometimes, in elderly persons with osteoporosis, it takes only months.

These changes of shape evoke new biomechanical conditions in the hip joint.

The first new condition is that the center of rotation *CR*, through which the resultant force *R* passes, in a deformed head no longer has the same importance as in a spherical head. In fact, in an osteoarthritic hip there is more than one center of rotation and the centres of stress *CS* instead of being widespread, as in a normal hip, tend to be confined to an ever diminishing, highly stressed zone because of the new elliptical shape of the femoral head.

The second new biomechanical condition is the gradual decrease of the force *Q*, the gradual increase of the force *P*, and the appearance of a new force, the force *S*.

In fact, the weight-bearing surface (acetabulum) is no longer parallel to the plane *X-Y* (Fig. 8b) and, therefore, the component forces of the counter-resultant force R_1 are no longer in the same direction as before.

There is a contraction of the adductor and flexor muscles provoked by pain. Moreover the patient, because of a pain reflex, shifts the body's center of gravity S_5 toward the supporting painful hip (Pauwels, 1961, 1963, 1965a/b) in order to decrease the magnitude of the force *R* (Fig. 9).

* From this study we exclude the central type of osteoarthritis of the hip, coxa profunda, and protrusio acetabuli.

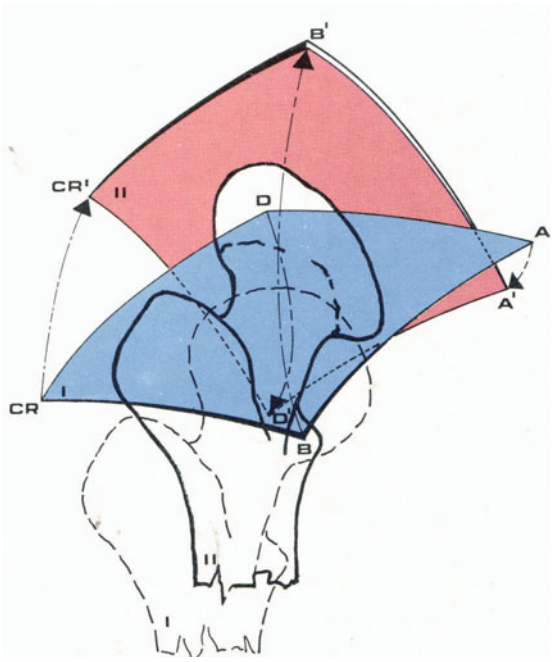


Fig. 8a. In osteoarthritic hip, progressive degeneration of cartilage and bone flattens head of femur and wears away superoanterior and superolateral part of acetabulum. As a result, articular weight-bearing surface becomes oblique in two planes. It shifts anterocranially in sagittal plane *X* and craniolaterally in frontal plane *Y*

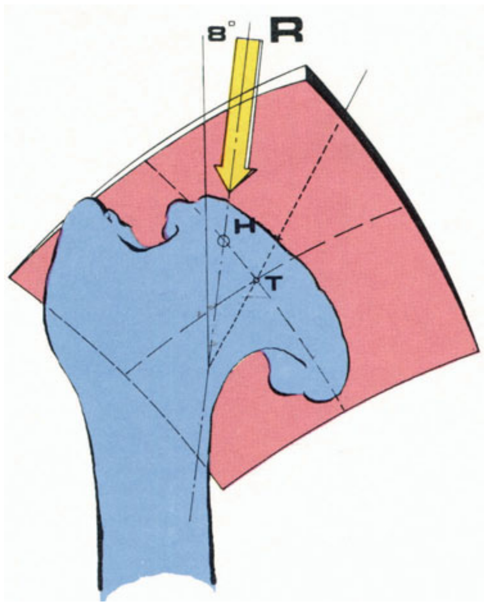
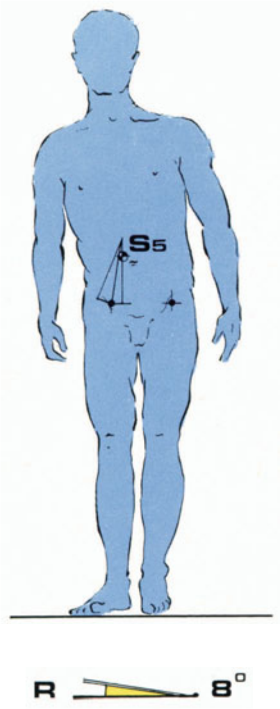


Fig. 8b. Because of obliquity of weight-bearing joint surface, tangent point *T* progressively moves medially and posteriorly to point *H* and then gradually shifts medially and posteriorly beyond it



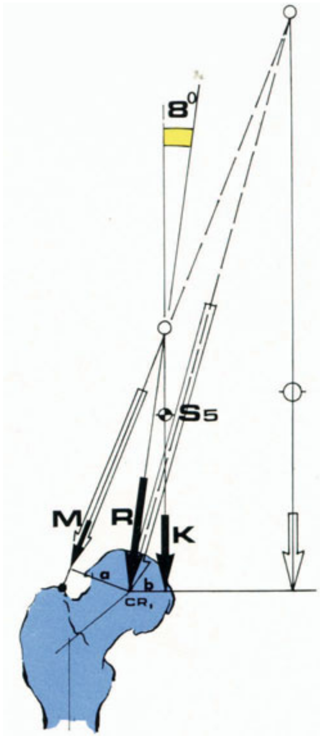


Fig. 9. Positions of body's center of gravity when resultant force *R* has inclination of 16° and 8° in frontal plane. Shifting of body's center of gravity toward supporting limb reduces length of lever arm (*b*) of weight (*K*) and therefore reduces moment (*M.a*) on the other side of the center of rotation CR_1 of head of femur, required to balance now diminished moment of body weight. Together these achieve a significant reduction in the resultant force *R*

I. Examination of a Deformed Femoral Head

In osteoarthritis the femoral head loses its spherical shape. The part of the spherical surface, that which is under greatest stress, flattens and the weight-bearing surface becomes reduced. Geometrically the outline of the head takes the shape of an ellipse. The greater the pressure, the more accentuated is the eccentricity of the ellipse (Fig. 10).

To understand fully the importance of this change from the spherical to the elliptical shape, we must consider it as a geometrical concept.

We must distinguish two different centers:

1. The center of rotation *CR*
2. The center of stress *CS*

The center of rotation in a spherical head is a fixed point, whereas in an ellipse it varies, according to the section of the surface considered.

The center of stress, the point under greatest stress at any particular moment, is constantly varying.

In a healthy spherical head it will vary over a wide area, but in a diseased head it will vary over an ever-diminishing zone, which is therefore subjected to an increasingly high stress. The reduction of this zone, caused by the reduction of the weight-bearing joint surface, is due to pain, which shortens the patients's stride, and to the deformity of the head, which prevents it revolving freely in the socket.

II. Search for the Center of Rotation (CR) and the Center of Stress (CS)

We can consider the head of the femur as a hemisphere that revolves round its center of rotation *CR* in the acetabulum, which is looked upon as a hollow sphere (although the head rests only on the "facies semilunaris").

When different spherical sectors are under pressure at different instants of time, it is important to distinguish the center of rotation of the sphere *CR* from the points on which the stress acts with the highest magnitude (centers of stress: *CS*).

The center of rotation *CR* is the point at which the perpendiculars from the planes tangent to the spherical surface converge (Fig. 11a). This point is unique and is always under stress during gait and in a standing position.

In a normally shaped hip with a healthy bone, the center of rotation reacts to stress with a large range

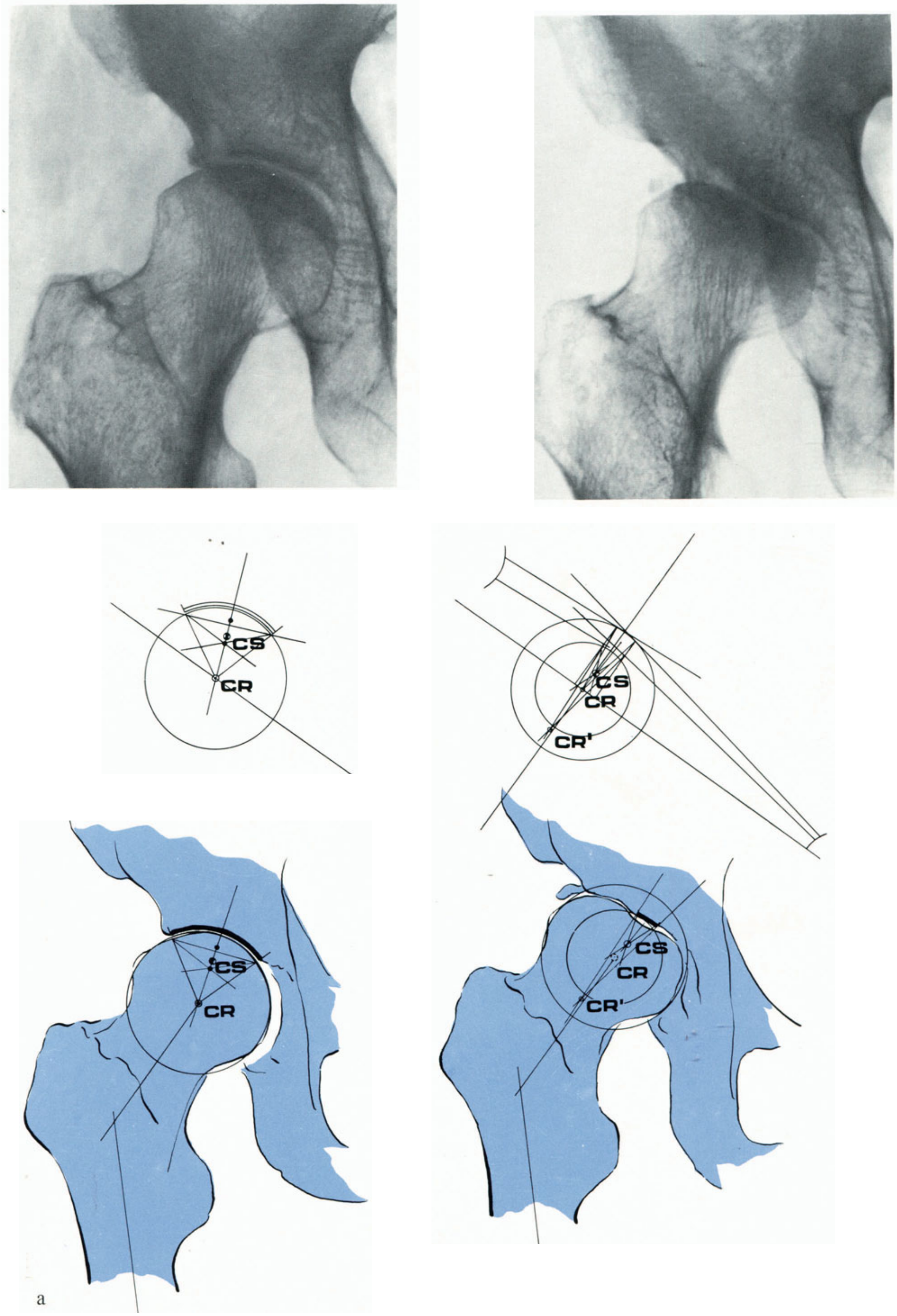


Fig. 10. In osteoarthritis of the hip, the head of femur assumes elliptical shape. Center of rotation is no longer center of head, but a different point CR_1, which is located in different positions, according to shape and extent of bearing area of sector under pressure. Each sector has a corresponding center of stress *CS*

of elasticity; this means that the point *CR* is not altered by the stresses acting on it, which usually are not very high.

On the other hand, considering an instant of time during gait, the most stressed point in the head is not the center of rotation *CR* but another one, which is called the center of stress (*CS*). This one in contrast to the center of rotation *CR* is not always located at the same point in the head, but has different positions according to the spherical sector under pressure. To clarify this fact a simple example may be used.

If a small area of a sphere is under pressure, compressive stress acts upon the conical zone of the sphere (spherical sector) under this area.

The spherical sector is described by the perpendiculars to the planes tangent to the compressed area. These perpendiculars converge at the apex of the sector, the point *CR*, which is the center of the sphere (Fig. 11b). Examining the principal section of the spherical sector, this section appears as a triangle with a base formed by a part of the circumference of a circle. Its inner structure is stressed by lines of force converging at the point *CR* (Fig. 11c).

On its surface there are perpendicular forces σ (compressive) and tangential forces τ (attrition), which oppose the penetration of the triangle into the material in which it is included (Fig. 11d). The acting and the reacting forces in an elastic system are in equilibrium at the point *CS*. This is the center of stress *CS* (Fig. 12a).

We realize now that, at each instant of gait the point under the greatest stress is the *CS* of the spherical sector under pressure at that moment.

But, because the spherical sectors are always different, according to the position of the head in the acetabulum (flexion, extension, abduction, adduction), there is more than one center of stress. In short, while the center of rotation *CR* is unique and always moderately stressed, the *CS* are numerous, according to the spherical sector under pressure at each instant, and are very highly stressed.

The larger the bearing area of the sector, the nearer the point *CS* is to the point *CR* (Fig. 12b).

The smaller the bearing area, the nearer the point *CS* is to the surface (Fig. 12c).

If the surface is pointlike, the *CS* is upon the surface.

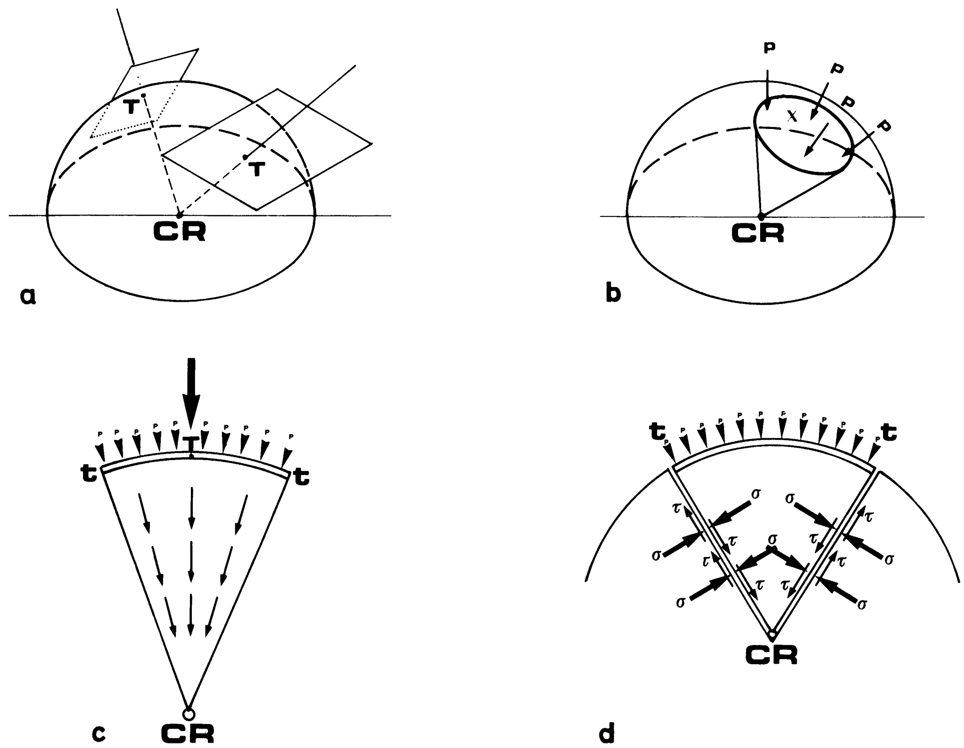


Fig. 11a–d. (a) Center of hemisphere is the point *CR* at which the perpendiculars from the planes tangent to hemispheric surface converge. (b) The spherical sector is described by forces *P* perpendicular to area under pressure. These forces converge on center of hemisphere. (c) The principal section of a spherical sector, which is a circular sector, has shape of triangle with base formed by part of circumference of circle. (d) Forces acting on surface *t-t* of circular sector may be resolved into perpendicular forces σ and tangential forces τ. These forces are counteracted by similar forces in the rest of the hemisphere, which oppose penetration of circular sector into material

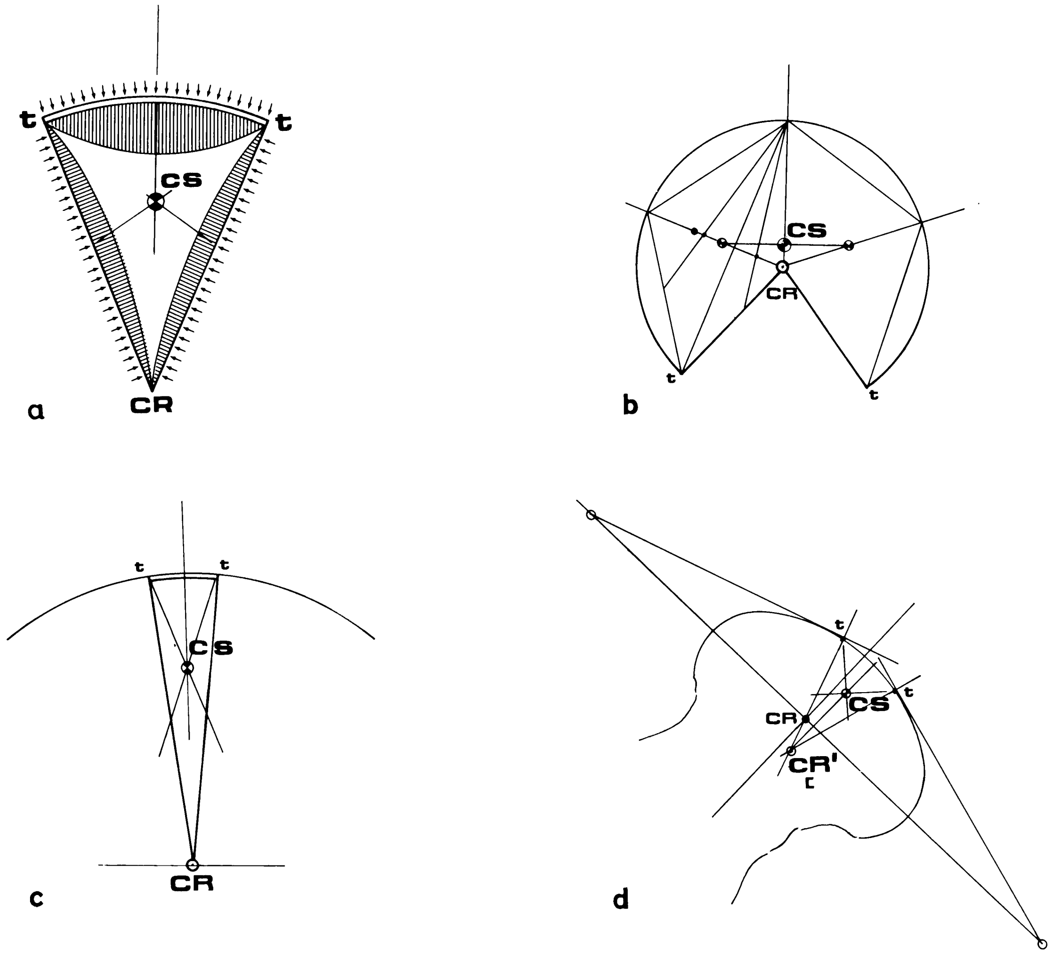


Fig. 12a–d. (a) In an elastic system, acting and reacting forces $\sigma\tau$ are in equilibrium at point *CS* (center of stress), which is the center of gravity of the sector. (b) The larger the bearing area of the sector, the nearer point *CS* is to point *CR*. (c) The smaller the bearing area, the nearer point *CS* is to the surface. (d) In osteoarthritis of the hip, the femoral head flattens and takes the outline of an ellipse. In it there are different centers of rotation *CR* and different centers of stress *CS*, according to the sector under pressure at any instant

Fig. 13. Two bone cysts are visible in the femoral head. From a geometric drawing, given the actual weight-bearing surface, *CS* (center of stress) is localized in center of greater cyst. The *CS* had probably been previously in the more lateral cyst, when the head was more centrally placed in the socket, that is, before force *S* pushed the head further outward. After the operation, cysts have almost disappeared. Geometric drawing localizes *CS* more medially and therefore central and lateral sections of head are no longer the most stressed places. ▷ Because bearing surface is larger and formed by osteophytes, pain has disappeared and stride becomes longer. For this reason, spherical sectors under pressure are more numerous than before and each has its own CR_1 and its *CS*. There is a large part of head in which different centers of stress *CS* change in turn. As a result osteosclerosis decreases

III. Consequences of Deformity in the Femoral Head

Little by little the disease progresses, the shape of the femoral head becomes elliptical (Fig. 12d) the pain increases, and the patient is compelled to shorten his stride. As a consequence, the pressure is concentrated on a reduced articular area. The stressed sector becomes smaller and eburnation is evident.

When the load can no longer be supported by the bone, the bone collapses and bone cysts develope (Fig. 13).

Some important conclusions emerge: The center of stress *CS*, that is, the center of gravity of each spherical sector, is the point which bears at each instant of time the greatest stress. Its position changes continually, according to the spherical sector under pressure from the force *R*.

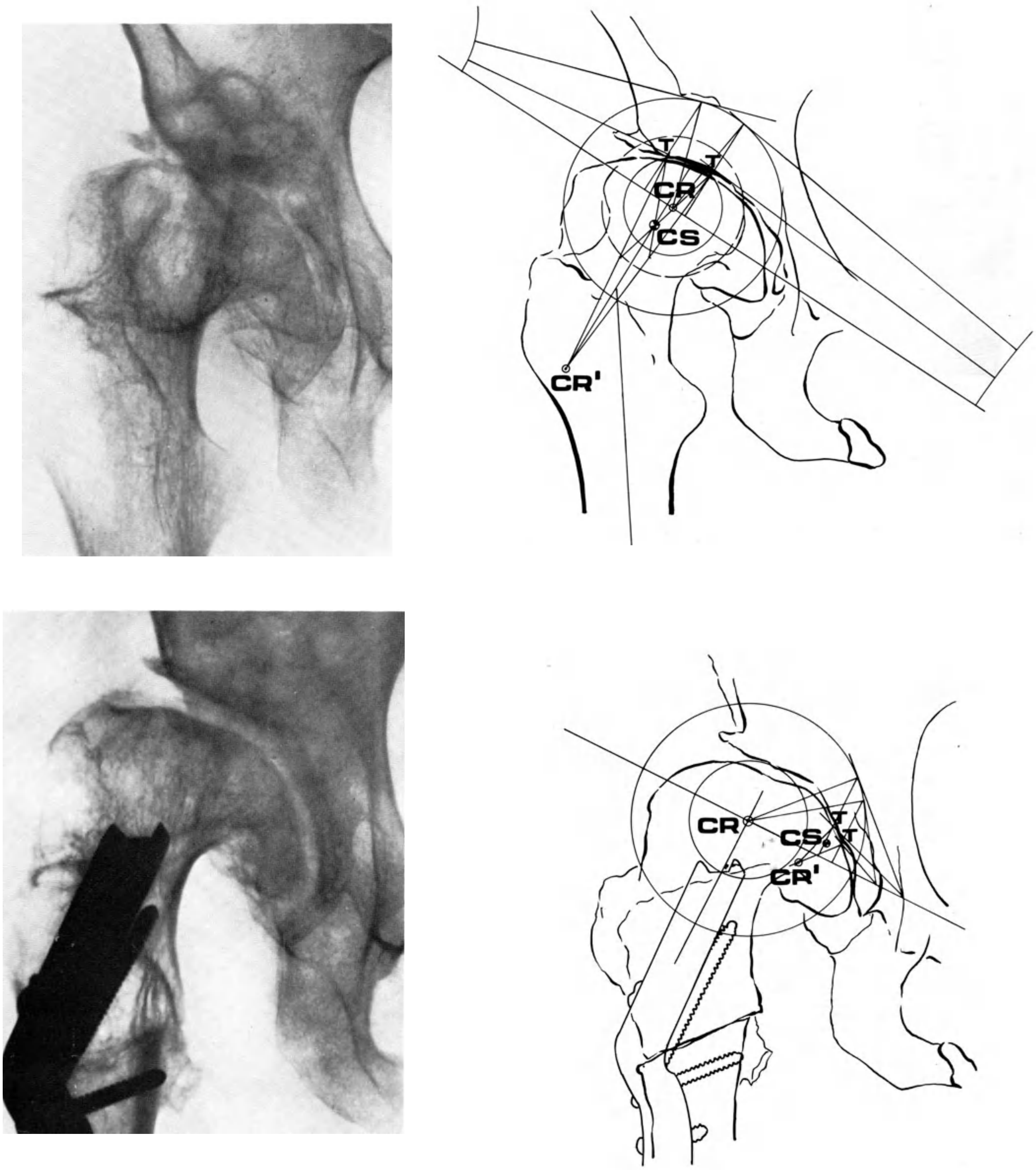


Fig. 13. Legend see opposite page

Only in a sphere do the apices of all the spherical sectors coincide in a single point *CR*, the center of rotation. In an ellipse the apex of each sector, which is the CR_1 of that sector, is at a point unique to itself (Fig. 14).

In conclusion: The center *CR* of a spherical head is always under stress, although the amount of stress is low. Each *CS* bears a high stress but only for an instant of time. In an ellipse the situation is:

1. The center of rotation varies and therefore no one point is constantly stressed.
2. The number of *CS* is reduced and therefore the total stress on each is increased.

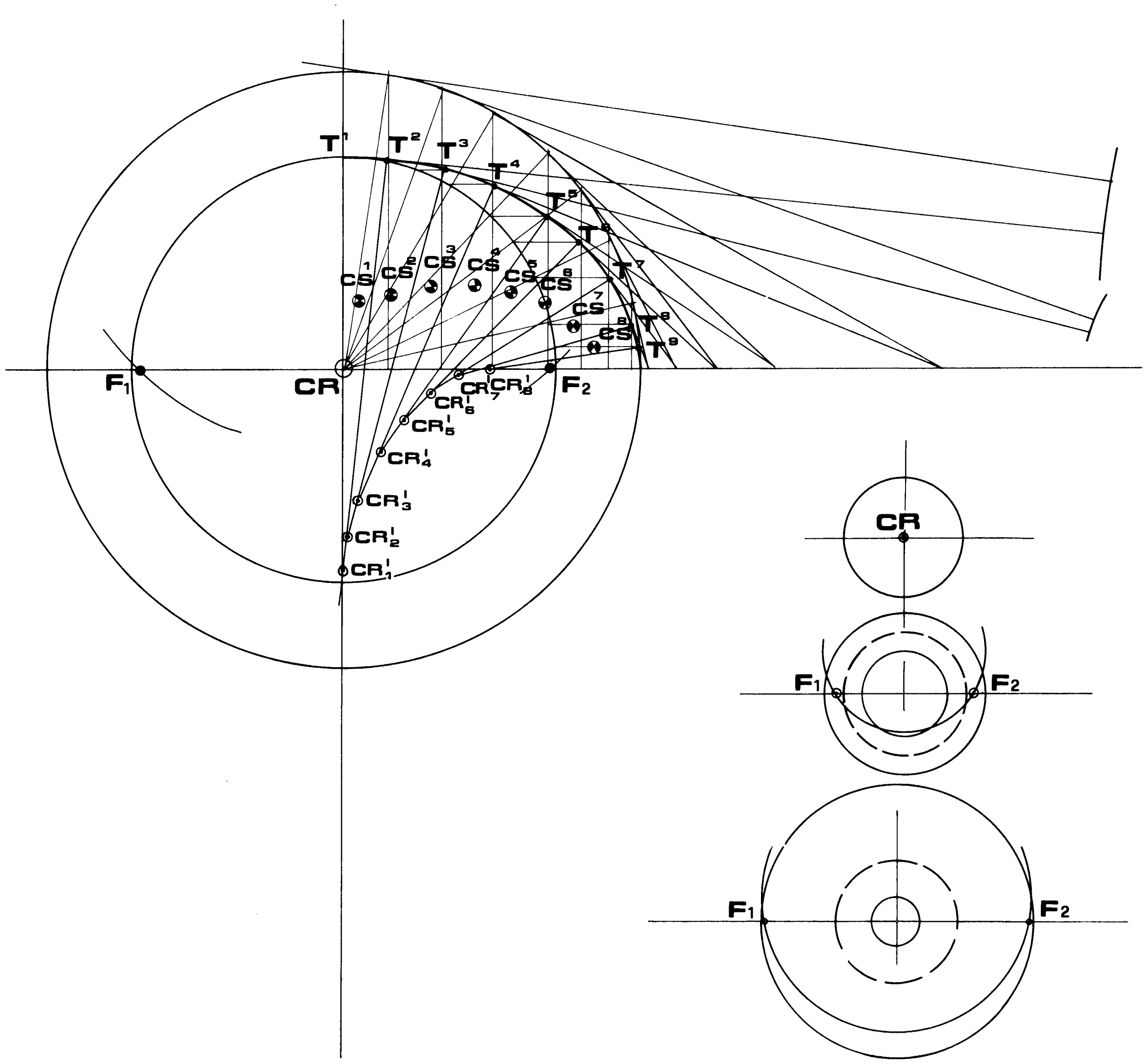


Fig. 14. Diagram shows different centers of rotation CR_1, according to different sections of ellipse $T_1 - T_2$ and so on. Each section has a particular center of stress *CS*. The more lateral the section under compression, the nearer its corresponding center of rotation CR_1 and its center of stress *CS* are to the surface. CR_8 and CS_8 are nearer to surface $T_8 - T_9$ than CR_1 and CS_1 to surface $T_1 - T_2$

IV. Detection of CR, of CR_1, and of CS, from X-ray of a Deformed Elliptical Femoral Head

The outline of the femoral head and of the acetabulum, taken from an anteroposterior X-ray is drawn on tracing paper. The place is determined at which was situated before the disease the original center of rotation of the femoral head *CR*.

The axis of the shaft and of the neck are marked on the X-ray and on the tracing paper.

On the tracing paper is marked the perpendicular to the axis of the neck, which passes through *CR*; the minor circle and the major circle, both whose centers are at the point *CR*, are also marked. The minor is the circle tangent to the more flattened surface, the major is the circle tangent to the more bulging extremity of the surface of the femoral head.

The perpendiculars are drawn to the tangents at the extreme points of the reduced bearing surface.

These perpendiculars meet at one point CR_1, which is the center of rotation relative to the bearing surface. The perpendiculars limit, at the same time, the femoral sector under stress whose center is the center of stress *CS* (Fig. 10). On X-ray it corresponds to an area of eburnation.

Figure 15 shows the geometrical particulars of Figure 10.

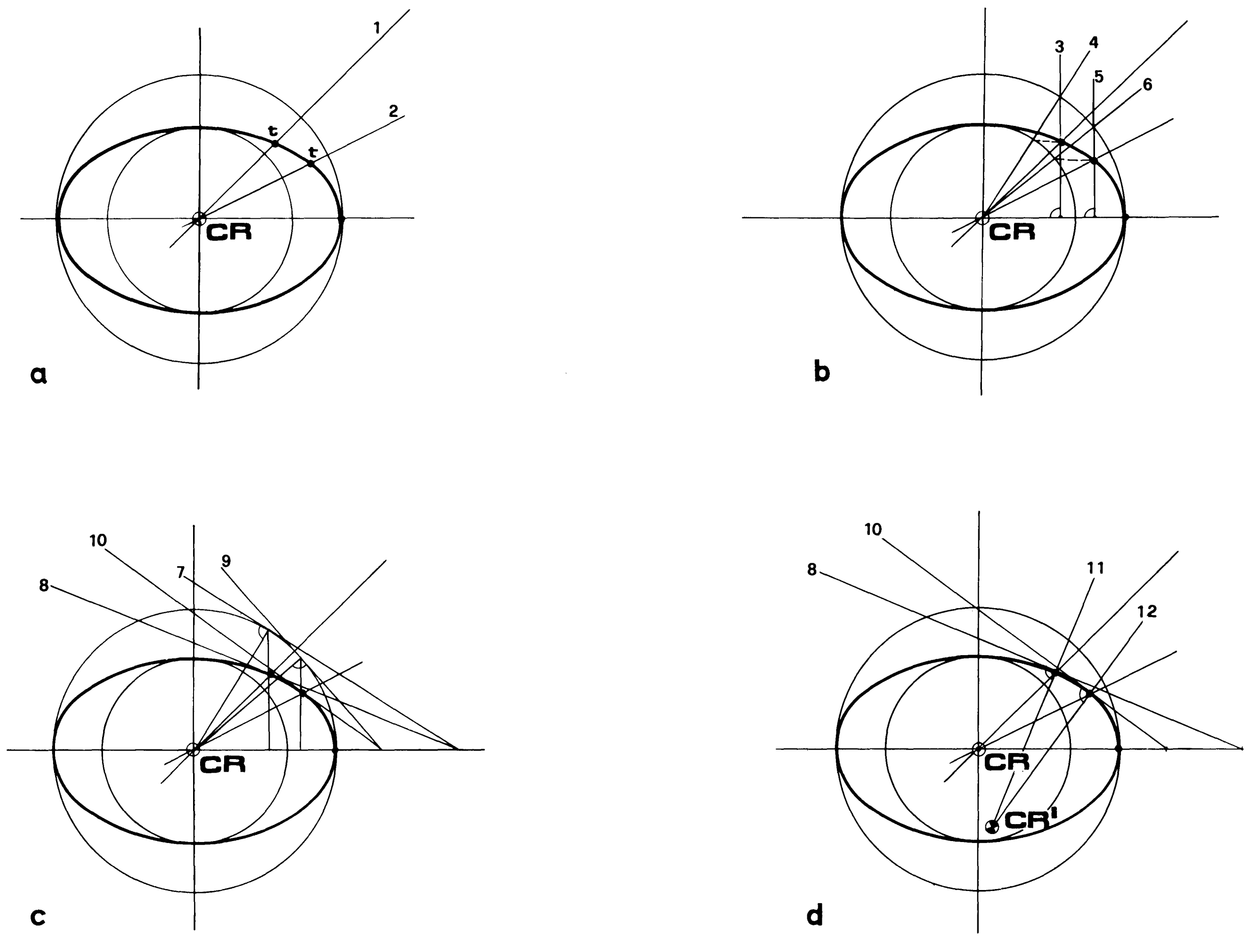


Fig. 15a—d. How to find center of rotation CR_1 corresponding to part of elliptical surface *t-t*, knowing center *CR* of concentric major and minor circles. (a) Determine extreme points of weight-bearing surface *t-t* (1—2). (b) From points *t-t* draw perpendicular lines to major axis of ellipse (3—5). They meet major circle. From these meeting points draw their radii (4—6) and (c) their tangents (7—9). Tangents intersect prolongation of major axis of ellipse. From these intersecting points draw tangents to points *t-t* (8—10) and (d) the perpendiculars to these tangents (11—12). These perpendiculars meet in one point, which is center or rotation CR_1 corresponding to surface *t-t*

V. Appearance of Force S

As the hip deteriorates further, the pain worsens and, therefore, the patient shifts the body's center of gravity S_5 towards the painful side. In this way the resultant force R becomes progressively more vertical. Its inclination in the frontal plane may be reduced from 16° to 8° or less. Gradually the component force Q disappears and the force P increases until it is equal to R_1, when the force R is perpendicular to the weight-bearing surface.

At this moment a little more obliquity of the weight-bearing surface or a more accentuated shifting of the body's center of gravity, or both, make a new force appear; we call it force S (thrust- spinta- Schub) (Figs. 16a–f and 17a, d).

This new force is directed craniolateroanteriorly. This direction is constant during the stance phase, from the 12th position to the 22nd position (Figs. 18–20).

The biological consequence of force S is the appearance and development of the osteophytes (Fig. 21).

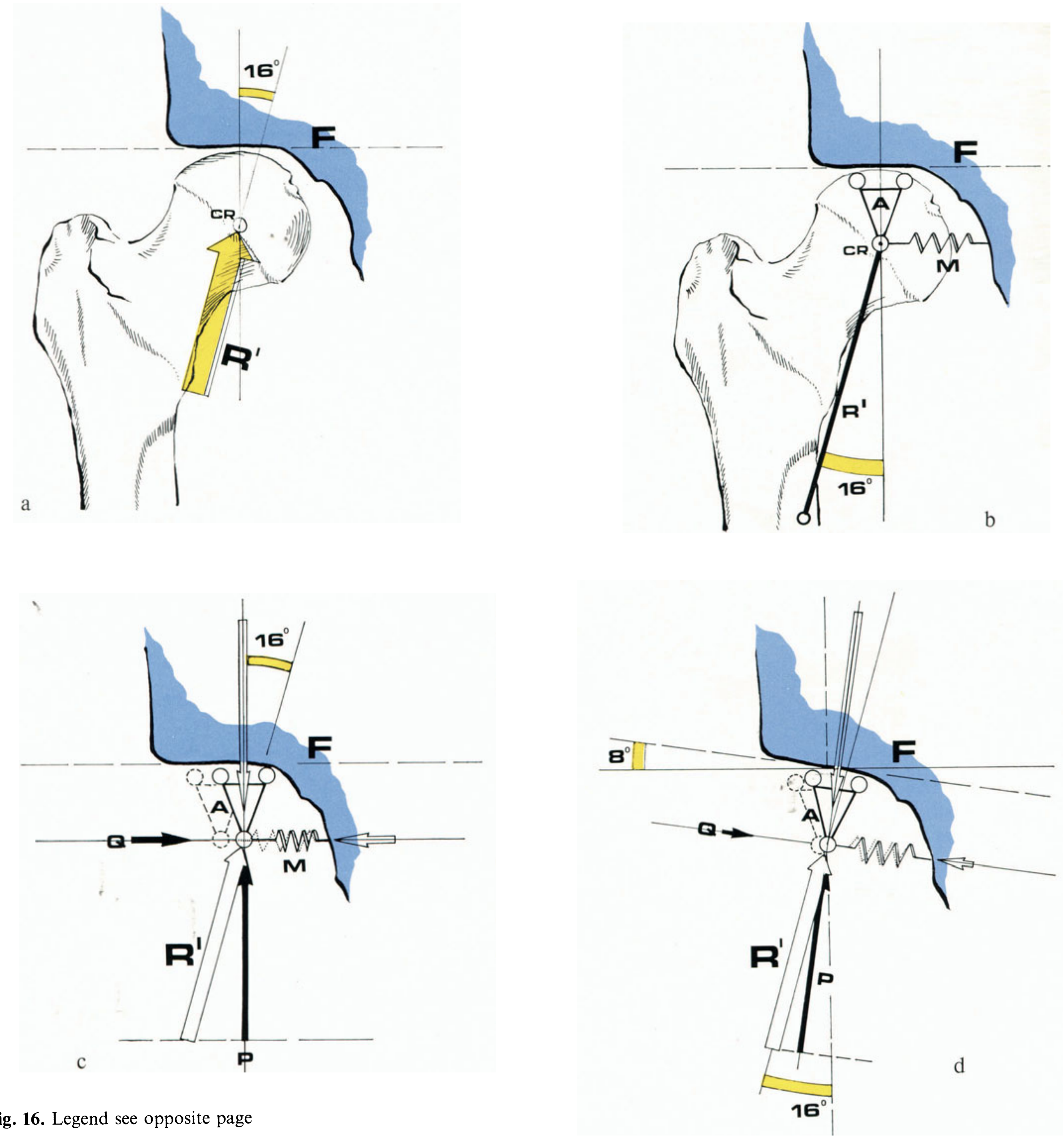


Fig. 16. Legend see opposite page

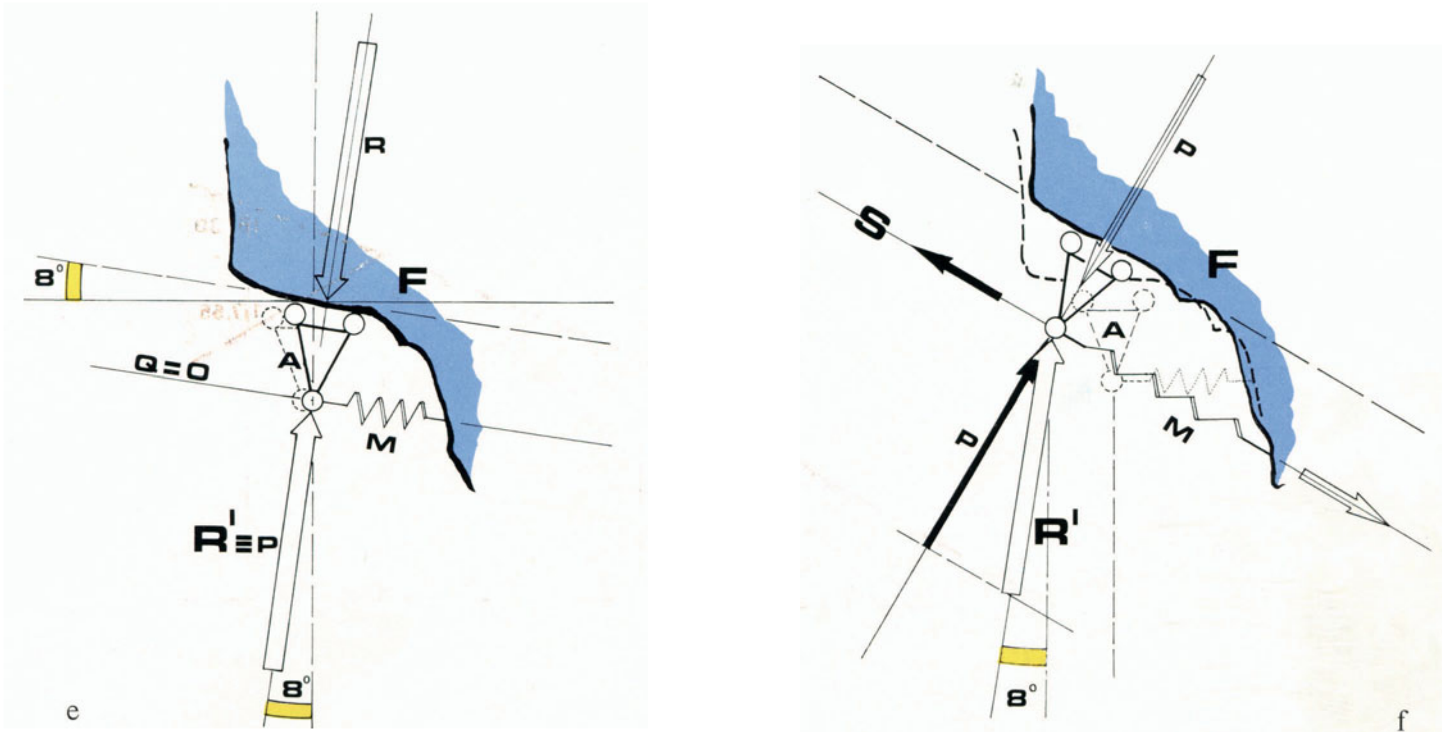


Fig. 16a–f. Scheme showing progressive disappearance of force *Q*, increase of force *P*, and appearance of force *S*, when weight-bearing joint surface becomes oblique. (a) In a normal hip, force *R* has caudolateral inclination of 16° in the frontal plane in 16th position; counter-resultant force R_1 has same inclination, but in the opposite direction. (b) In mechanics the hip joint can be represented as a light two-wheeled cart (femur) sliding without friction on a polished surface (acetabulum). (c) Counter-resultant force R_1 is resolved into component *P* (compression), directed cranially and component *Q*, directed medially. Force *Q* compresses imaginary spring *M* against "fundus acetabuli." (d) Pathologic process has partially worn out superolateral portion of acetabulum, inclining its direction to 8° in frontal plane. Force *P* increases and force *Q* decreases. Action of force *Q* on spring *M* is less effective. (e) Patient with pain reflex shifts, during monopodal support (stance phase), center of gravity of body toward diseased hip. Obliquity of weight-bearing joint surface plus more vertical direction of force *R* make force *Q* disappear and force *P* equal to R_1 (point of reversal). Spring is no longer compressed. (f) It needs only little more obliquity of surface, or more accentuated shifting of body to make force *S* appear. Force *S* is directed craniolaterally and stretches the spring. Biological consequence is appearance of osteophytes

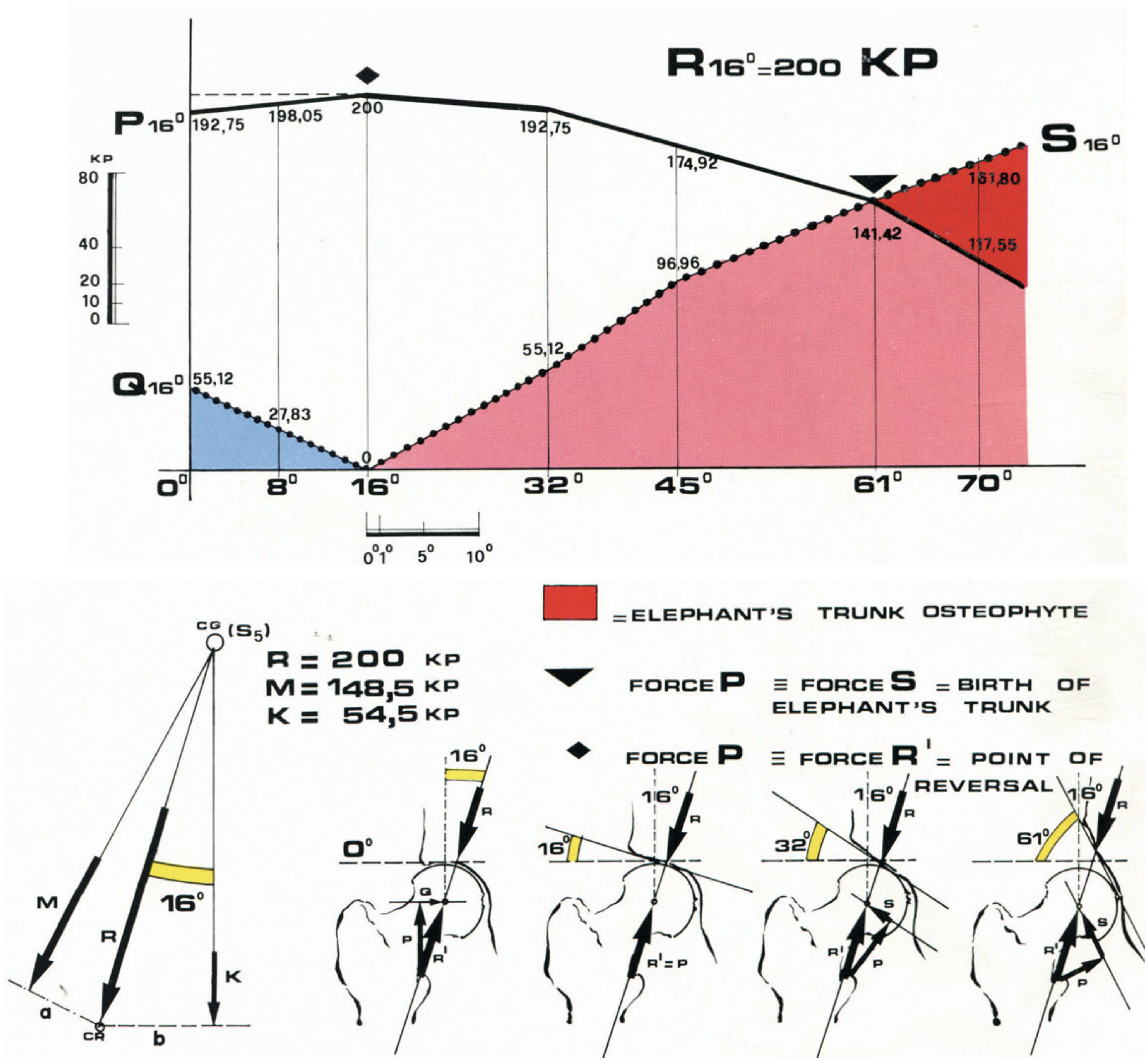


Fig. 17a. First diagram of forces *P* and *Q* when acetabular surface slants (In displastic hips before appearance of pain).
In this case the weight of the body (67 kp) during stance (monopodal support) on normal hip, in 16th position (Fischer, 1899a), less weight of right supporting limb, is 54.50 kp, muscular force of abductors *M* which maintains pelvis in equilibrium, is 148.5 kp. Resultant force *R* is 200 kp. Counter-resultant force R_1 is 200 kp, its component forces are: $P = 192.75$ kp, $Q = 55.12$ kp. When weight-bearing joint surface inclines, magnitude of forces *P* and *Q* are modified according to degree of inclination. When inclination is 16°, force *Q* disappears and value of force *P* corresponds to value of force *R* (200 kp) (point of reversal). More accentuated inclination makes force *S* appear and progressively reduces value of force *P*. When inclination is 61°, values of force *P* and of force *S* are equal (141.42 kp). From this degree of inclination onward force *S* is dominant and "inferior cervical osteophyte" may take the shape of an elephants's trunk

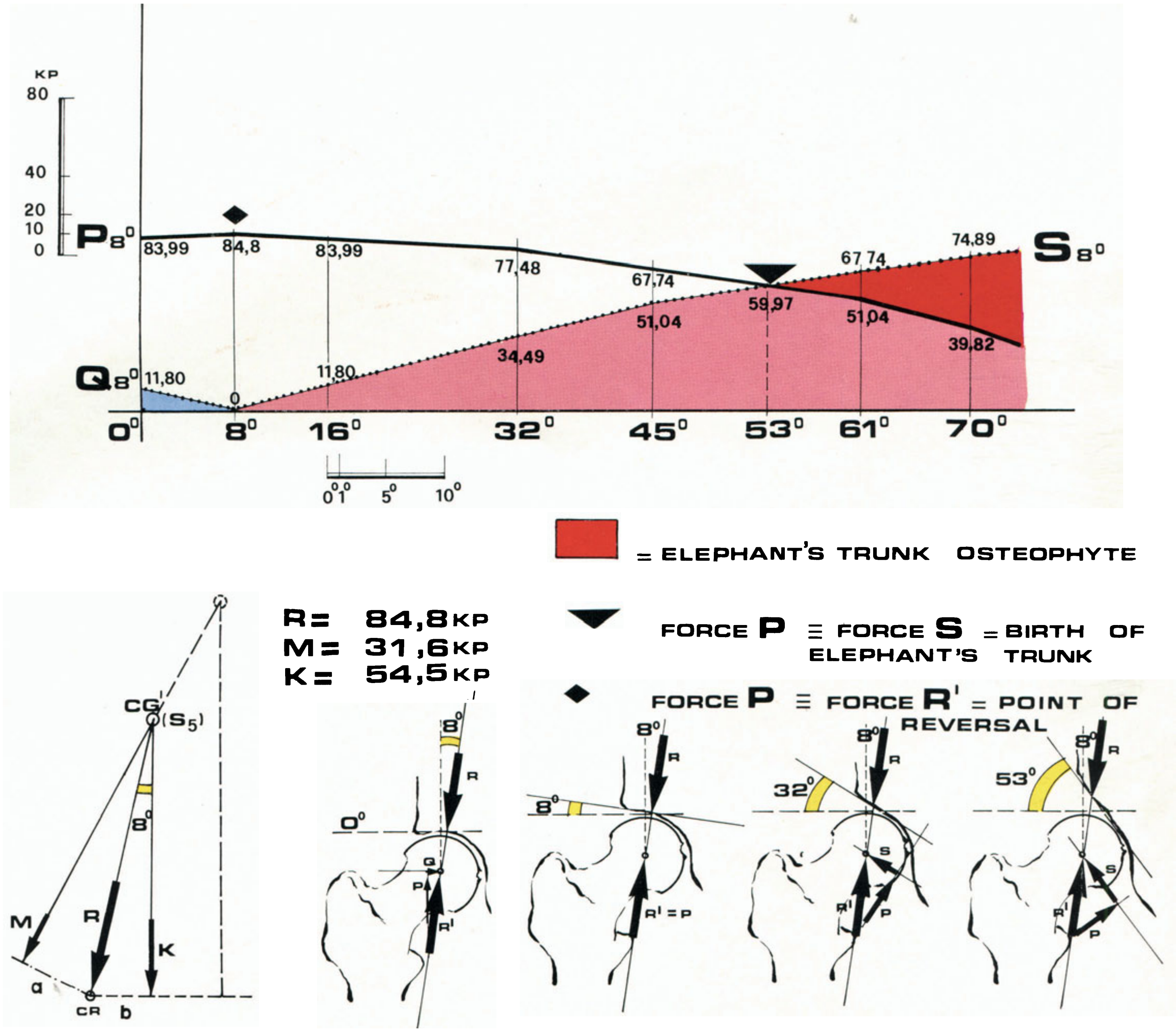


Fig. 17b. 2nd diagram of forces *P* and *Q* when acetabular surface slants and load on hip provokes pain.

In the case of a painful hip, patient is compelled, by painreflex, to shift center of gravity of his body toward that side and therefore inclination of resultant force *R* in frontal plane is reduced (8°). By this simple reflex value of force *R*, when body weight (67 kp), less weight of right supporting limb, is 54.50 kp, is reduced to 84.80 kp. The muscular force of abductors *M* is 31.60 kp. Counter-resultant force R_1 is 84.80 kp, when weight-bearing joint surface is still horizontal; its component forces are: $P=83.99$ kp and $Q=11.80$ kp. When inclination of weight-bearing joint surface increases to 8°, force *Q* disappears and value of force *P* corresponds to value of force R_1 (84.80 kp) (point of reversal). More accentuated inclination makes force *S* appear and reduces progressively value of force *P*. Values of force *P* and of force *S* are equal (59.97 kp) when joint surface has inclination of 53°. From this point on, force *S* is dominant and inferior cervical osteophyte may take shape of an elephant's trunk

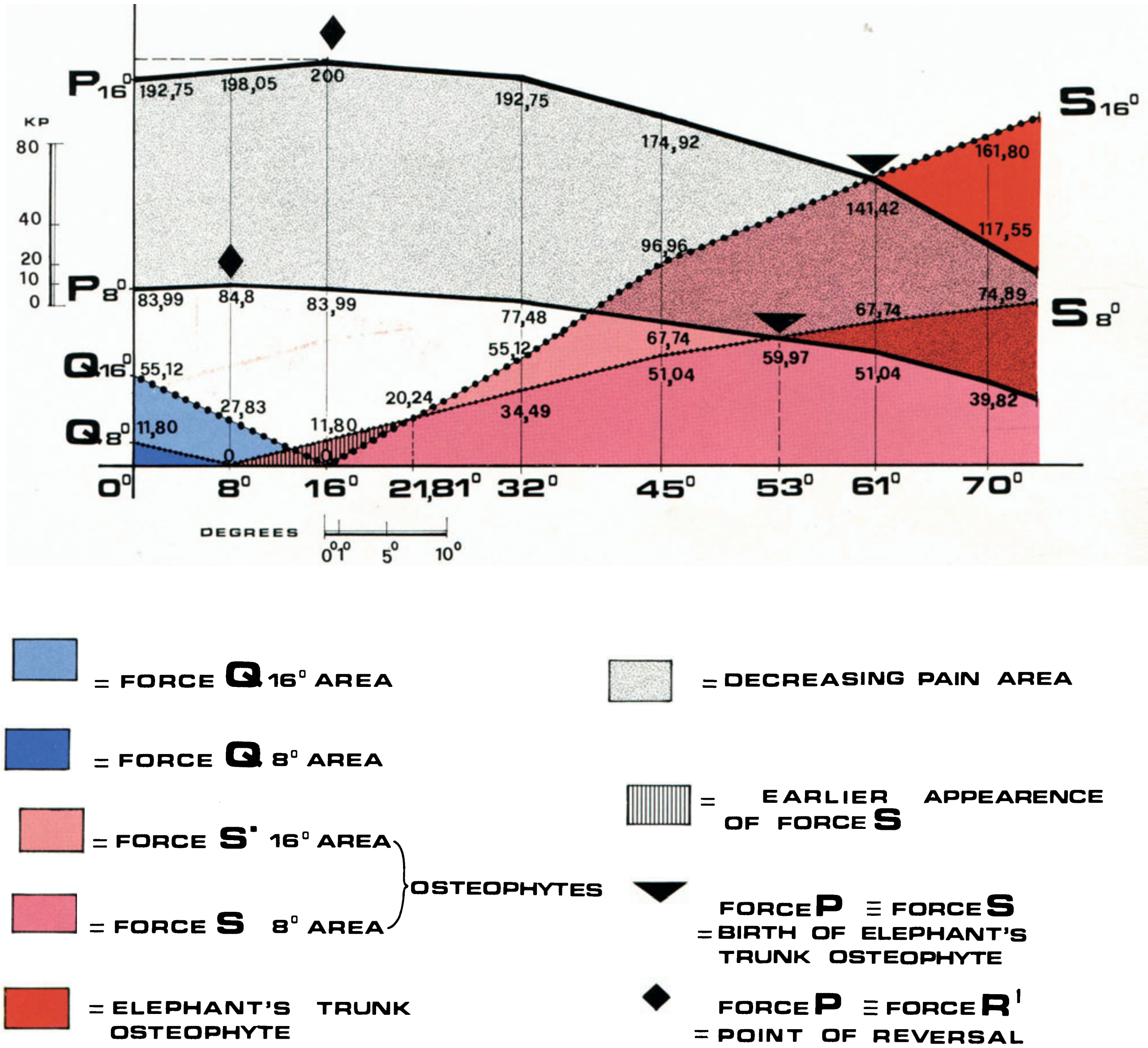


Fig. 17c. Comparison of diagrams 1 and 2 shows that by shifting body's center of gravity toward painful hip, pain is greatly reduced (grey dotted area); value of force $Q_{8°}$ (11.80 kp) is also reduced in comparison to value of force $Q_{16°}$ (55.12 kp). Point of reversal, however, is at 8° of inclination of weight-bearing joint surface and no longer at 16° (as seen in diagram 1). That means that force $S_{8°}$ appears earlier and hence also the formation of osteophytes. An "elephant's trunk osteophyte" may form when inclination of surface is 53° instead of 61°. Briefly: pain-reflex displacement reduces pain, because compression at 8° is decreased (83.99 kp) in comparison to compression at 16° (192.75 kp), but disarranges biomechanics of joint. Diagrams show clinical difference between secondary and primary osteoarthritis of the hip. In secondary osteoarthritis, because of defect of shape, the load is real cause of degeneration of material (bone and cartilage). In primary osteoarthritis, unknown etiology is actual cause of material decay in spite of a greatly reduced load

Fig. 17d. Effect of posteromedial-inferior glide of weight-bearing joint surface of acetabulum on femoral head. (Femoral head is presented from an axonometric view) (see bottom right). Force *R* in normal hip, in 16th position has inclination of 16° in frontal plane. This force intersects horizontal weight-bearing surface π_1 at point *H*. Tangent point *T* (point of contact head surface) is lateral to point *H*. For this reason component force *P* of counter-resultant force R_1 is directed vertically and force *Q* (which pushes head into socket) is horizontal (see top right). If we keep direction of force *R* fixed and incline surface to 16° (π_2), tangent point *T* coincides with point *H*. In this case force *R* is perpendicular to the surface and force *P* is equal to force R_1. Force *Q* is no longer present (point of reversal) (see top right). If we incline the surface to 32° (π_3), tangent point *T* moves medially to point *H*. Component forces of counter-resultant force R_1 are: force *S*, which pushes the head out of acetabulum and force *P* (oblique), which continues decreasing as the surface slants (see top right). If the surface is inclined at 61° (π_4), value of force *P* is equal to value of force *S* (see top right) (point of birth of elephant's trunk osteophyte) ▷

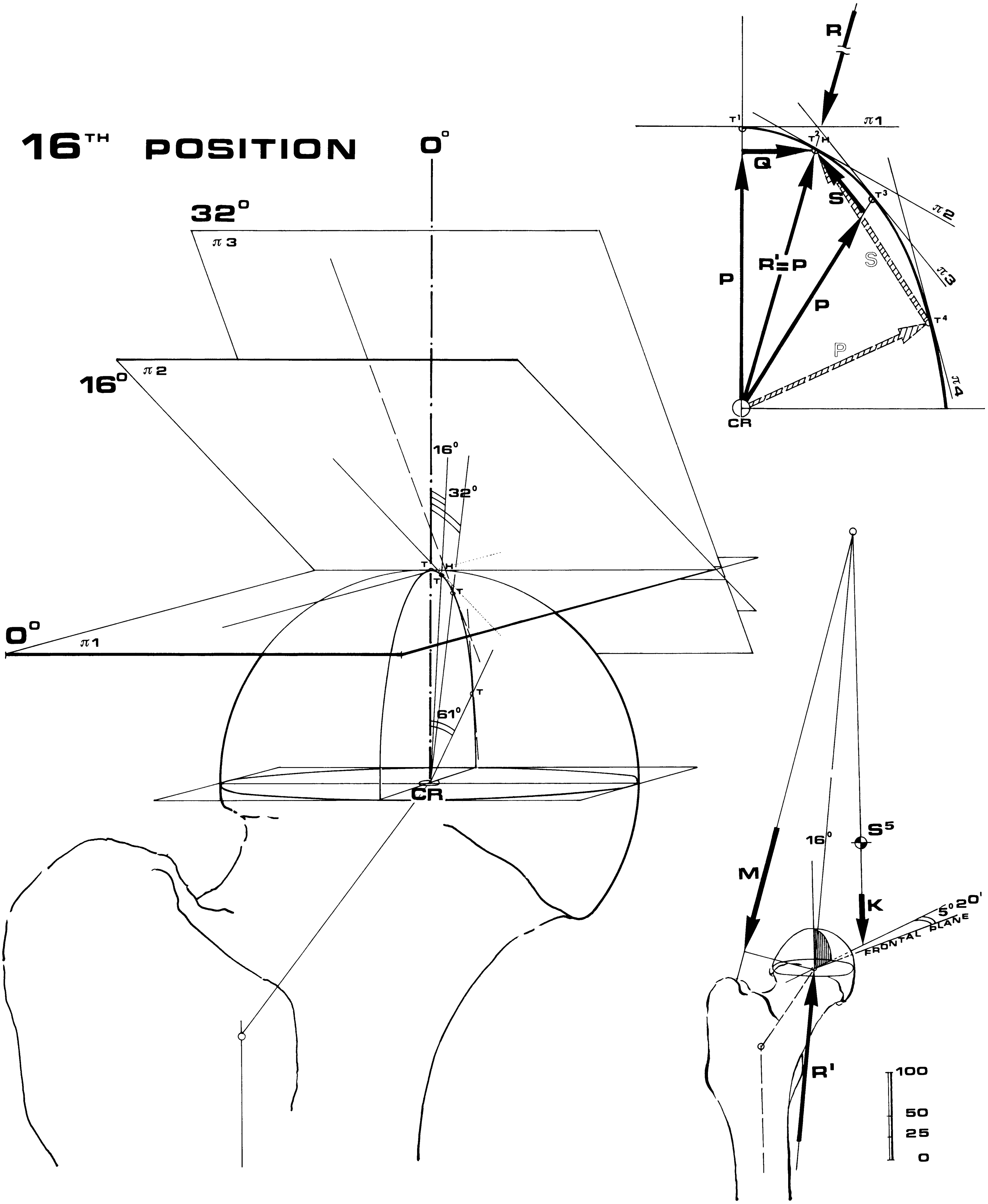


Fig. 17d. Legend see opposite page

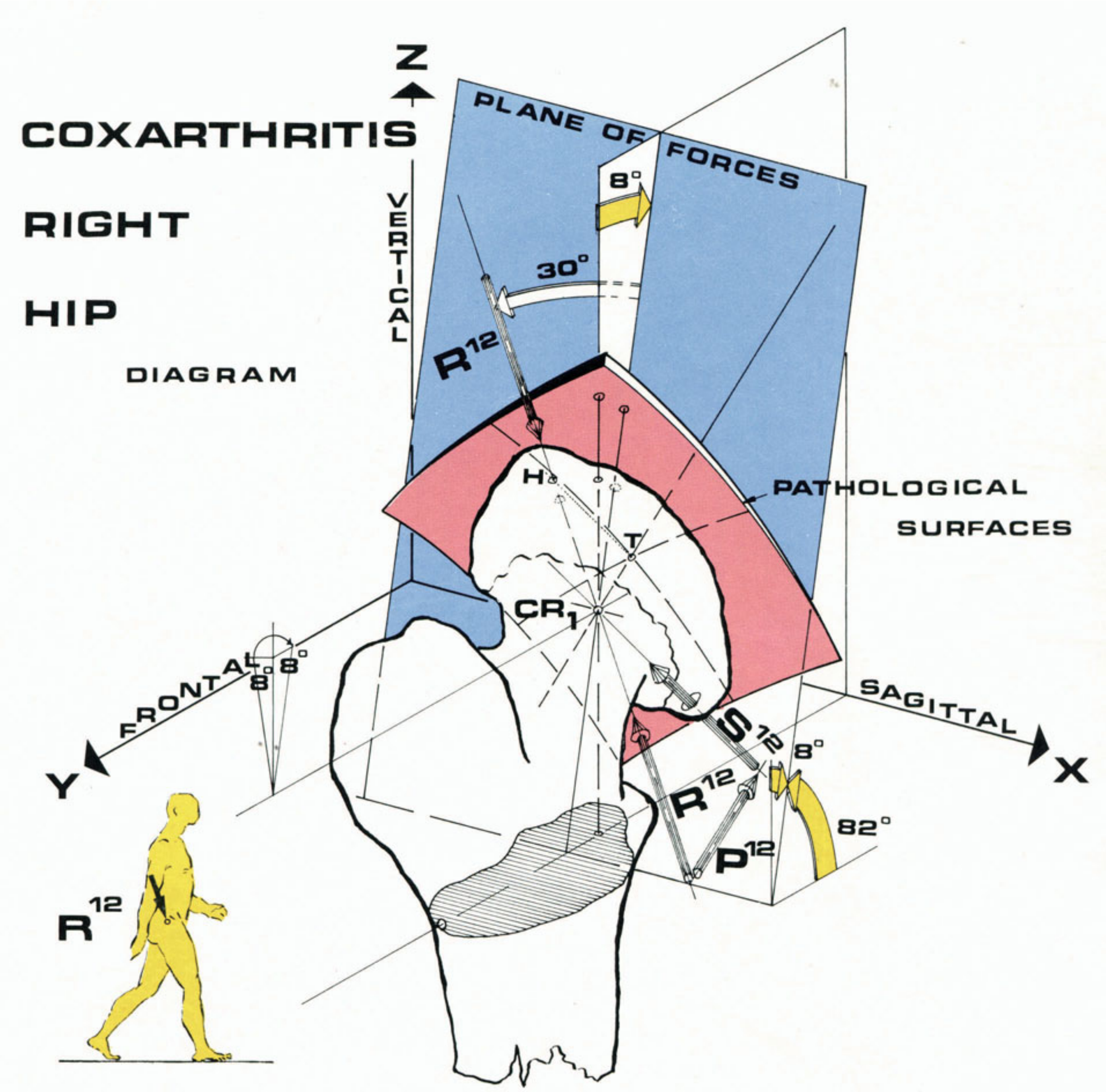


Fig. 18. Diagram shows forces acting upon pathologic hip during position 12.
Resultant force *R*, passing through center CR_1, has in the frontal plane an inclination of 8° and in the sagittal plane a posteroanterior inclination of 30°. Tangent point *T* is located medially to point *H* (point of acetabulum through which force *R* passes). Counter-resultant force R_1 has an opposite direction to *R*. Its component forces are: *P*, perpendicular to acetabular surface and *S*, parallel to acetabular surface. Force *S* has craniolateroanterior direction and pushes femoral head out of acetabulum

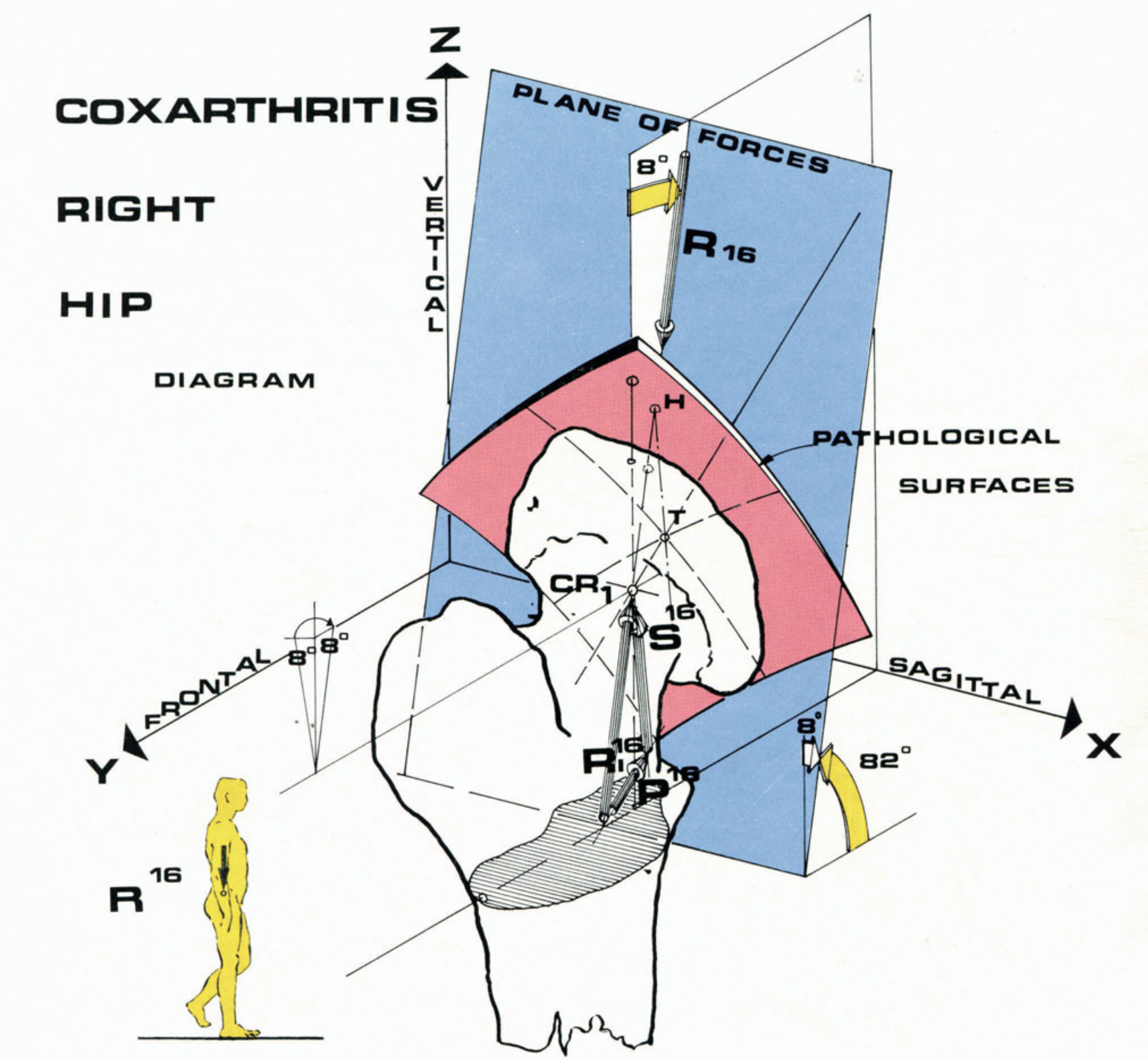


Fig. 19. In position 16 resultant force *R*, passing through CR_1, is located in the frontal plane and has inclination of 8°. Tangent point *T* is medial to point *H*. Counter-resultant force R_1 has an opposite direction to force *R*. Its component forces are: *P*, perpendicular to acetabular surface and *S*, parallel to acetabular surface. Force *S* has craniolateroanterior direction and pushes femoral head out of acetabulum

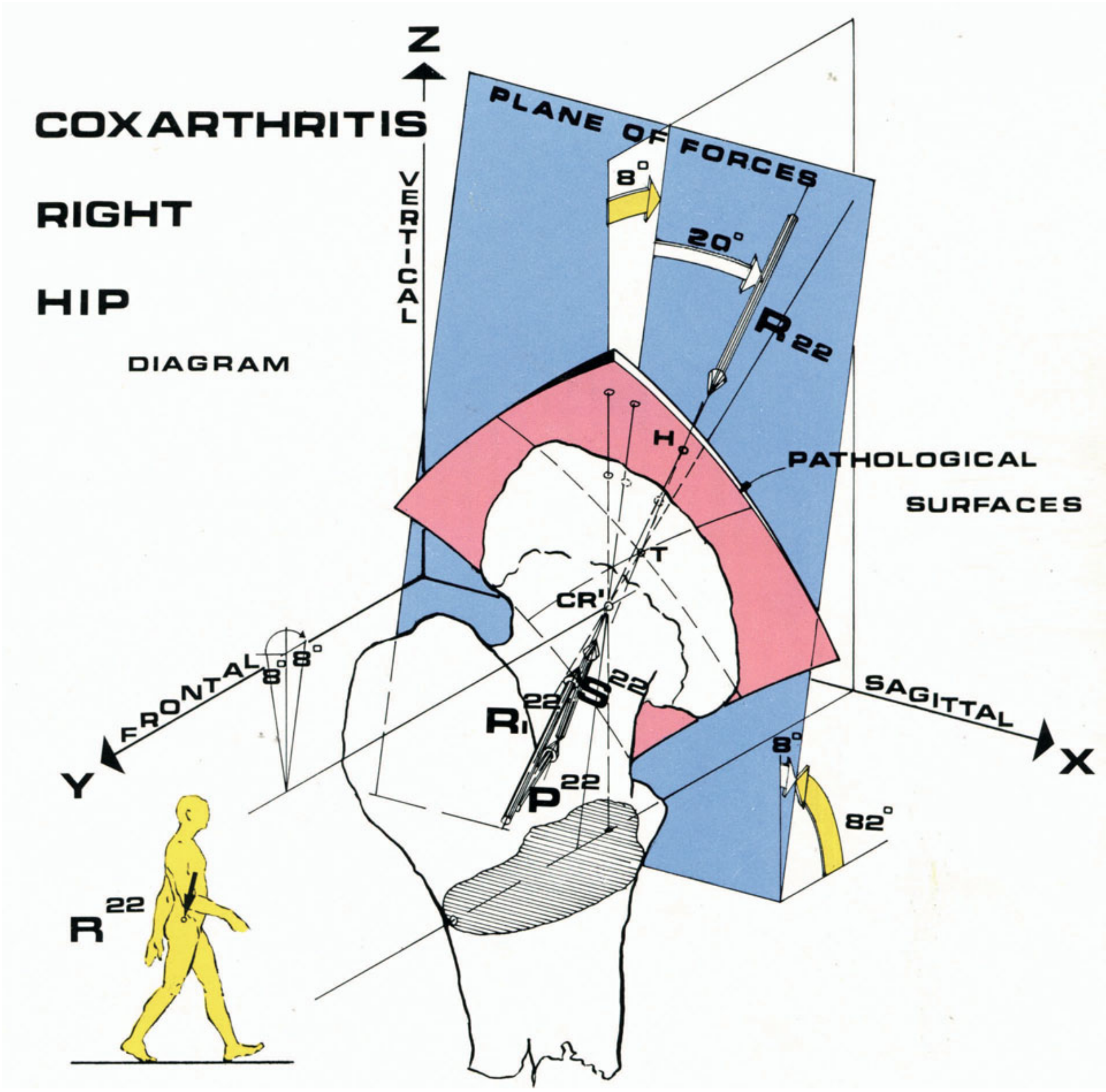


Fig. 20. In position 22 resultant force *R*, passing through CR_1, has inclination of 8° in frontal plane and anteroposterior inclination of 20° in sagittal plane. Tangent point *T* is located medially to point *H*. Direction of counter-resultant force R_1 is opposite to that of force *R*. Its component forces are: *P*, perpendicular to acetabular surface and *S*, parallel to it. Force *S* has cranio-latero-anterior direction and pushes femoral head out of acetabulum.

From the three diagrams we can see that force *S* always has verticolateroanterior direction, but in position 22 anterior direction is predominant

D. Pathogenesis of Osteoarthritis of the Hip

I. Osteophytes

Both in the primary and secondary osteoarthritis three factors are present:

1. A slanting inclination of the weight-bearing joint surface. In secondary osteoarthritis it may be congenital or have developed after birth.
   In primary osteoarthritis it is provoked by a progressive disintegration of cartilage and bone, due to many causes as yet unknown.
2. The contraction of the adductor muscles due to pain.
3. The progressive inclining toward the vertical of the resultant force *R*, caused by shifting the body's center of gravity S_5 toward the painful bearing hip in a monopodal support (PAUWELS, 1961–1965b).

These three factors make the force *S* appear. It provokes osteophytes in particular zones of the hip joint.

In mature osteoarthritis we can detect six main osteophytes (Fig. 21).

Three are located on the femoral head:

a) The "superior cervical osteophyte"
b) The "capital drop" comprised of the } "fovea osteophyte" / "inferior marginal osteophyte"
c) The "inferior cervical osteophyte" (sometimes this may hypertrophy and take the shape of an elephant's trunk).

Three are located on the acetabulum:

a) The "roof osteophyte"
b) The "tent osteophyte"
c) The "floor osteophyte".

These osteophytes, richly vascularized (HARRISON et al., 1953), may, in the author's view, be responsible for the natural healing of osteoarthritis of the hip over a very long period of time (Fig. 22).

Some of these osteophytes, if well orientated by a suitable operation, can be responsible for the healing of the joint in a short period of time.

The osteophytes are the result of two phenomena:

1. plastic deformity of the femoral head and of the acetabulum, and

2. tension in the ligamentum teres and its synovial membrane, in the joint capsule and its synovial membrane, and in the synovial membrane covering the neck of the femur.

1. Plastic Deformity of the Femoral Head and of the Acetabulum

This phenomenon may be simplified by two diagrams: one relating to the head (Fig. 23a), the other relating to the acetabulum (Fig. 23b).

In the diagrams the bone is considered as an elastic structure.

2. Tension in the Ligamentum Teres and its Synovial Membrane, in the Joint Capsule and its Synovial Membrane, and in the Synovial Membrane Covering the Neck of the Femur

Tension in the Ligamentum Teres and its Synovial Membrane

The ligamentum teres, considered by nearly all anatomists as a remainder of the pectineous tendon (an atrophic formation without any apparent function), assumes, according to us, an important role in the successive changes in the hip. Because of the outward, cranialward, and forward slipping of the head of the femur, caused by the force *S*, the distance between the two attachments of the ligamentum teres (the fovea capitis and the acetabular notch) increases and the ligamentum teres is stretched. The femoral head is, therefore, because of the situation of the fovea capitis on the head, passively pulled anteriorly and cranially, compelling the femur to rotate externally (Fig. 24). The synovial membrane covering the ligamentum teres becomes taut and gradually detaches itself both from the cranial insertion of the ligamentum teres, around the fovea capitis (Fig. 25), and from the caudal part. The tension at the points of attachment of the ligamentum teres and of its synovial membrane is a stimulus for the formation of bone (osteophytes). As a result, an osteophyte (the fovea osteophyte) appears around the fovea capitis, as we can see on the X-rays of Fig. 25.

Another osteophyte appears on the inner periphery of the facies semilunaris, the tent osteophyte (phase I of Fig. 26), which may become so large as to cover the fundus acetabuli (phase II of Fig. 26), as we can see on the X-ray of Fig. 26.

The tent osteophyte is due to the tension of the synovial membrane covering the fundus acetabuli (Fig. 27); this membrane is a continuation of the synovial membrane of the ligamentum teres.

Tension in the Joint Capsule, its Synovial Membrane, and the Synovial Membrane Covering the Neck of the Femur

Let us take into consideration two zones:

1. The anterocranial zone
2. The posterocaudal zone.

1. The acetabular roof and the base of the superior part of the neck of the femur are pushed apart by the force *S*. The distance then increases. The capsule, its synovial membrane, and the synovial membrane covering the anterosuperior part of the neck of the femur are stretched and two osteophytes appear:

a) The roof osteophyte on the superior edge of the acetabulum

b) The superior cervical osteophyte on the anterosuperior surface of the femoral neck, starting as a superior marginal osteophyte (Fig. 28).

2. The distance between the Adam's arch and the transverse notch ligament increases due to the force *S* and, therefore, the capsule, its synovial membrane, and the synovial membrane covering the posteroinferior part of the neck of the femur become stretched. As a consequence two osteophytes appear:

a) The floor osteophyte on the periphery of the inferior part of the acetabulum; in some cases it may become very pronounced (Fig. 29a and b).

b) The inferior cervical osteophyte around the posteroinferior periphery of the femoral head, starting as an inferior marginal osteophyte.

The inferior marginal osteophyte usually fuses with the fovea osteophyte; this results in a larger osteophyte, which covers the inferoposterior surface of the head. Because of its shape it is called the capital drop (Fig. 30).

The inferior cervical osteophyte extends along the Adam's arch. It may be flat and wide and cover the inferoposterior part of the neck (on the X-ray we can see it as a double contour of the Adam's arch) (Fig. 31).

A constant, well elevated synovial fringe on the posteroinferior surface of the neck of a normal femur was described by Amantini (1888) as a "Pectineous Foveal Plica." It contains an artery with a diameter of about 1,5 mm (Fig. 32a–c) from Testut (1923); Lanz and Wachsmuth (1938).

Studying the radiographic appearance and the direction of the inferior cervical osteophyte, could it be that it originates from this plica?

Sometimes the inferior cervical osteophyte extrudes like an elephant's trunk, in a mediocranial direction (Figs. 33 and 34). This "elephant's trunk osteophyte" may fuse with the descending capital drop and the two may build up a pseudo-head of the femur (mega-head) (Figs. 35 and 36).

In some cases the mega-head is due to the hypertrophic superior cervical osteophyte.

This osteophyte may correspond to a large roof osteophyte. The two together can increase the weight-bearing joint surface (Fig. 88).

The tent osteophyte may fuse with the floor osteophyte and build up a large osteophyte like a "molar tooth", which widens the inferior part of the socket (Fig. 37).

After the inferior part of the capsule has been divided in order to remore an inferior cervical osteophyte, which had become too developed and was blocking the rotation of the head after a valgus osteotomy, the floor osteophyte disappears, because it is no longer stretched (Fig. 38).

3. Fatigue Fractures of Osteophytes

When the tension, caused by the force *S*, in the ligamentum teres and in the capsule is excessive, the osteophytes may undergo fatigue fractures (Fig. 39a–c).

If the force *S* is removed, the fracture heals.

It is important to study by X-rays the shape of the osteophytes before performing a valgus osteotomy.

In order to understand the mechanism of formation of the osteophytes (Fig. 40), it is instructive to follow the progression of an osteoarthritis of the hip by the X-rays (Figs. 41a–b).

In osteoarthritis of the hip, bone cysts in the head of the femur are not infrequent.

From the hypothesis made on page 15, we could assume that bone cysts are the result of excessive stress and strain on the *CS* localized in a very limited area of a deformed femoral head (Fig. 13).

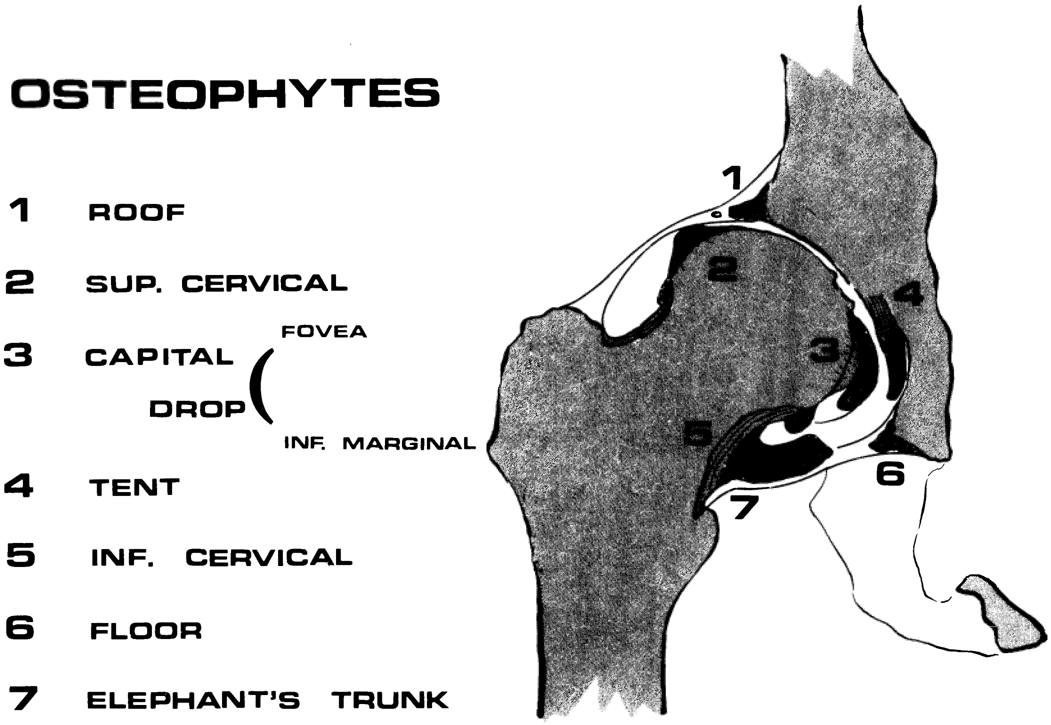


Fig. 21. Osteophytes are the result of plastic deformity in bone and of bone metaplasia both of joint capsule at particular zones and synovial membrane covering neck of femur, joint capsule, ligamentum teres, and fundus acetabuli.
In a completely developed osteoarthritis there are three principal osteophytes on the femoral head: superior cervical, starting as marginal osteophyte, inferior cervical, and capital drop; and three on the acetabulum: roof osteophyte, tent osteophyte, and floor osteophyte. The capital drop is made by the fusion of the fovea osteophyte and the inferior marginal osteophyte. The inferior cervical osteophyte may assume the shape of an elephant's trunk

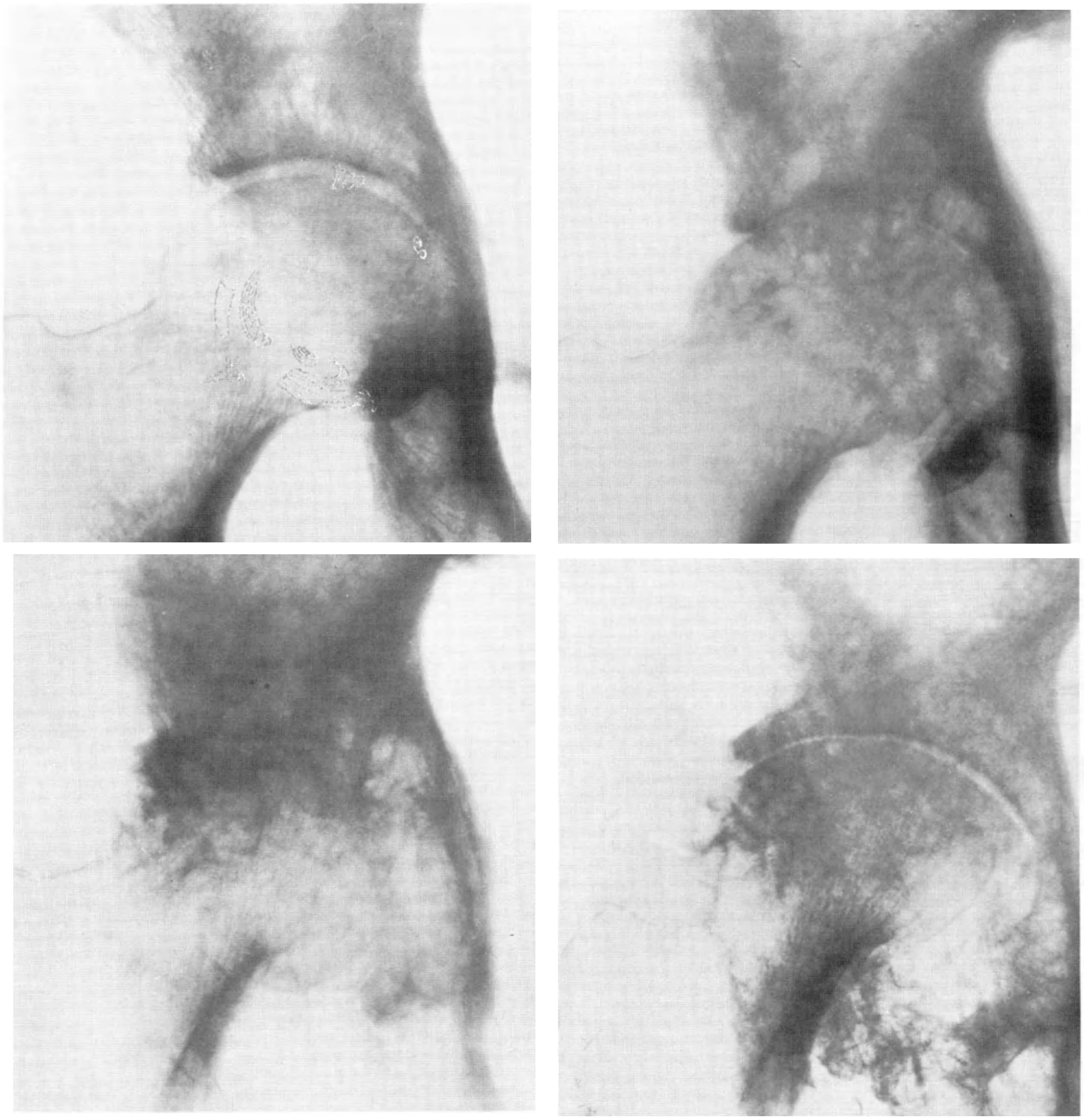


Fig. 22. Attempt at natural healing of osteoarthritis of hip in patient affected by Paget's disease. M.E., age 40. *3—1—49* Paget's disease in a normally shaped hip. *20—10—66* Osteoarthritis in Paget's disease. Femoral head is still spherical; capital drop and floor osteophyte have just appeared; joint space is just visible. *23—10—70* Disease has progressed. Head is flattened; on its medial surface capital drop has increased; inferior cervical osteophyte has appeared; joint space has disappeared. *20—1—75* Femoral head, although flattened, is fairly spherical due to capital drop. Inferior cervical osteophyte is well developed. They are fusing, forming a new big head, which adapts itself to the tent osteophyte arising in fundus acetabuli. Roof osteophyte is well formed and acts as "block" to laterocranial glide of head. Osteophytes have widened contact surface between head and acetabulum, reducing unit weight. For this reason a new joint space has appeared

---

Fig. 23a. Diagram relating to head of femur.
Imagine head of femur as elastic hemisphere encased in inelastic cup. force *R*, passing through center *CR* produces stresses and strains evenly distributed in the cup and in the hemisphere (1). If hemisphere displaces outward, force *R* acts on reduced surface and therefore pressure is not even, but concentrated on reduced load-bearing surface. Unit pressure on the surface is increased. The hemisphere loses its spherical shape and expands at its periphery (2). If the cup encasing hemisphere loses its hollow spherical shape and becomes flattened, elastic hemisphere expands and conforms to shape of the cup. Stresses and strains in the cup and in the hemisphere are unevenly distributed. Pressure is increased where the load is higher and tensile stresses appear on hemisphere (3). If both the cup is deformed and the hemisphere displaced outward, the two phenomena described in 1st and 2nd diagrams combined (4) can occur ▷

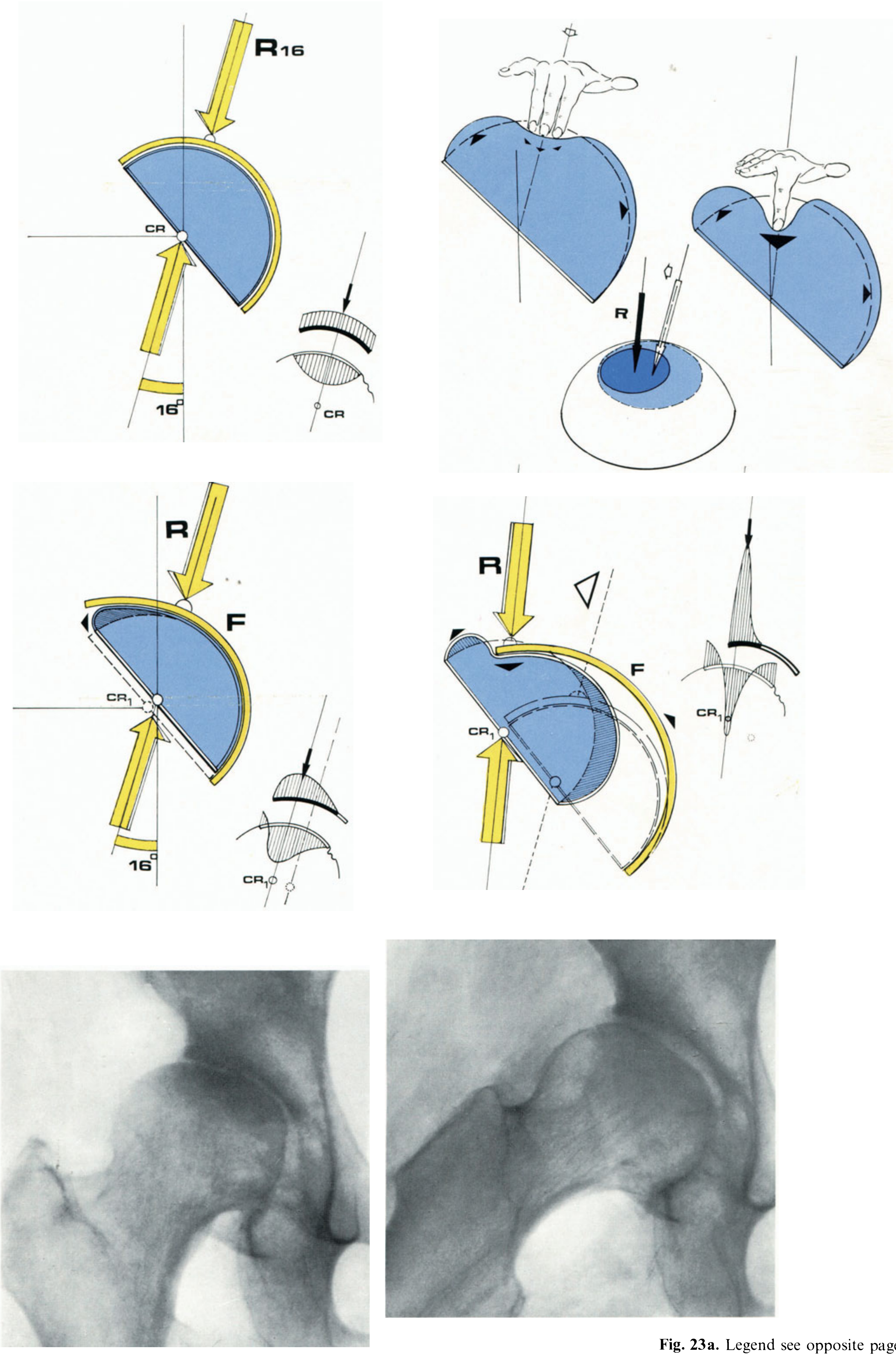


Fig. 23a. Legend see opposite page

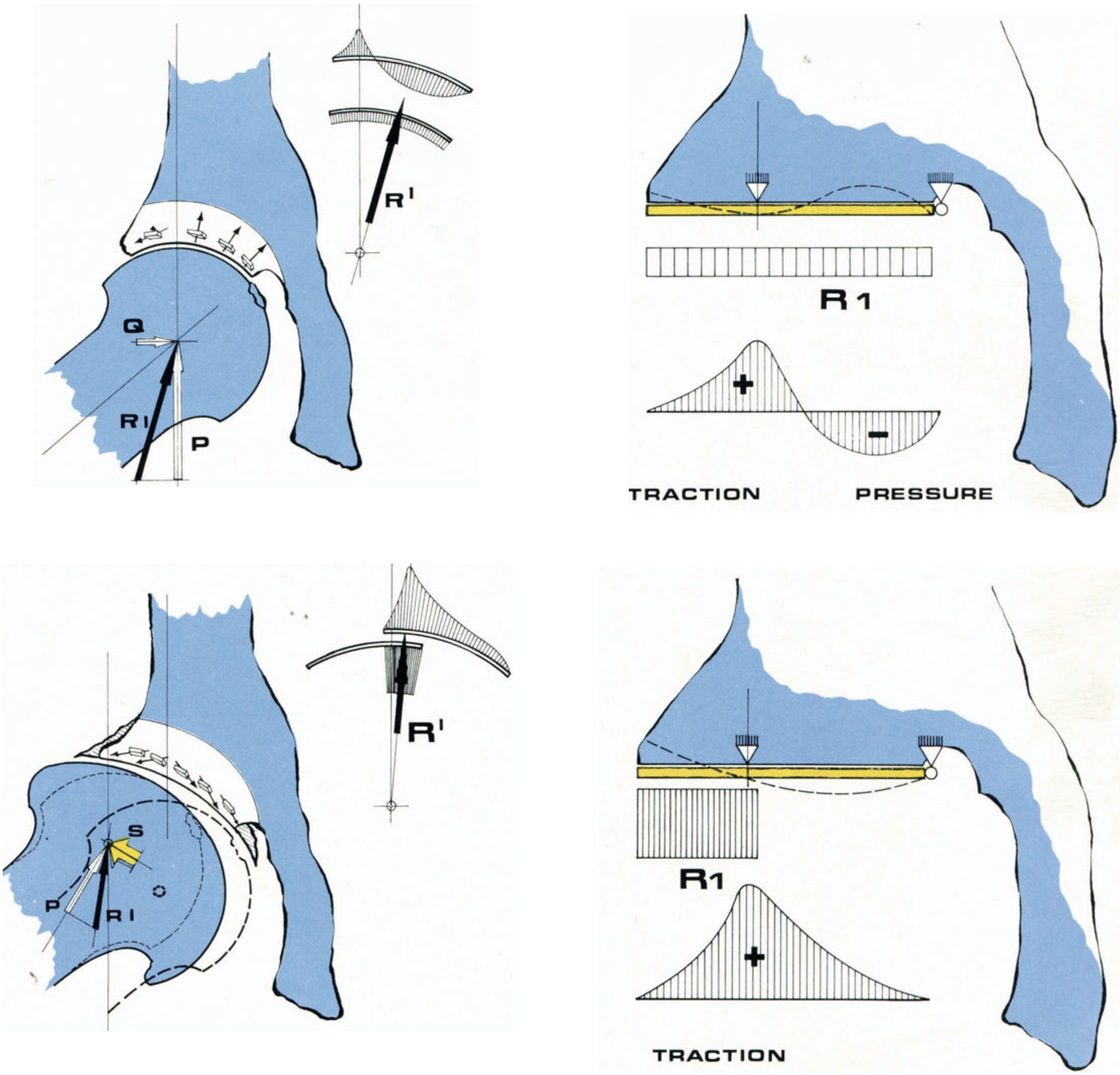


Fig. 23b. Diagram relating to acetabulum.
Pressure of femoral head, caused by counter-resultant force R_1, on acetabulum of normal anatomical shape is evenly distributed. This pressure causes stresses and strains of pressure in acetabulum, except in its lateral part where stresses and strains of tension develop, because of slightly extruding roof. But, in osteoarthritis the slipping out of femoral head causes stresses and strains of tension in whole acetabulum. These produce expansion in inner and outer peripheries of the surface. This expansion is the start of osteophytes around the socket

---

Fig. 26. Diagram shows two phases of formation of tent osteophyte. *Phase I* Bony plastic deformity of acetabulum caused by stresses of tension. Small osteophyte appears at medial edge of facies semilunaris. *Phase II* Osteophyte has increased in extent because of bone metaplasia ▷ of synovial membrane covering fundus acetabuli. This membrane has become taut by traction of ligamentum teres stretched by force S

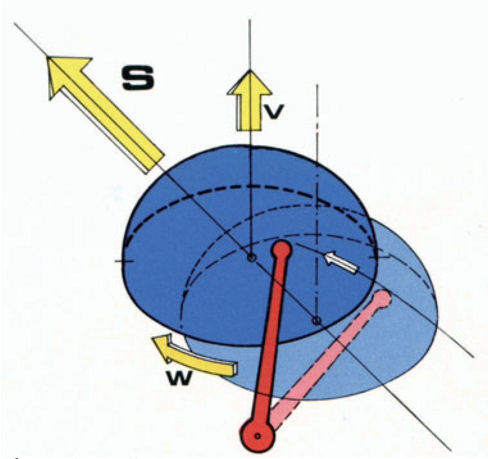
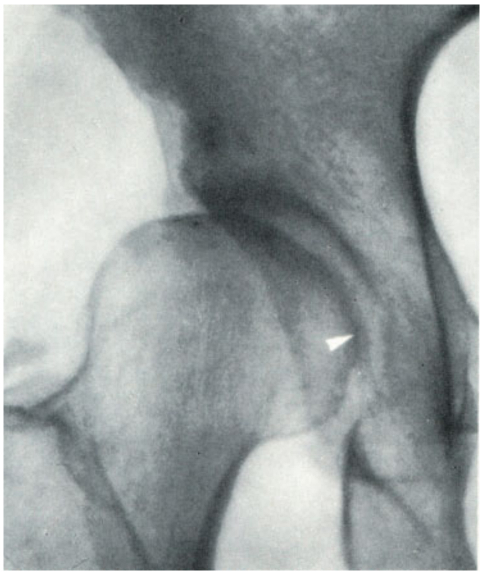


Fig. 24. Diagram shows effect of tension, due to force *S*, on ligamentum teres. Cranial insertion of ligamentum teres in fovea capitis is located in posteroinferior quadrant of femoral head. Femoral head, anchored by ligamentum teres, is pushed cranially, laterally, and anteriorly by force *S* and, therefore, is compelled to revolve externally



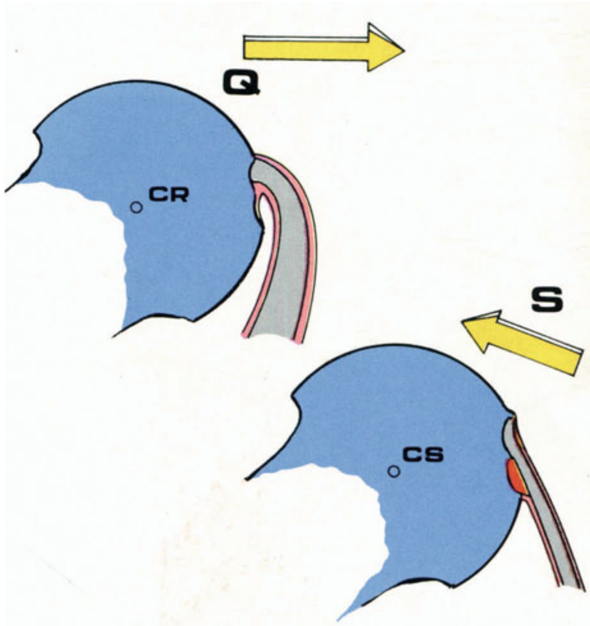
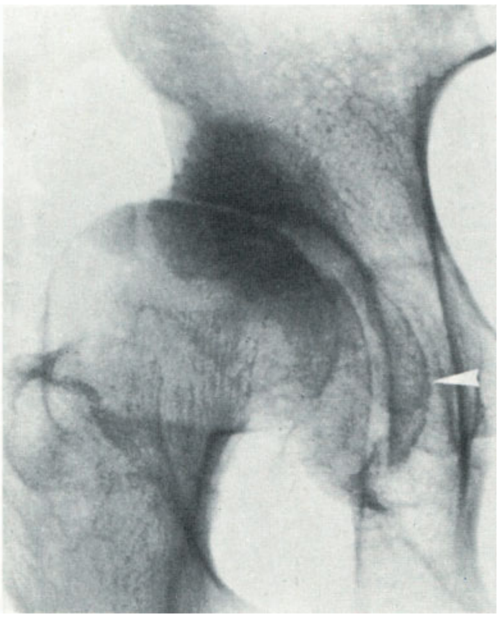


Fig. 25. Ligamentum teres is attached to cranial part of fovea capitis. Synovial membrane covers ligamentum teres and caudal surface of fovea. In the presence of force *S*, ligamentum teres becomes taut and synovial membrane is stretched. Around the insertion synovial membrane becomes bone



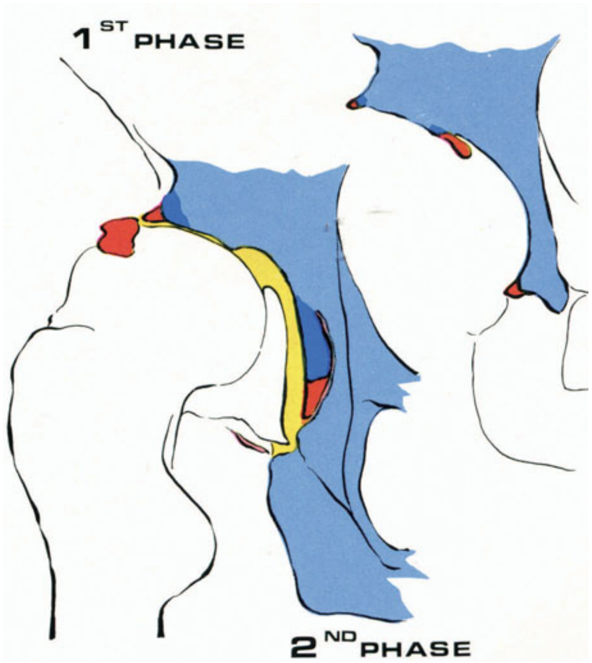


Fig. 26. Legend see apposite page

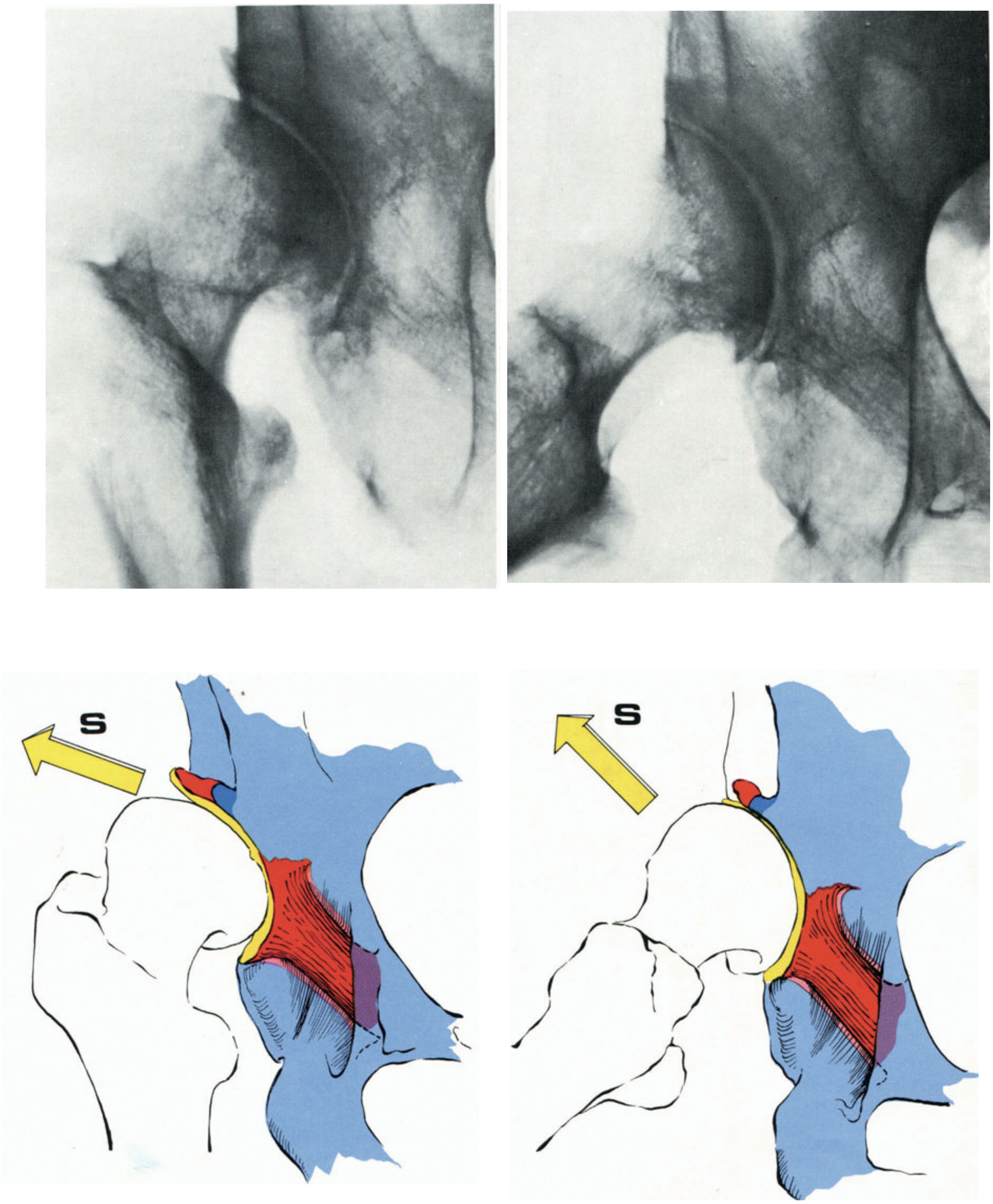
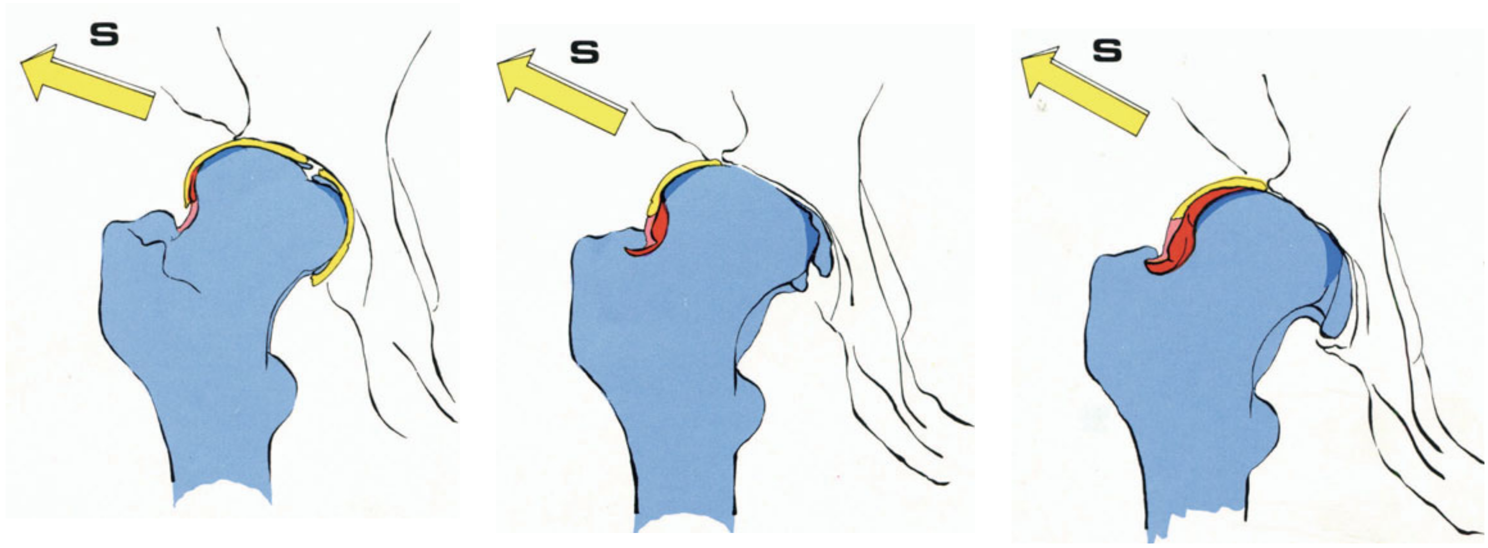
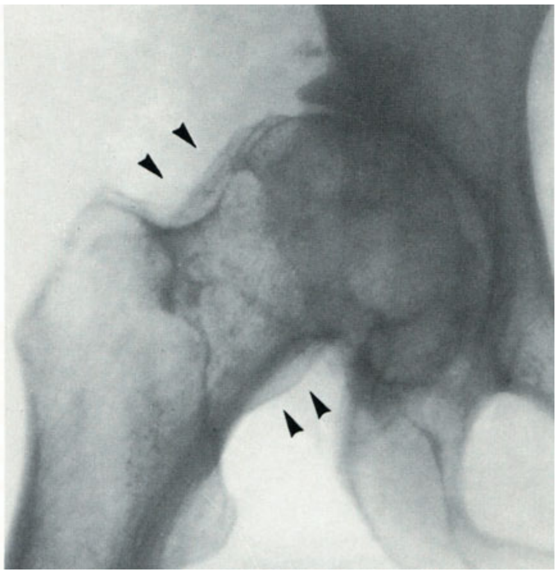


Fig. 27. Late congenital dislocation of the right hip. Persisting action of force *S* has dislocated the head from the socket and has stretched progressively ligamentum teres, its synovial membrane, and synovial membrane covering fundus acetabuli. The detachment of synovial membrane from bone has caused bone metaplasia, forming cylindrical tent osteophyte, whose direction corresponds to that of force *S*





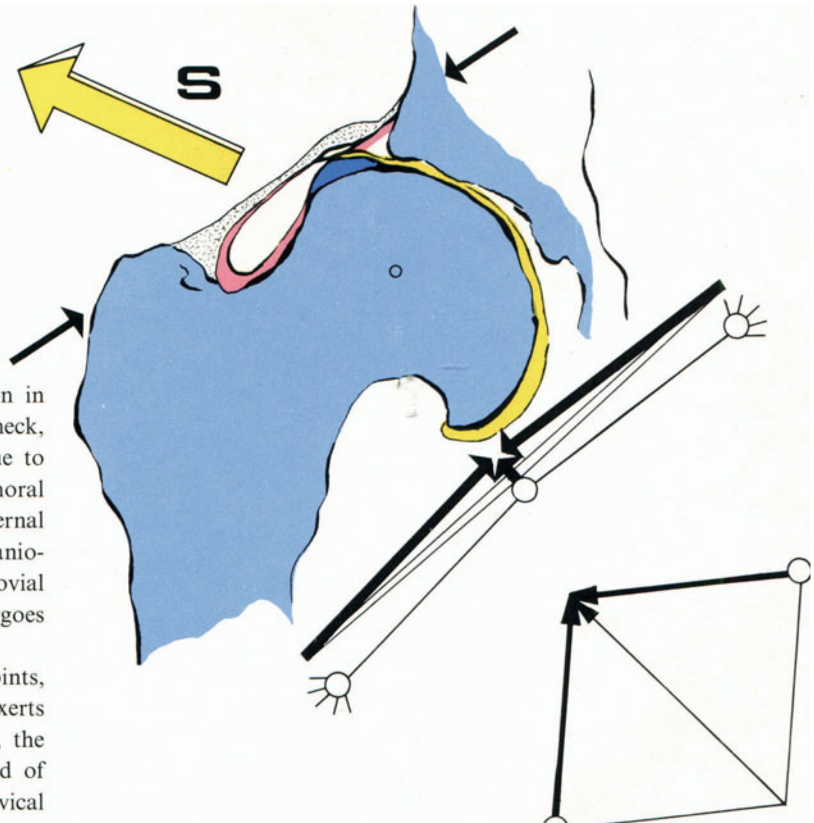
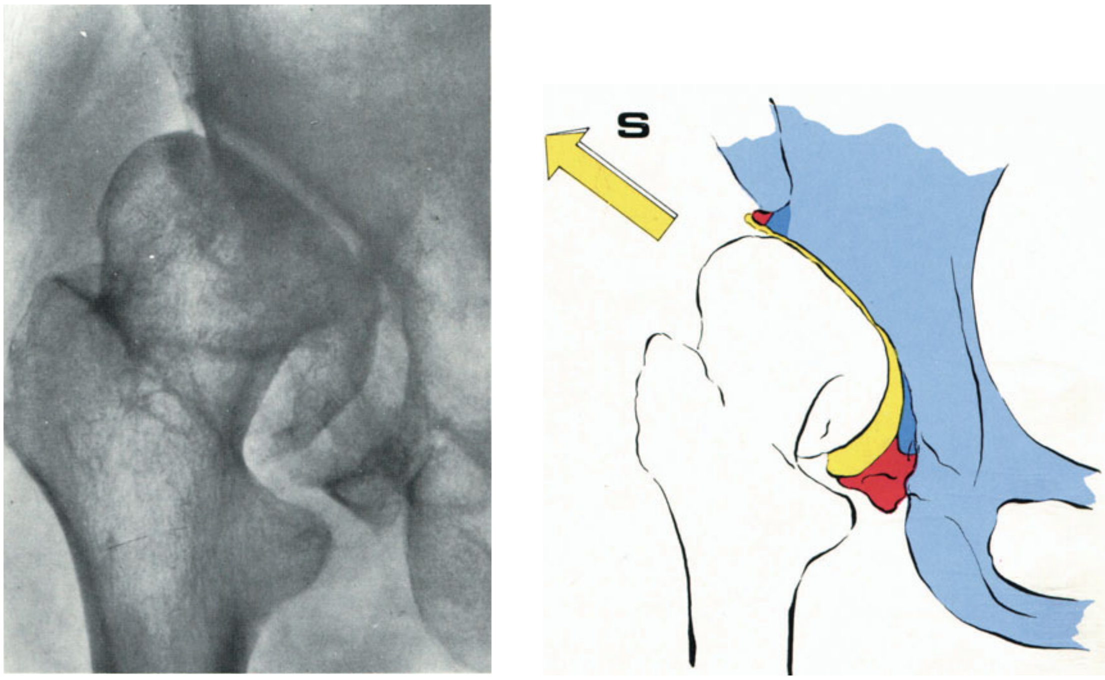


Fig. 28. X-ray shows: superior cervical osteophyte due to tension in synovial membrane covering anterosuperior surface of femoral neck, roof osteophyte, and inferior cervical osteophyte. This last is due to tension in synovial membrane covering posteroinferior part of femoral neck. A big capital drop is also present. The adduction and external rotation of femur, plus tendency of head of femur to glide anterocranio-laterally, stretch the superior zone of joint capsule and its synovial membrane. Synovial membrane loses contact with bone and undergoes osseous metaplasia.
Stretched Cable Principle: When a taut cable, fixed at two points, is acted on by a perpendicular force at its middle point, it exerts considerable tension on its extremities. By the same mechanism, the taut superior capsule and synovial membrane, acted on by head of femur, are responsible for roof osteophyte and for superior cervical osteophyte



b

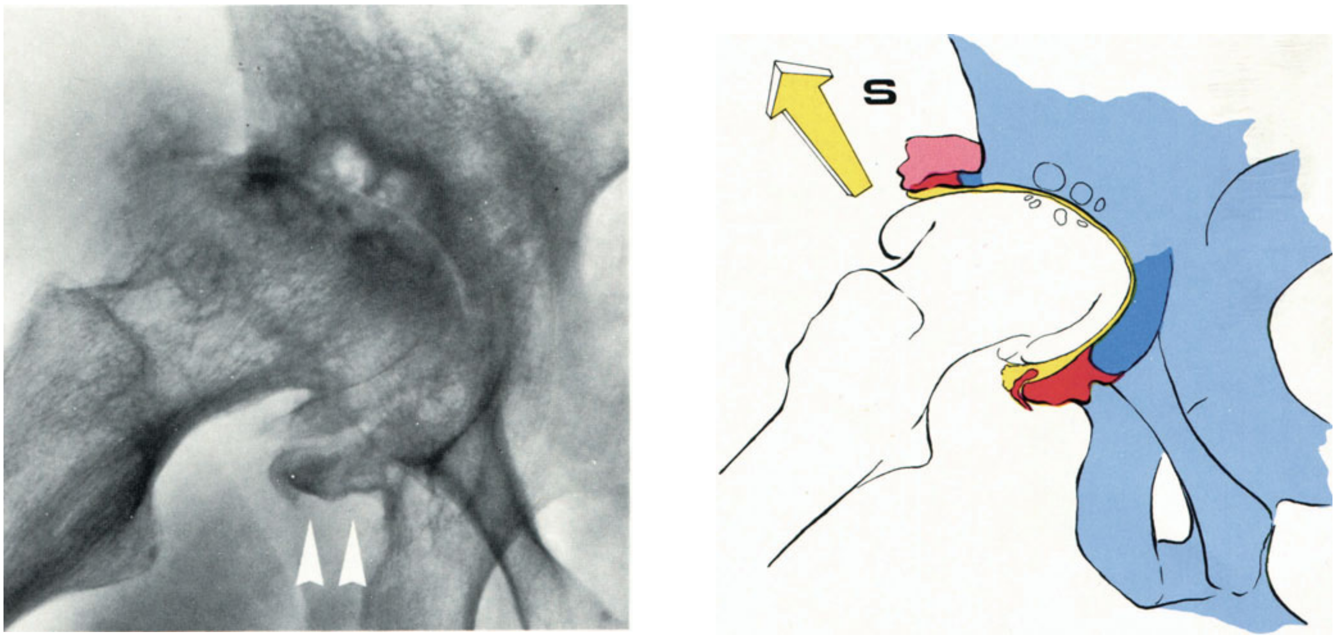
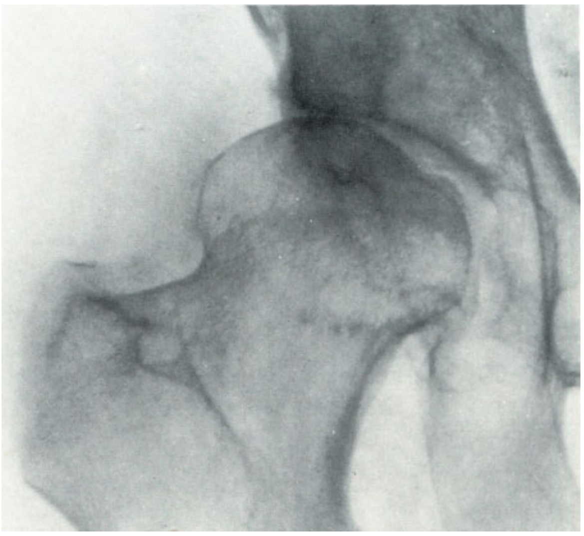


Fig. 29 a and b. X-ray shows floor osteophyte in secondary osteoarthritis of hip, fused with tent osteophyte



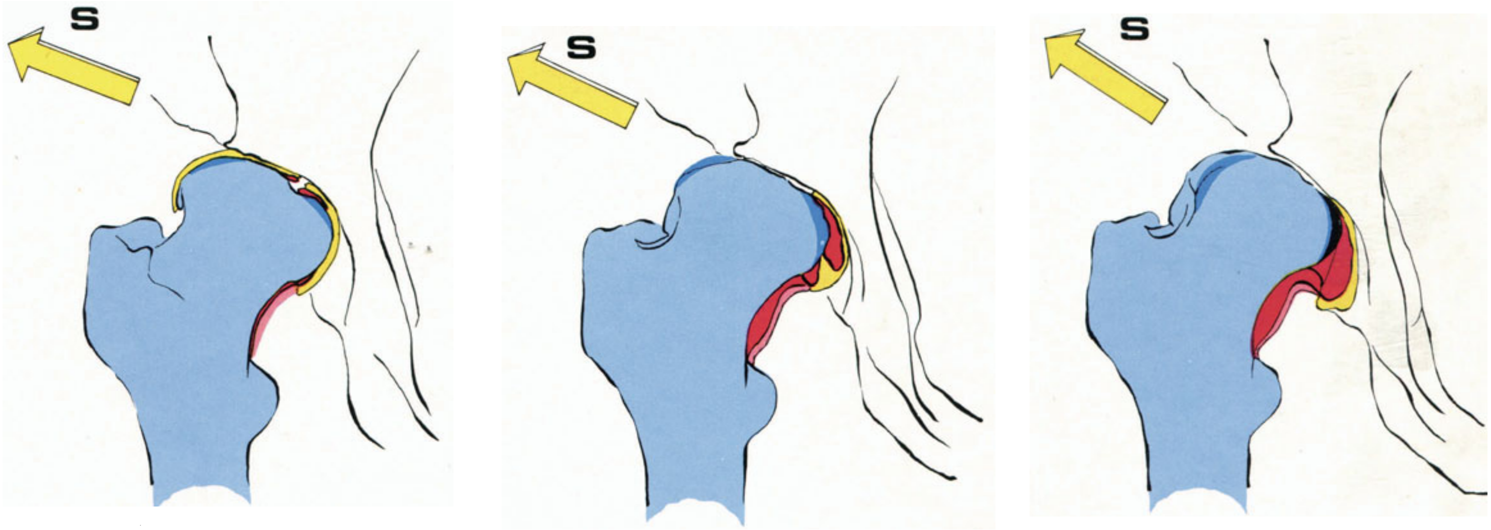


Fig. 30. Example of osteoarthritis secondary to C.D.H. (Congenital Dislocation of the Hip). Capital drop is the result of fusion of fovea osteophyte and of inferior marginal osteophyte. Fovea osteophyte is due to tension in ligamentum teres. Force *S* pushes femoral head anterocranially. Ligamentum teres and synovial membrane covering inferior part of neck are stretched. As a consequence, fovea osteophyte and inferior marginal osteophyte appear. Later on they fuse together, forming capital drop osteophyte

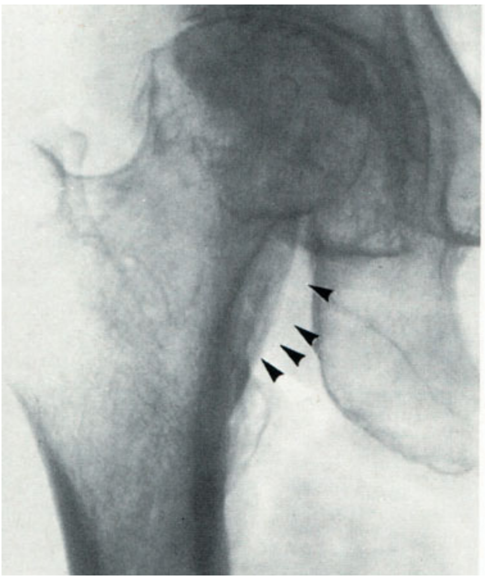
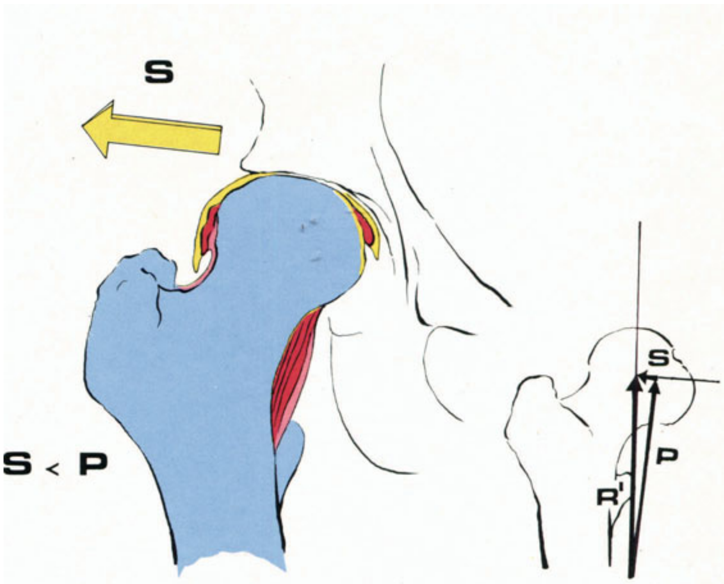


Fig. 31. X-ray shows inferior cervical osteophyte, which covers Adam's arch. Its trabeculae have a longitudinal direction because osseous metaplasia, due to detachment of synovial membrane from inferoposterior



part of neck of femur, produced by force *S*, are under influence of dominant force *P*. In other words: force *P* is greater than force *S*

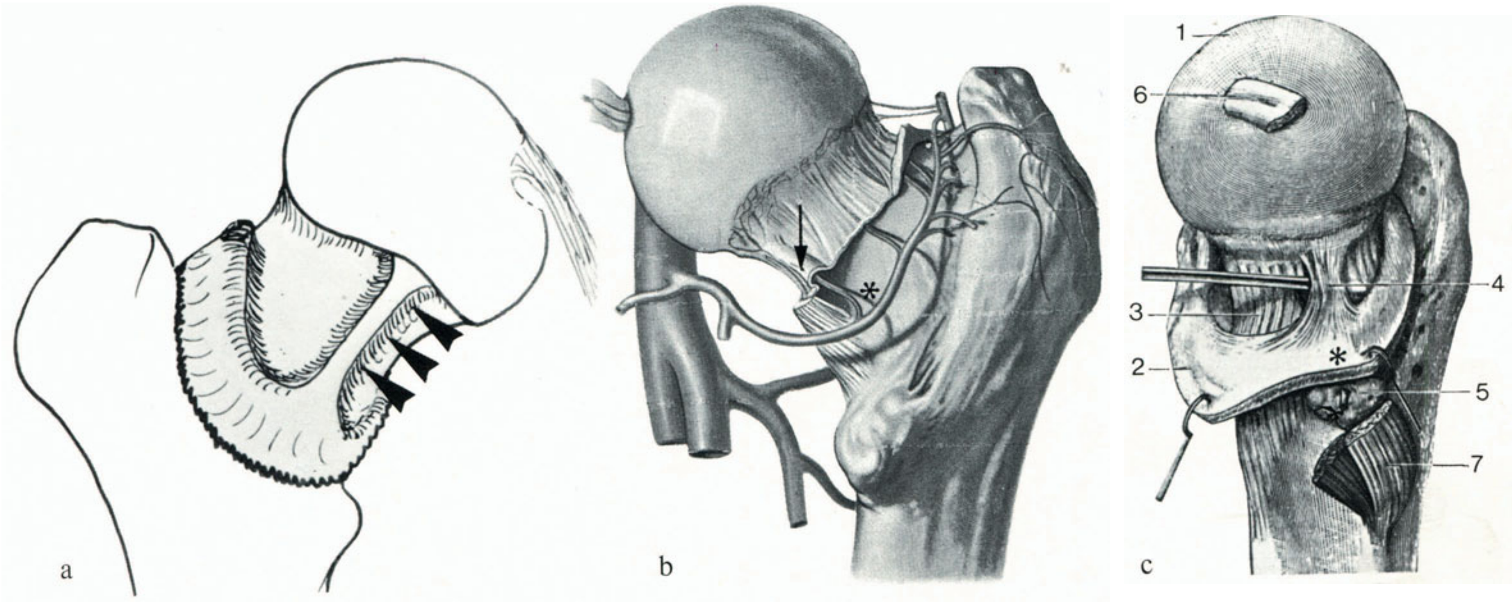


Fig. 32a–c. (a) "Pectineous Foveal Plica" from AMANTINI's work (1888–1889): *Di Una Men Nota Ripiegatura Sinoviale Dell'Articolazione Dell'Anca*. From detachment of this plica the inferior cervical osteophyte could derive. (b) Posteroinferior synovial plica, as described by LANZ and WACHSMUTH (1938) in: *Praktische Anatomie*. (c) AMANTINI's "Pectineous Foveal Plica" as it appears in figure of TESTUT's (1923): *Anatomia Umana*

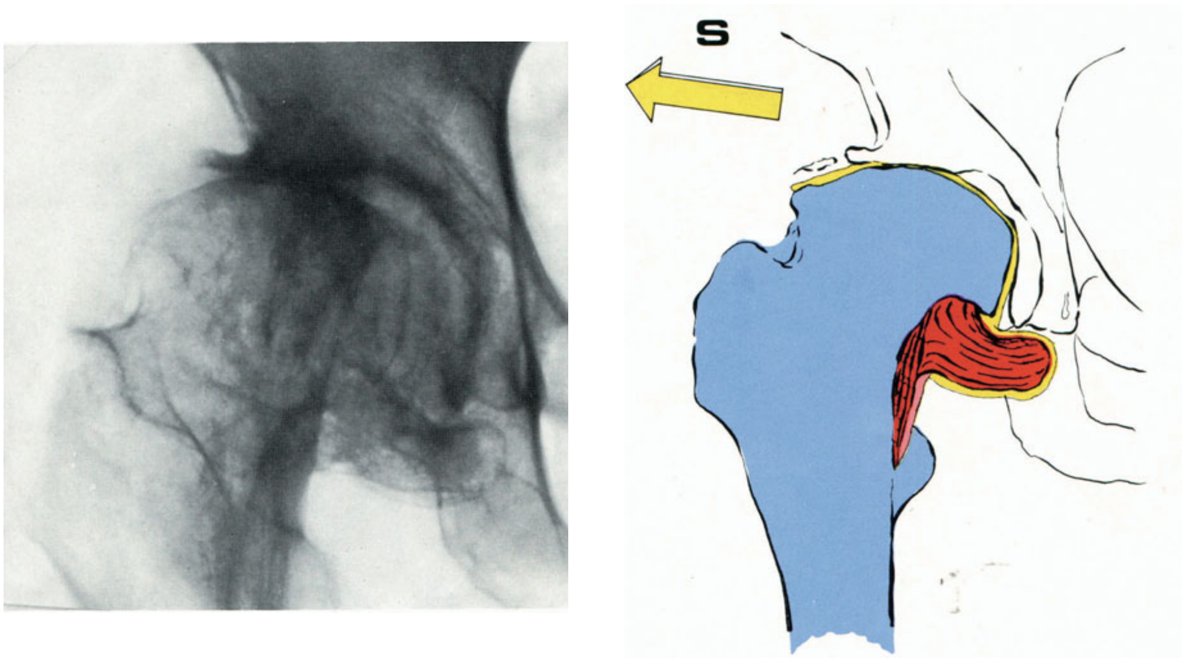


Fig. 33. Stout inferior cervical osteophyte similar to an elephant's trunk. This massive production is a result of excessive tension in membrane, due to force *S*, which exceeds force *P*. When a valgus osteotomy has to be done, it must be partially removed, otherwise it impinges on inferior edge of acetabulum

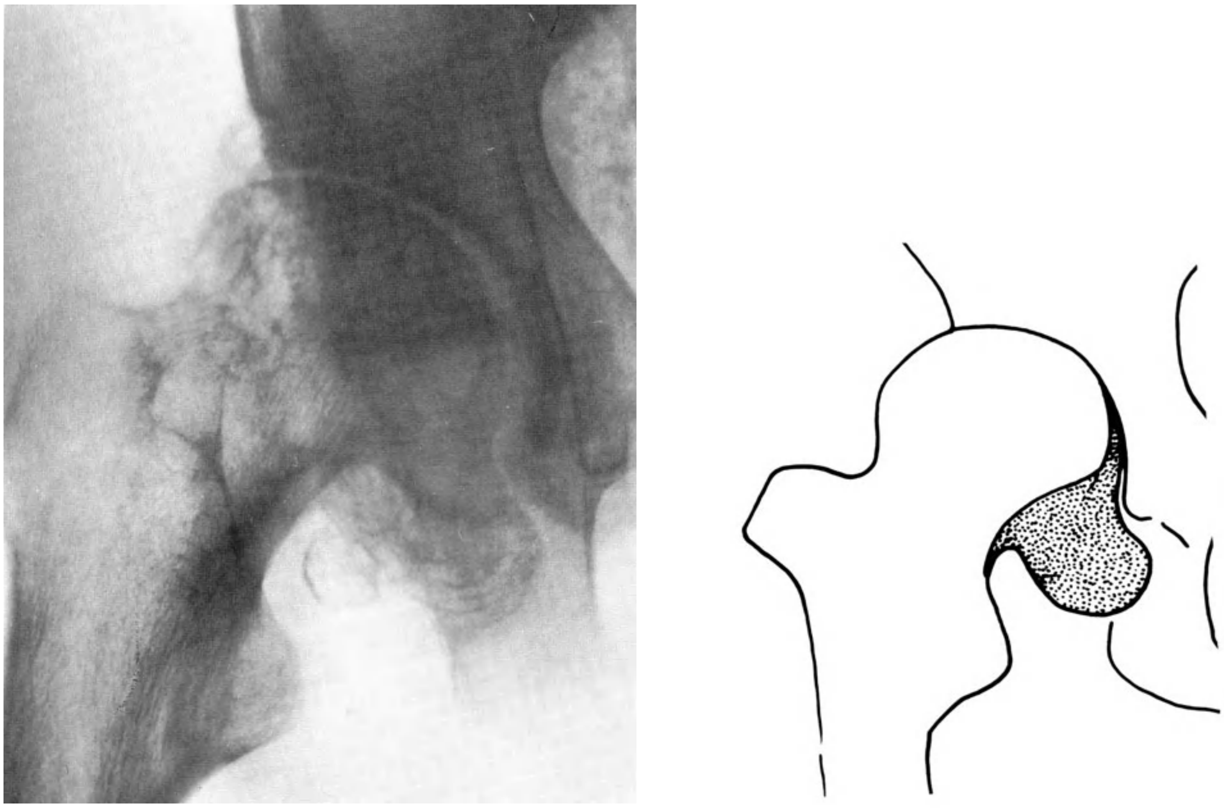


Fig. 34. Elephant's trunk osteophyte is completely fused with capital drop. As that in Fig. 33, when a valgus osteotomy is performed it must be removed

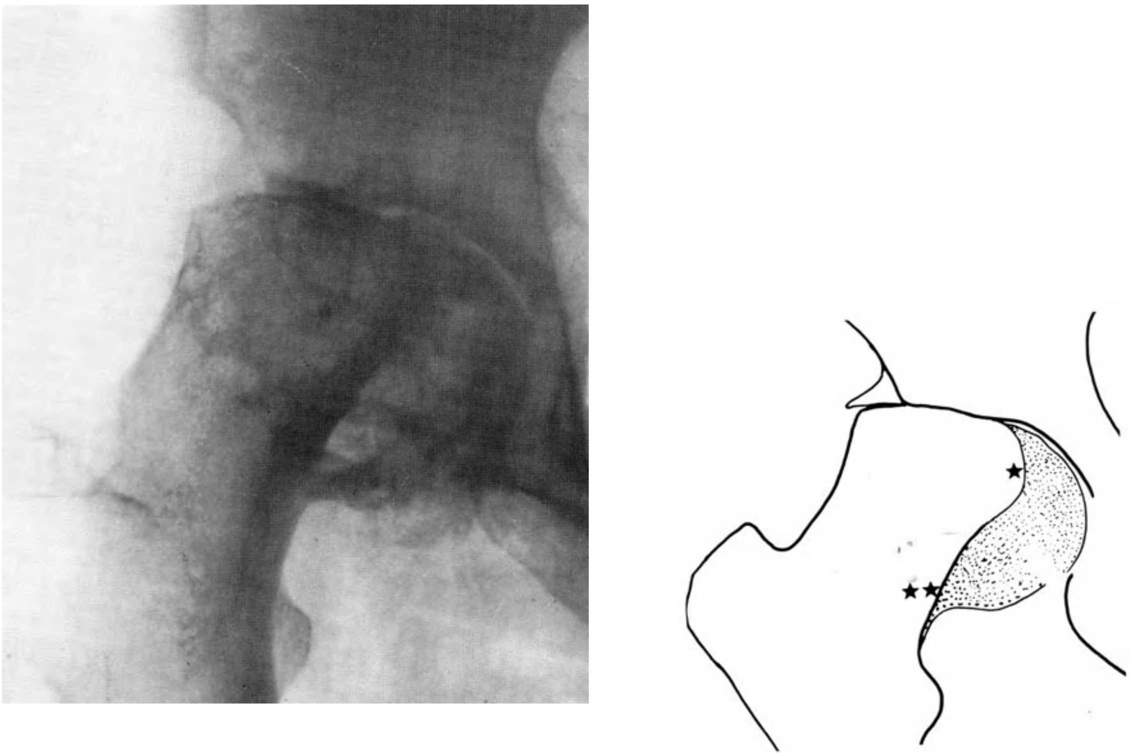
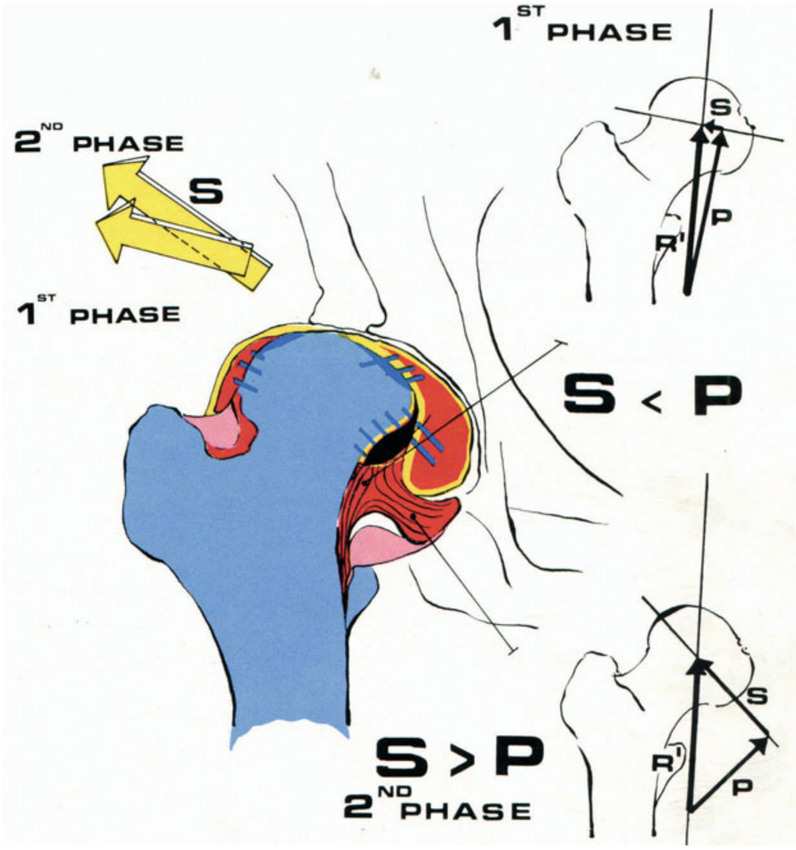


Fig. 35. Pseudo femoral head due to the fusion of capital drop (★) and elephant's trunk osteophyte (★★). The real femoral head has been flattened and has slipped laterally out of acetabulum. A valgus osteotomy of about 35° would exploit fused osteophytes and transform them into a new efficient head (Fig. 86)



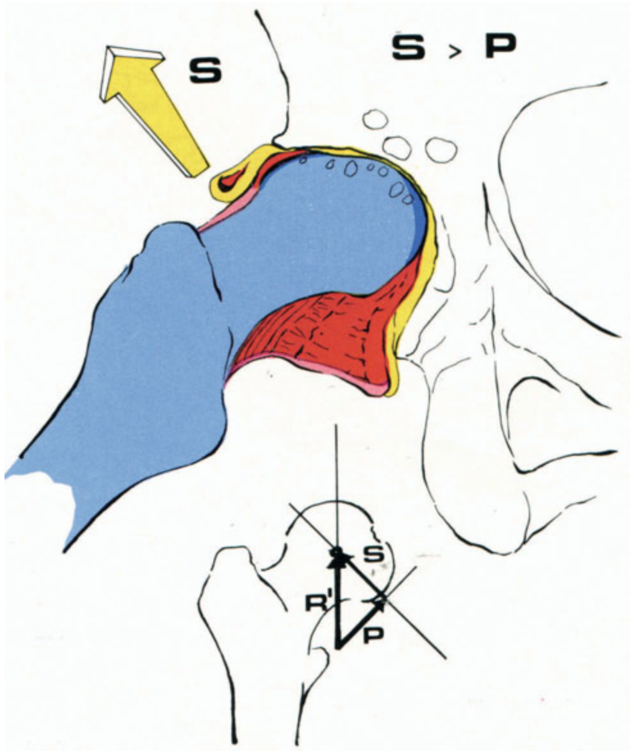


Fig. 36. X-ray shows how a mega-head is formed. Original femoral head is incompletely dislocated and femur still lies in socket. This is due to presence of big capital drop, of inferior cervical osteophyte, and of elephant's trunk osteophyte. These three osteophytes are fused into one massive neoproduction. Direction of trabeculae of inferior cervical osteophyte is influenced by high magnitude of force *P* (1st phase). As obliquity of acetabular roof increases, force *S* overcomes force *P* and builds up elephant's trunk osteophyte. The direction of its trabeculae is horizontal, corresponding to the direction of now dominant force *S* (2nd phase)

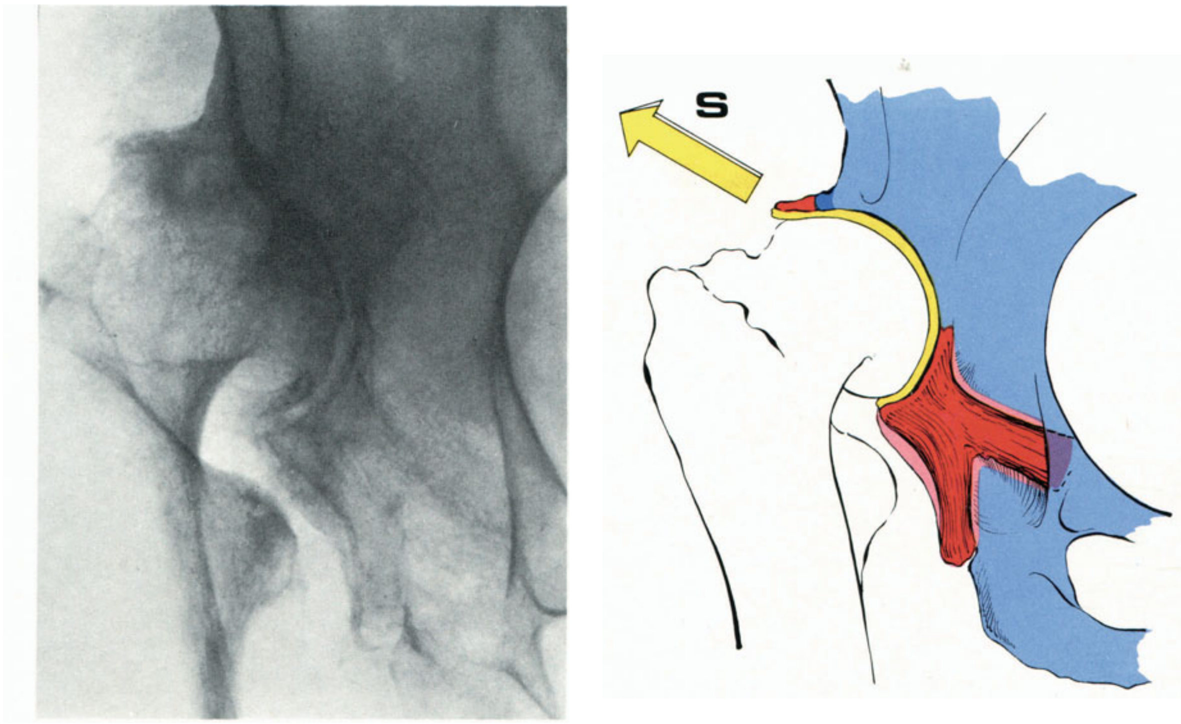


Fig. 37. Caudal part of socket is the result of fusion of elongated tent osteophyte and of floor osteophyte. After valgus osteotomy, this inferior part of socket offers to quadrants of head a good prop surface, like a fulcrum, allowing cranial quadrants of head to stand away from roof. This osteophyte has a shape of a molar tooth

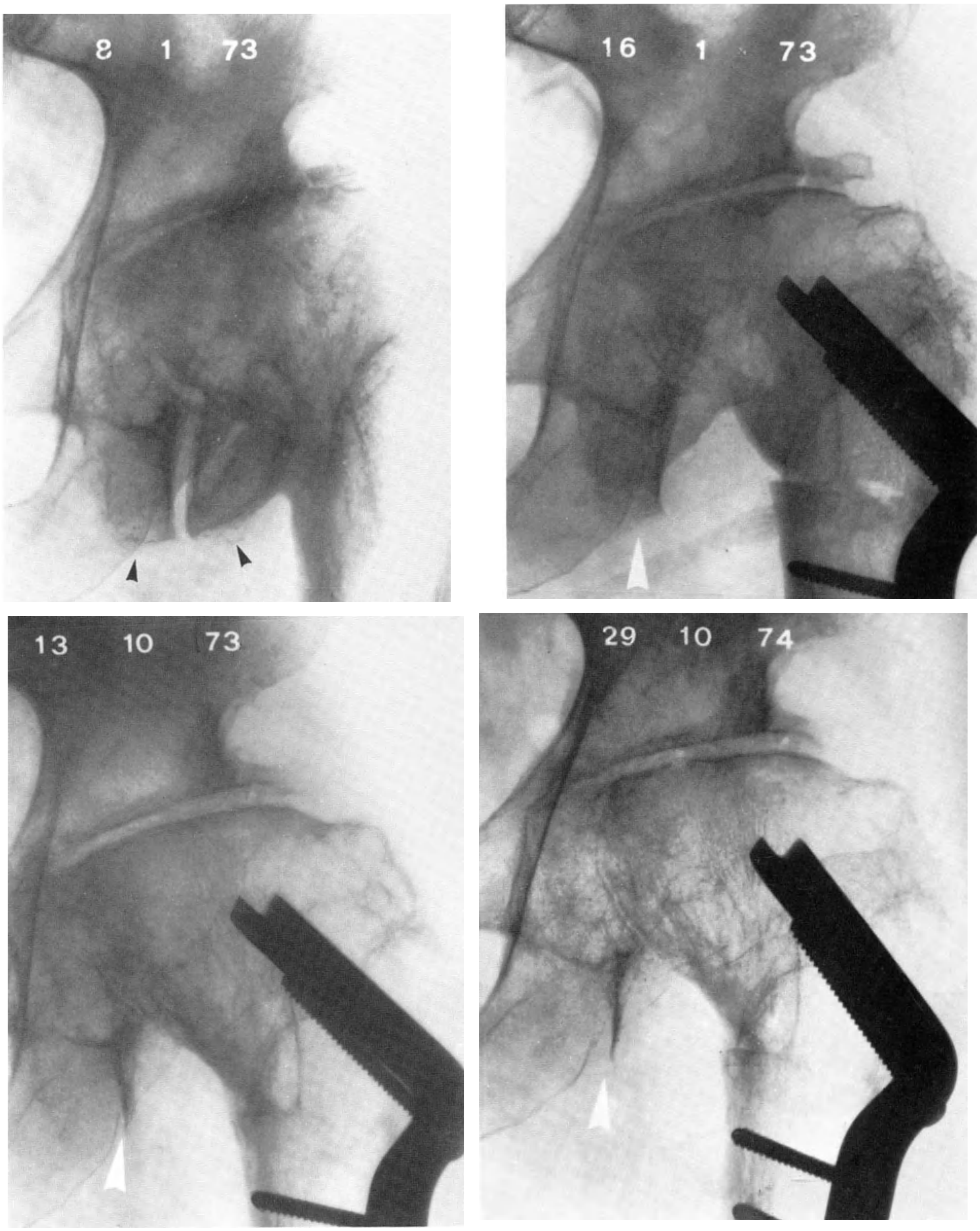


Fig. 38. Osteophytes are due to osseous metaplasia of synovial membrane and joint capsule at points of their insertion.
8—1—73 Osteoarthritis of hip secondary to idiopathic necrosis of head. Tent osteophyte and floor osteophyte are stout and have fused together. Capital drop and inferior cervical osteophyte are also fused together. *16—1—73* Valgus osteotomy of 30° has been performed. Opening of inferior part of joint capsule and removal of section of inferior cervical osteophyte have been carried out. Osteophyte has been removed to allow rotation of head. *13—10—73* 9 months after operation. Due to absence of tension floor osteophyte atrophies. *29—10—74* 21 months after operation. Atrophy of floor osteophyte has progressed. Joint space has improved. Patient walks painlessly

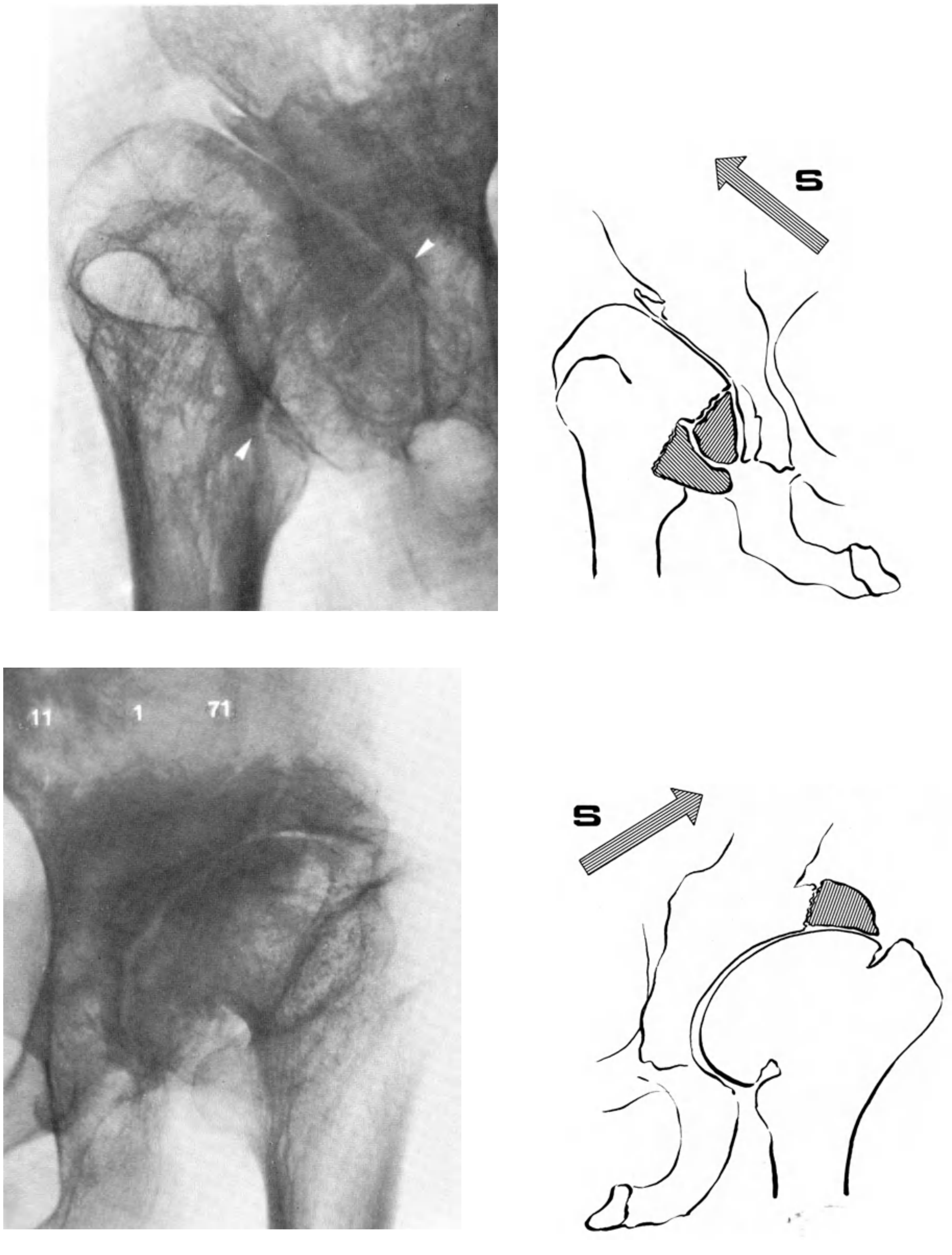


Fig. 39a–c. Fatigue Fractures of Osteophytes. (a) X-ray shows broken capital drop and broken elephant's trunk osteophyte. This is consequence of too high a force *S*, as can be deduced by observing direction of roof osteophyte. (b) When tension on capsule is excessive because of marked obliquity of superior part of joint surface, roof osteophyte may undergo fatigue fracture. (c) In March, 1971 elephant's trunk osteophyte appears intact; in June, 1975 it has been interrupted because of progression of the disease, which has caused increased obliquity of superior weight-bearing surface. (See also page 44)

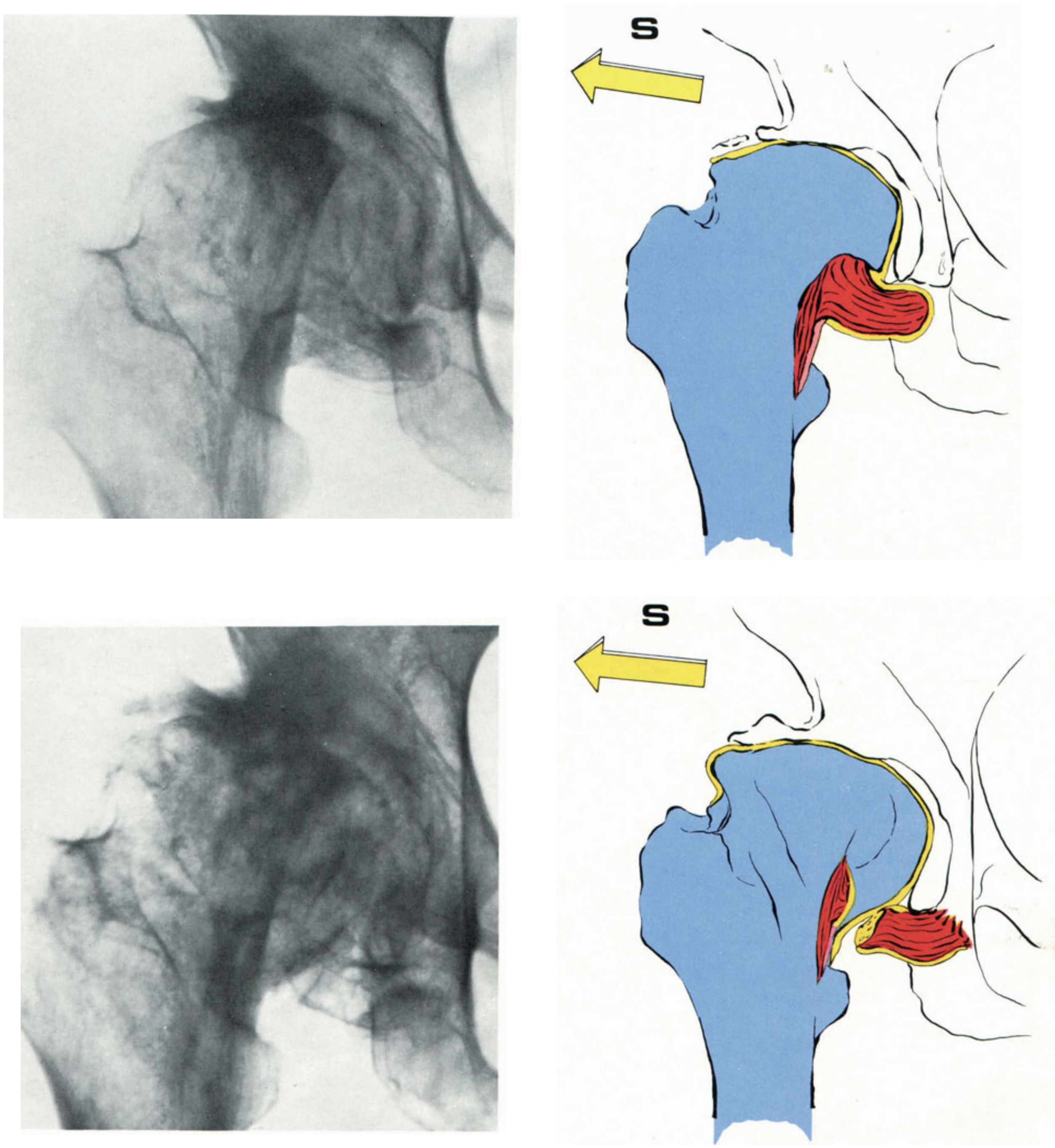


Fig. 39c. Legend see page 43

Fig. 40. Osteophytes. Drawings, taken from X-rays, demonstrate different shapes of osteophytes. A. Fovea osteophyte and tent osteophyte. Latter begins at inner edge of facies semilaris. B. Fovea osteophyte, superior marginal, and inferior marginal osteophyte on head of femur and tent osteophyte. C. Fovea osteophyte and inferior marginal osteophyte are fused and build capital drop. Superior cervical osteophyte has appeared and is fused with superior marginal osteophyte. Tent osteophyte has grown. D. Case similar to the previous one, except for appearance of roof osteophyte. E. Roof osteophyte, superior cervical osteophyte, and hypertrophic capital drop fused with inferior cervical osteophyte. Floor osteophyte and hypertrophic tent osteophyte. F. Big elephant's trunk osteophyte is visible on inferior cervical osteophyte. G. Mega-head: the lateral part due to fusion of superior marginal and superior cervical osteophyte; medial part due to fusion of capital drop, inferior cervical, and elephant's trunk osteophyte. On acetabulum ▷ there are stout roof, floor, and tent osteophytes. H. Oblique roof osteophyte demonstrates oblique direction of force *S*. Tent and floor osteophyte are fused. I. Capital drop opposite to the tent osteophyte could make a good joint surface, if valgus osteotomy were to be performed. L. Mega-head and hypertrophic floor osteophyte. This last osteophyte must be removed to allow head to rotate, if valgus osteotomy is done. M. Molar tooth osteophyte, due to the fusion of tent and floor osteophyte. N. Tent osteophyte, similar to a column, extruding from fundus acetabuli.

Preoperative study of osteophytes is very important. When they are very pronounced, preventing rotation of head, a part of them must be removed. Usually, inferior cervical osteophyte and floor osteophyte impinge on one another

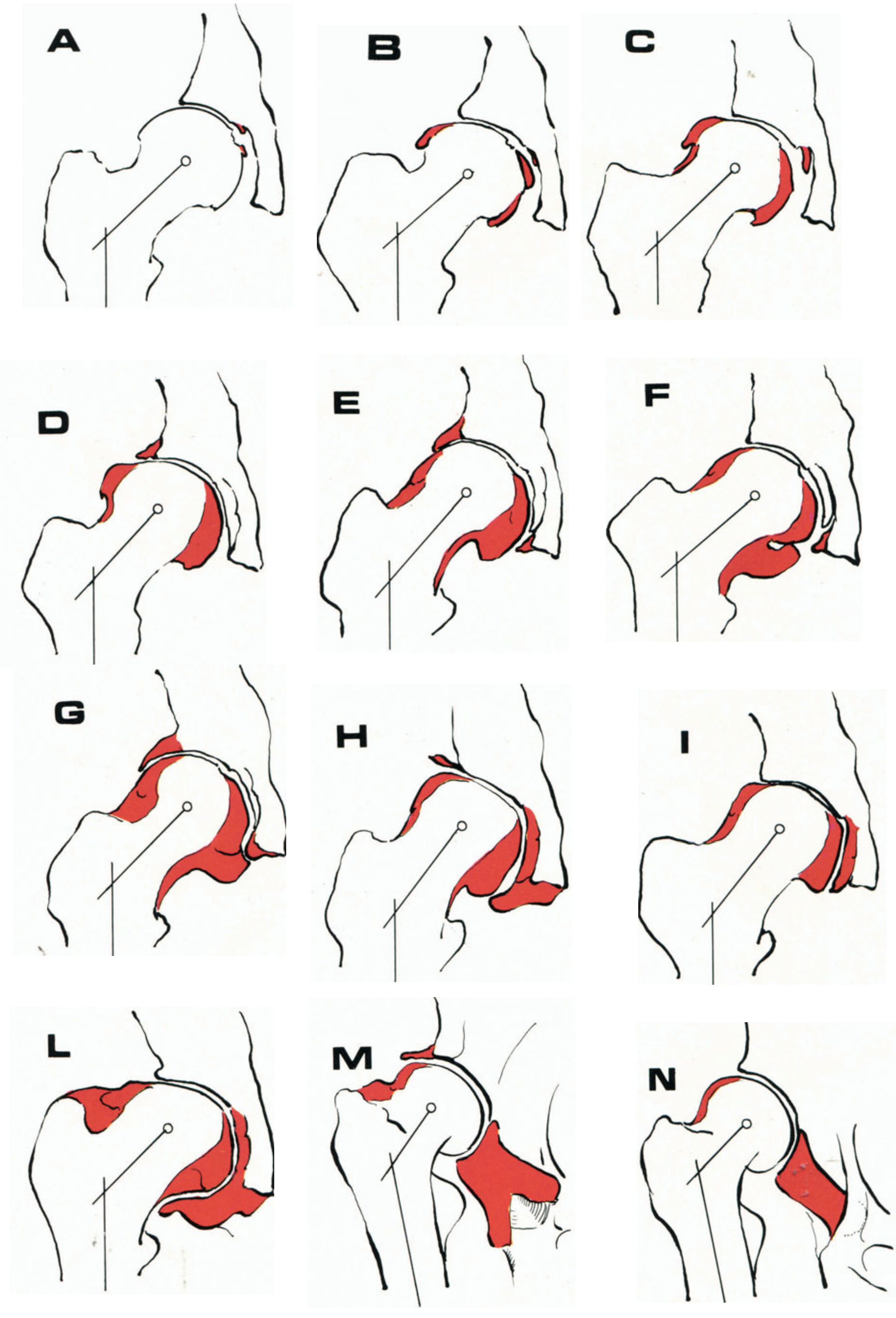


Fig. 40. Legend see opposite page

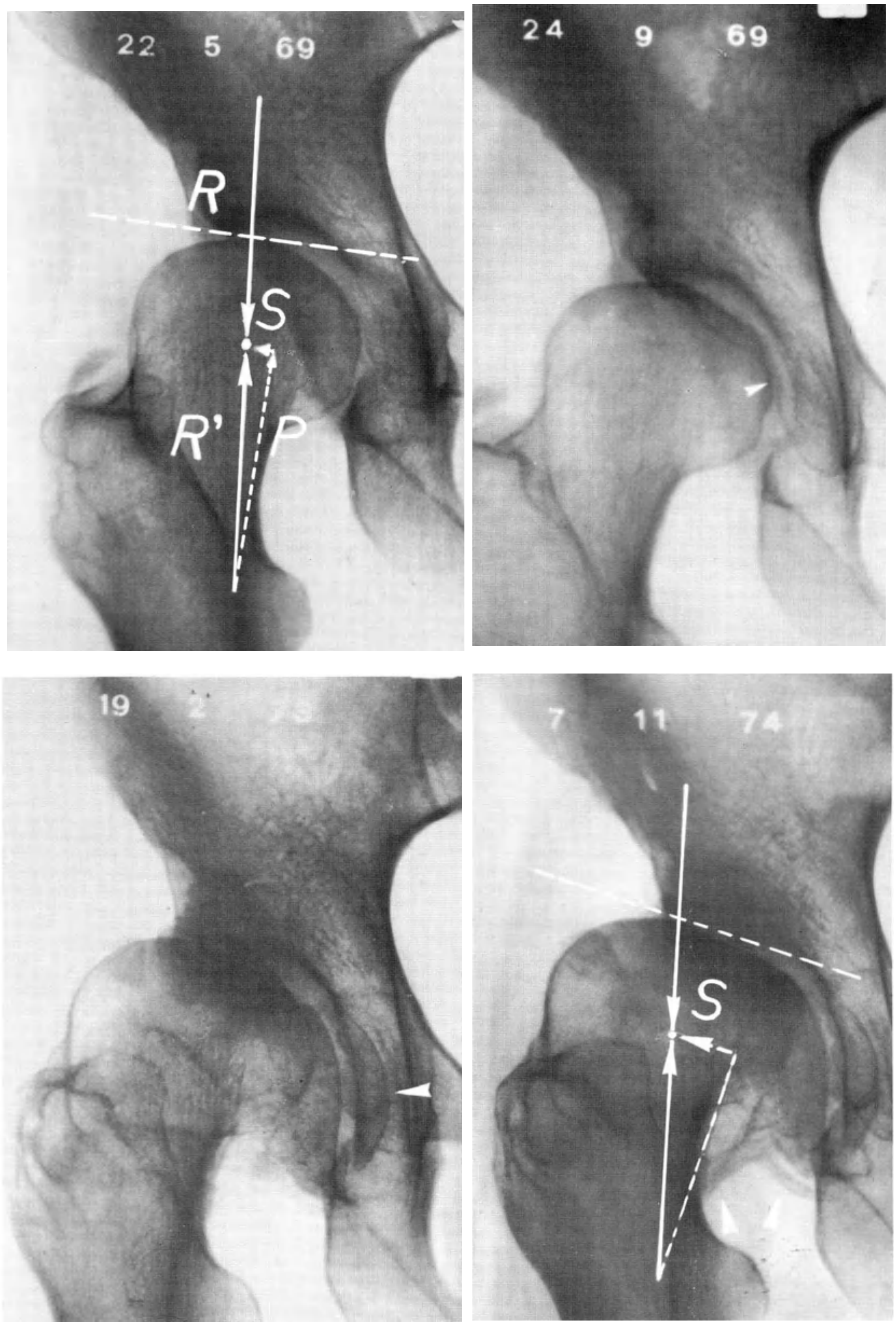


Fig. 41 a. Radiographic progression of osteoarthritis secondary to "coxa valga subluxans". Force *S* is present.
22—5—69 Coxa valga subluxans with early osteoarthritis. The wear of articular cartilage at weight-bearing area begins. Force *S* pushes head laterocranioanteriorly out of acetabulum. *24—9—69* Around fovea capitis femoris the fovea osteophyte appears. *19—2—73* Capital drop has appeared, the tent osteophyte at fundus acetabuli is well formed; at superior acetabular edge roof osteophyte appears; at Adam's arch inferior cervical osteophyte develops. *7—11—74* Capital drop and tent osteophyte are more developed. Inferior cervical osteophyte is more pronounced and has the shape of an elephant's trunk. Inferior joint capsule has ossified. Capital drop and inferior cervical osteophyte have fused and are building mega-head

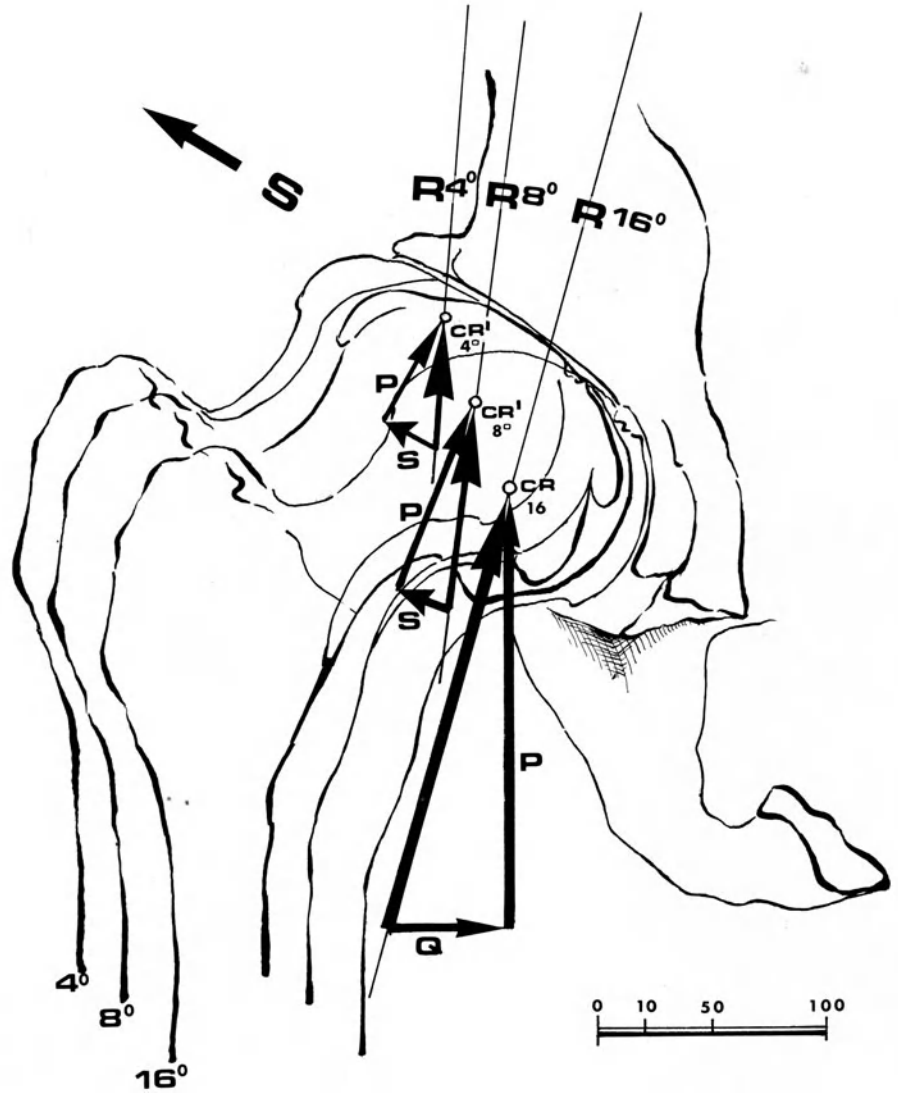


Fig. 41 b. Osteoarthritis of right hip. Different stages of disease. R_{16} corresponds to resultant force R in normal hip during 16th position of right stance phase. Counter-resultant force is resolved into two forces: (1) P (pressure) perpendicular and (2) Q parallel to weight-bearing surface. Force Q is horizontal because in normal hip the weight-bearing surface is horizontal. Force Q pushes femoral head into acetabulum.

R_8 corresponds resultant force R inclined at 8° in the frontal plane (position 16) in a hip affected by osteoarthritis. This inclination is due to pain. In fact, patient shifts center of gravity of his body toward supporting limb in monopodal support. By doing this the magnitude of resultant force R and of counter-resultant force R_1 is reduced. The weight-bearing surface has become oblique. Counter-resultant force is resolved into two components: (1) P (pressure) perpendicular to weight-bearing surface and (2) S (Schub—spinta—thrust) parallel to bearing surface. The force S pushes femoral head cranially, laterally, and anteriorly out of acetabulum. Because joint capsule, ligamentum teres, and synovial membrane, covering both these anatomical structures and neck of femur, are stretched, osteophytes appear at particular zones of hip joint.

R_4. Disease has progressed and resultant force R has become even more vertical and has reduced its magnitude. Magnitude of two components P and S of counter-resultant force are also reduced. The head has slipped out of acetabulum even more. From this diagram it appears that, as disease progresses: (1) center of stress glides cranially, laterally, and anteriorly; (2) resultant force R becomes more vertical; (3) component forces P and S of counter-resultant force reduce in magnitude. By doing this nature protects a worn out bone, which otherwise could not tolerate high stress and strain

E. Consequent Therapy

From these premises we can understand how an intertrochanteric osteotomy aimed at provoking a marked valgus together with an extension of the femoral head stimulates the osteophytes and an increase in the weight-bearing surface, and therefore is indicated.

In another paragraph we will deal with the varus osteotomy.

I. Valgus-Extension Osteotomy

From the information obtained from the follow up X-rays of patients operated on by valgus-extension osteotomy, we realize that such an osteotomy works by stretching the ligamentum teres and its synovial membrane and by stretching the superior zone of the joint capsule and its synovial membrane.

This results in a stimulus for building the capital drop and the tent osteophyte, which increase the bearing surface of the joint. This also results in a stimulus for building up or hypertrophying the superior cervical osteophyte and the roof osteophyte. This last osteophyte, in turn, helps not only to increase the weight-bearing joint surface, but also, importantly, helps to make the weight-bearing joint surface horizontal, causing the force S to disappear and the force Q to reappear (Fig. 42). In a word, the roof osteophyte may put a "stopper" on the development of osteoarthritis (Fig. 43).

An extension of about 15°–20° usually is combined with a valgus osteotomy, because the head of the femur is also compressed against the anterior part of the acetabulum, due to the peculiar direction of the force S (Fig. 44).

According to PAUWELS' direction (1963–1973), the valgus osteotomy is worthwhile only in cases in which it can be presumed beforehand that a congruent joint will be obtained. This presumption is reached before the operation by means of a diagram reproducing the outline of the hip taken from an X-ray. If congruency cannot be obtained, a valgus osteotomy will not have good results.

In the author's view, however, evidence obtained from X-rays taken during the healing process suggests that congruency of the head and acetabulum can occur later, sometime after the valgus osteotomy.

This congruency is due to the osteophytes produced by the stretching of the ligamentum teres and its synovial membrane and by the stretching of the superior zone of the joint capsule and its synovial membrane.

1. Effect of Valgus-Extension Osteotomy

In order to stretch the ligamentum teres and its synovial membrane and the cranial zone of the joint capsule and its synovial membrane, the wedge to be removed in a valgus-extension osteotomy must be of 30° or more.

The radiographic result just after such an osteotomy may puzzle the surgeon, but unnecessarily.

Performing a valgus osteotomy of 30° or more, we can obtain a joint in which the weight-bearing surface of the acetabulum and of the femur are wide apart and the only parts in contact, forming a fulcrum, are the medial osteophytes; i.e.: the capital drop and the tent osteophyte.

In this way the center of movement of the hip is no longer at the center of the head of the femur, but at the fulcrum. The shorter lever arm $CR'-M$ becomes lengthened to CR_1-M^+ and the longer lever arm is shortened to CR_1-K.

Therefore, the resultant force R is reduced to R^+ (Fig. 45b).

The osteophytes are not innervated and therefore the fulcrum is not painful.

These compressed osteophytes (fulcrum) appear incongruous at first, but they are capable of being remodelled into good, functional weight-bearing tissue. In the long run they are molded by the active movement of the joint (Fig. 46). They hold the joint surfaces apart until new cartilages can regenerate on them. The space obtained between the lateral portion of the femoral head and the acetabulum becomes filled with synovial fluid. The synovial fluid acts as a buffer-like device similar to a hydraulic mechanism that spreads out the resultant force R on the superoanterior, inferoposterior part of the head and the neck of the femur, on the whole acetabulum, and on the joint capsule (Figs. 47–49).

The weight-bearing joint surface has increased two- or three-fold and the unit weight is therefore reduced.

In this case nature repeats the physical phenomenon commonly adopted in the intervertebral disc. Under pressure "nucleus polposus" of the disc flattens (the thickness of the layer of synovial fluid in the hip joint under pressure from the resultant force R diminishes) and stretches the annular fibres (and stretches the hip joint capsule), protecting the cartilage plates and the vertebral bodies (helping the remaining parts of joint cartilage to reproduce and protecting the bone of the acetabulum and of the head of the femur) (Fig. 50). By this mechanism the joint may heal: the joint cartilage reappears, the bone cysts disappear, and the structure of bone and the shape of the joint become moderately regular.

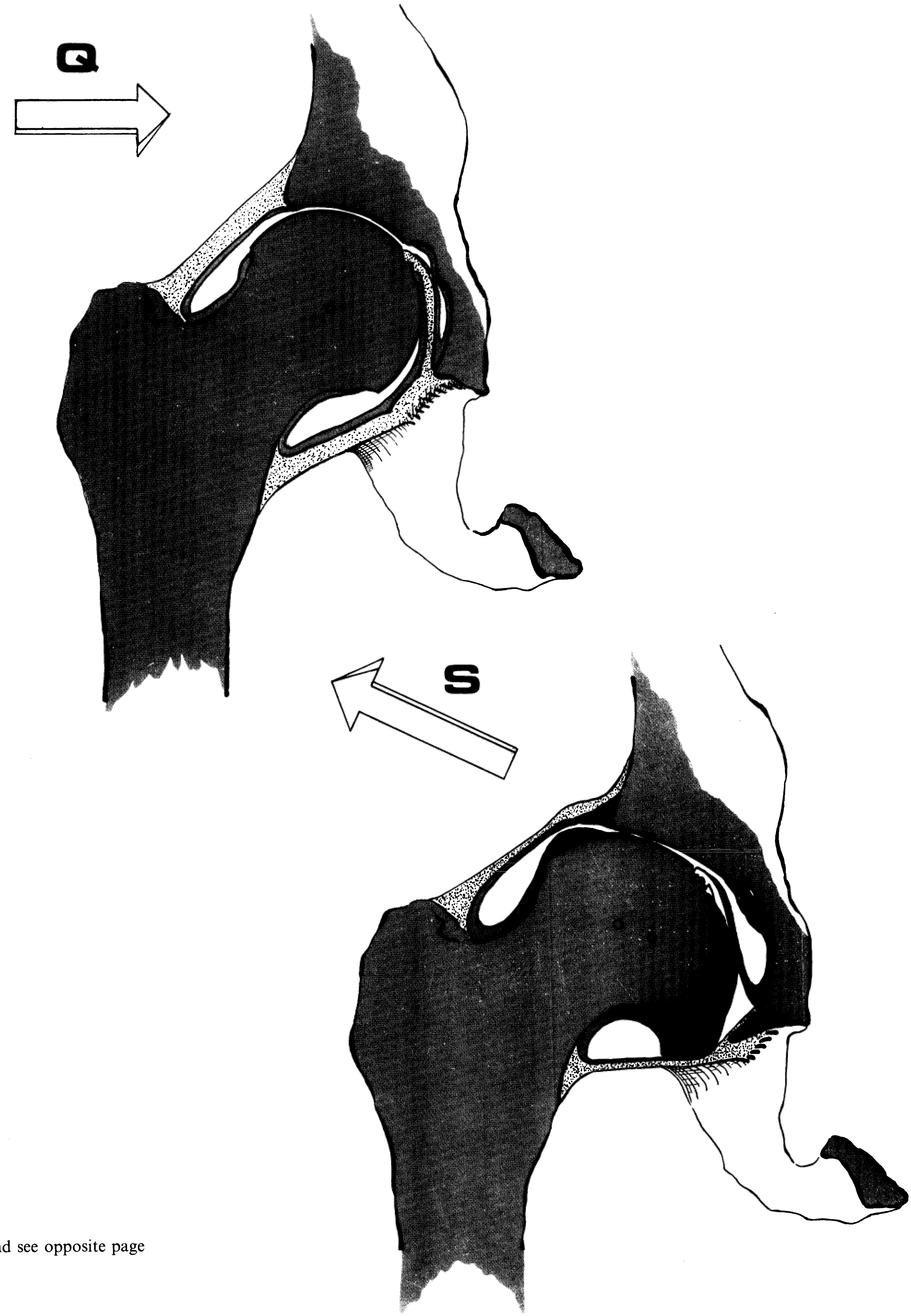


Fig. 42. Legend see opposite page

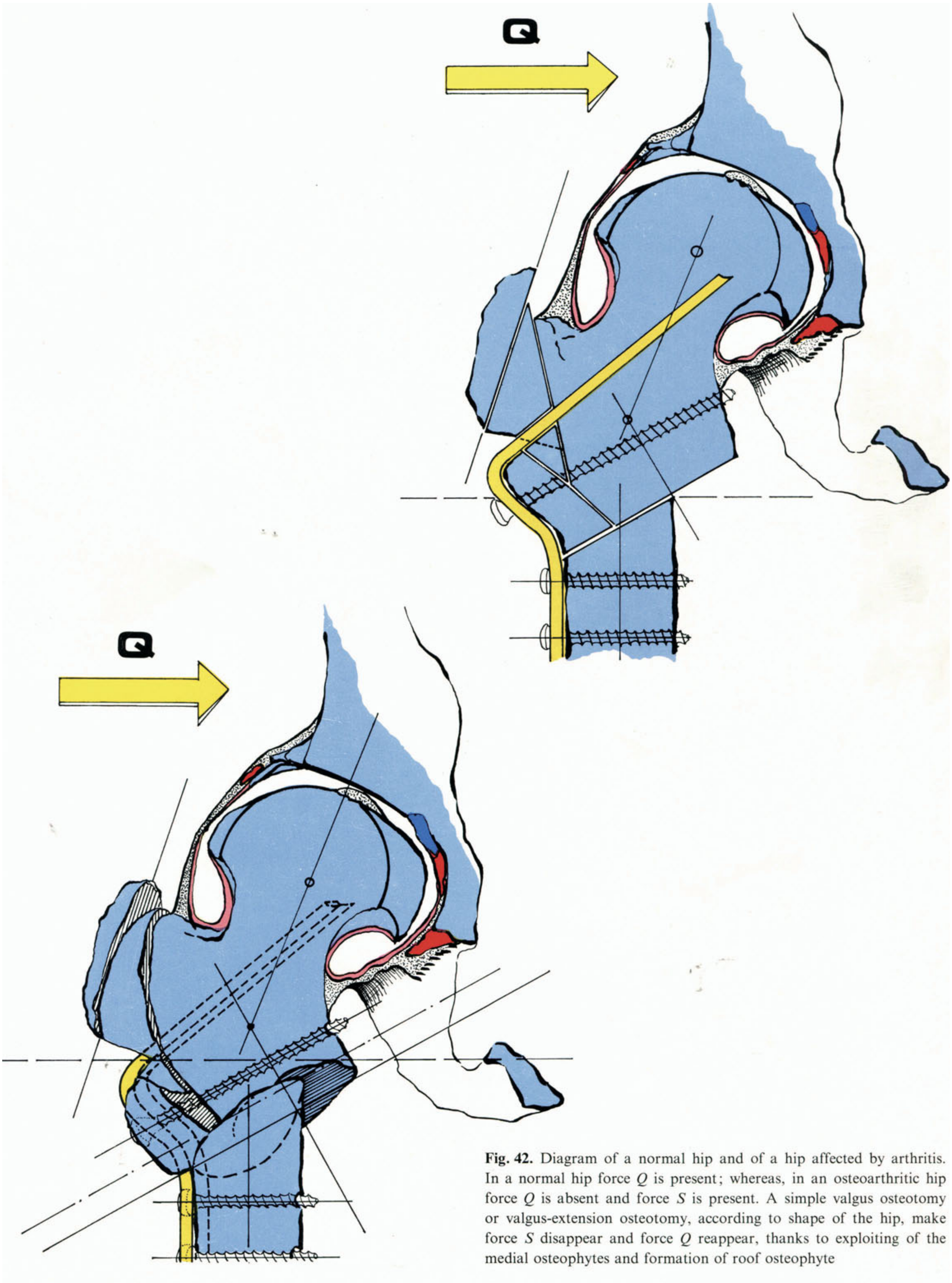
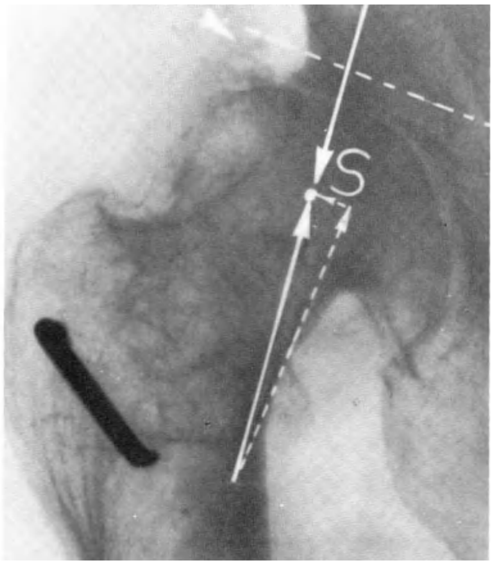


Fig. 42. Diagram of a normal hip and of a hip affected by arthritis. In a normal hip force *Q* is present; whereas, in an osteoarthritic hip force *Q* is absent and force *S* is present. A simple valgus osteotomy or valgus-extension osteotomy, according to shape of the hip, make force *S* disappear and force *Q* reappear, thanks to exploiting of the medial osteophytes and formation of roof osteophyte



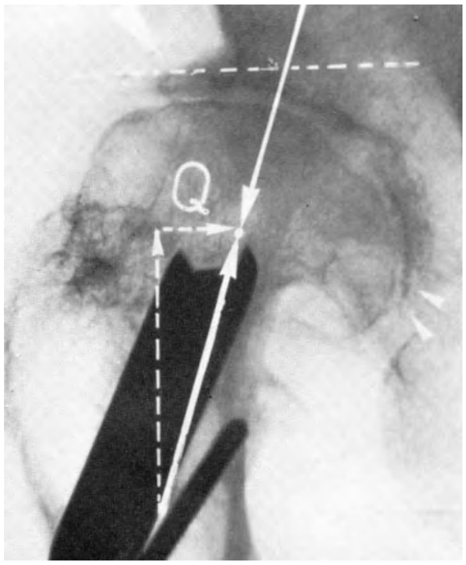
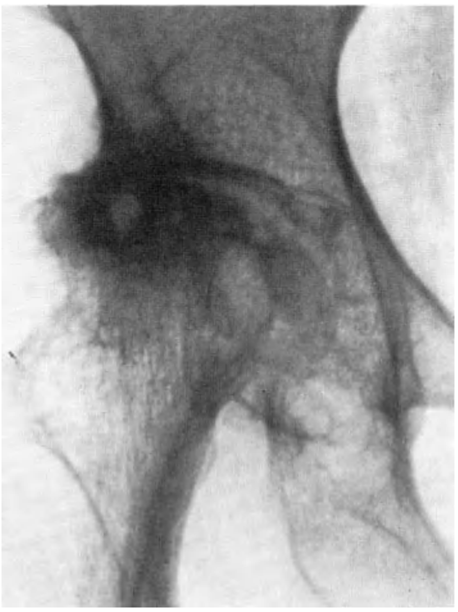
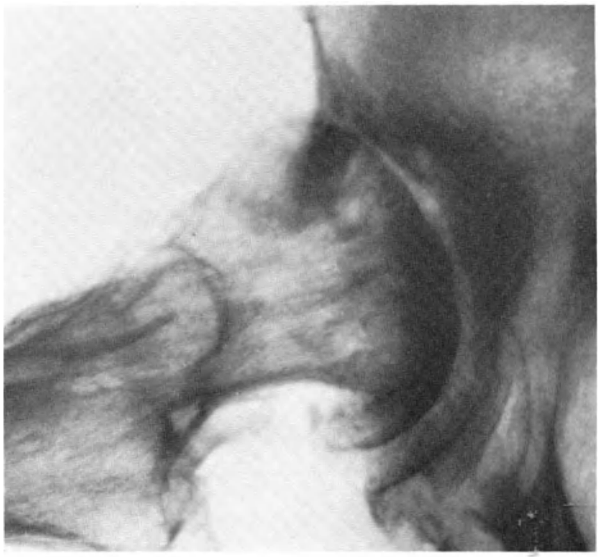


Fig. 43. *2—5—73* Osteoarthritis of right hip operated on 10 years previously with varus osteotomy. Previous osteotomy has not changed obliquity of weight-bearing joint surface. For that reason force *S* is still present and active. Roof osteophyte is just visible. Capital drop and tent osteophyte are clearly evident. *8—11—74* 18 months after operation. Hypertrophy of roof osteophyte due to tension in superior capsule, caused by valgus osteotomy, has modified inclination of weight-bearing joint surface. Force *S* has disappeared. Force *Q* has reappeared. Roof osteophyte acts as a "block" to the outward glide of head





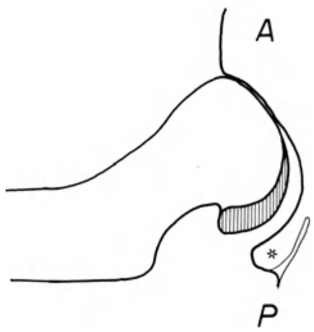


Fig. 44. X-rays: shape of head of femur and of acetabulum as a result of the action of force *S*. Superolateral and anterior part of femur is pressed against acetabulum

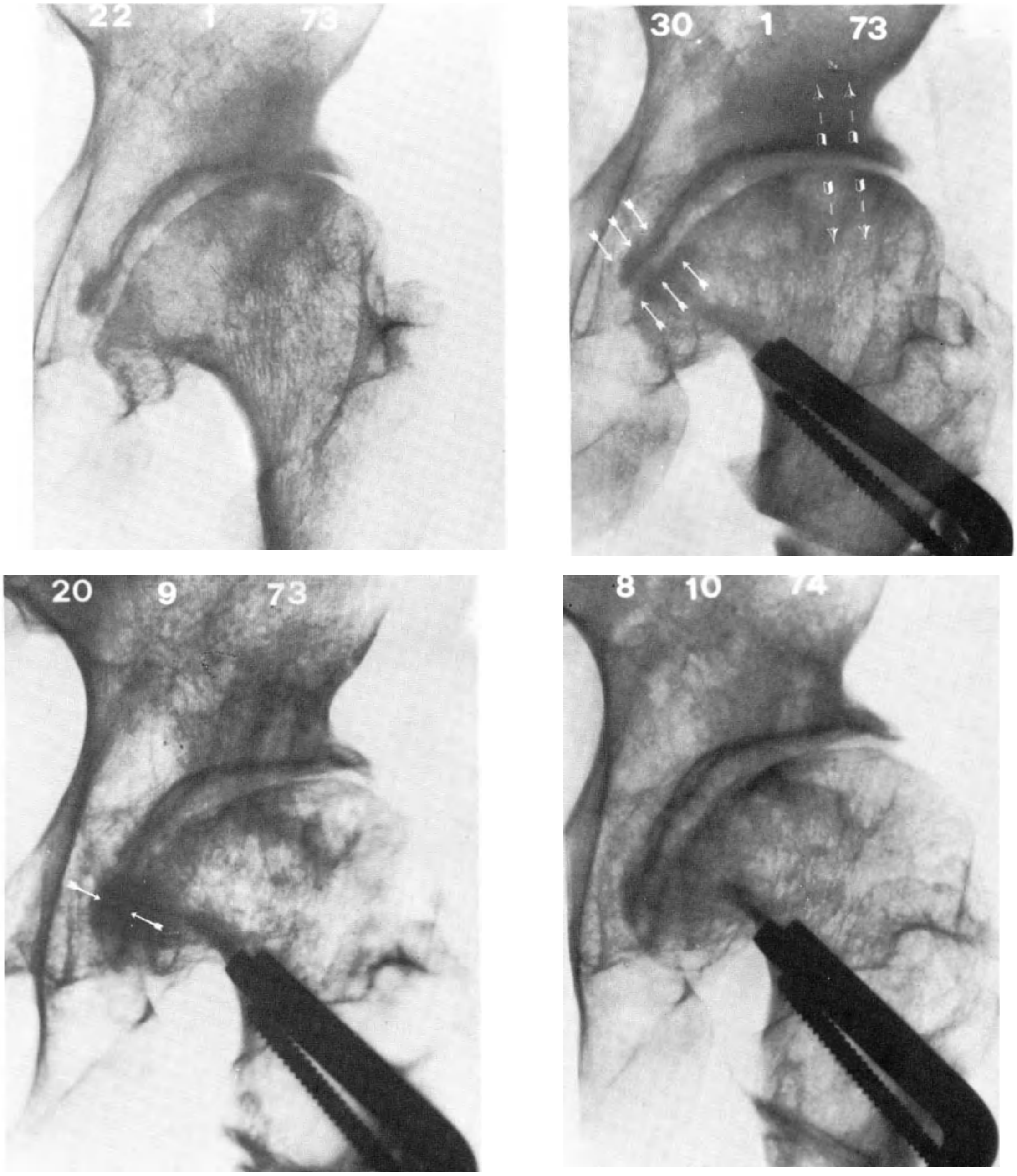


Fig. 45a. P.C., age 37. *22—1—73* Secondary osteoarthritis of left hip. Roof osteophyte, capital drop, and tent osteophyte are clearly visible. *30—1—73* Just after valgus osteotomy of 30°. Medial osteophytes (capital drop and tent osteophyte) are the fulcrum of movement. Lateral part of joint space has been passively widened. *20—9—73* 8 months after operation. The fulcrum, because of very high stress on it, has undergone eburnation, but is not painful. The joint space has increased and is moderately even. Patient walks with one stick. *8—10—74* 21 months after operation. The fulcrum, with less eburnation, has large surface. The joint space is becoming regular. Patient walks normally and, as a heavy worker, stands for many hours a day

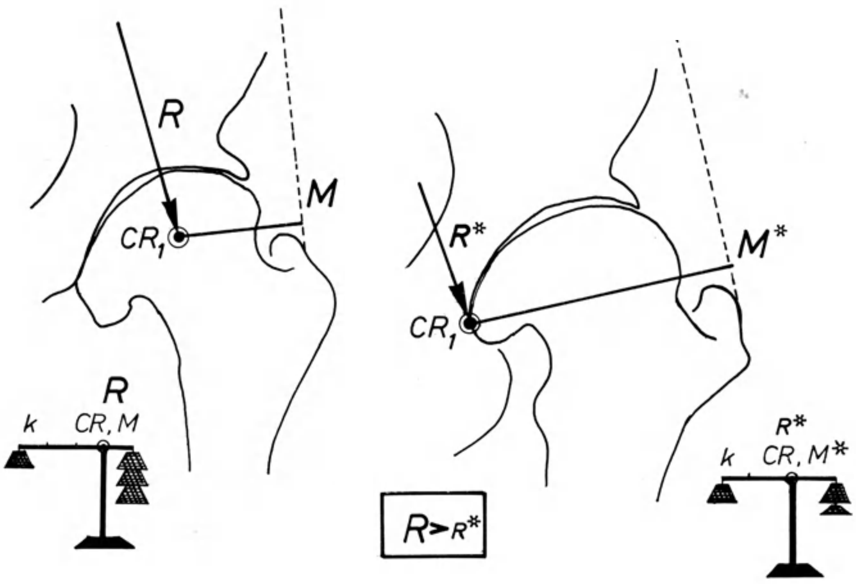


Fig. 45b. The drawing taken from the X-ray shows displacement of center of movement of hip after valgus osteotomy. Before the operation center of movement was center of head. After the operation center of movement is contact point capital drop and tent osteophyte, which is medial to center of head of femur and therefore, the distance $CR_1 - M^+$ is longer than $CR_1 - M$ (muscular lever arm). The longer lever arm of weight is shortened to $CR_1 - K$. By this, previous resultant force R is reduced to R^+

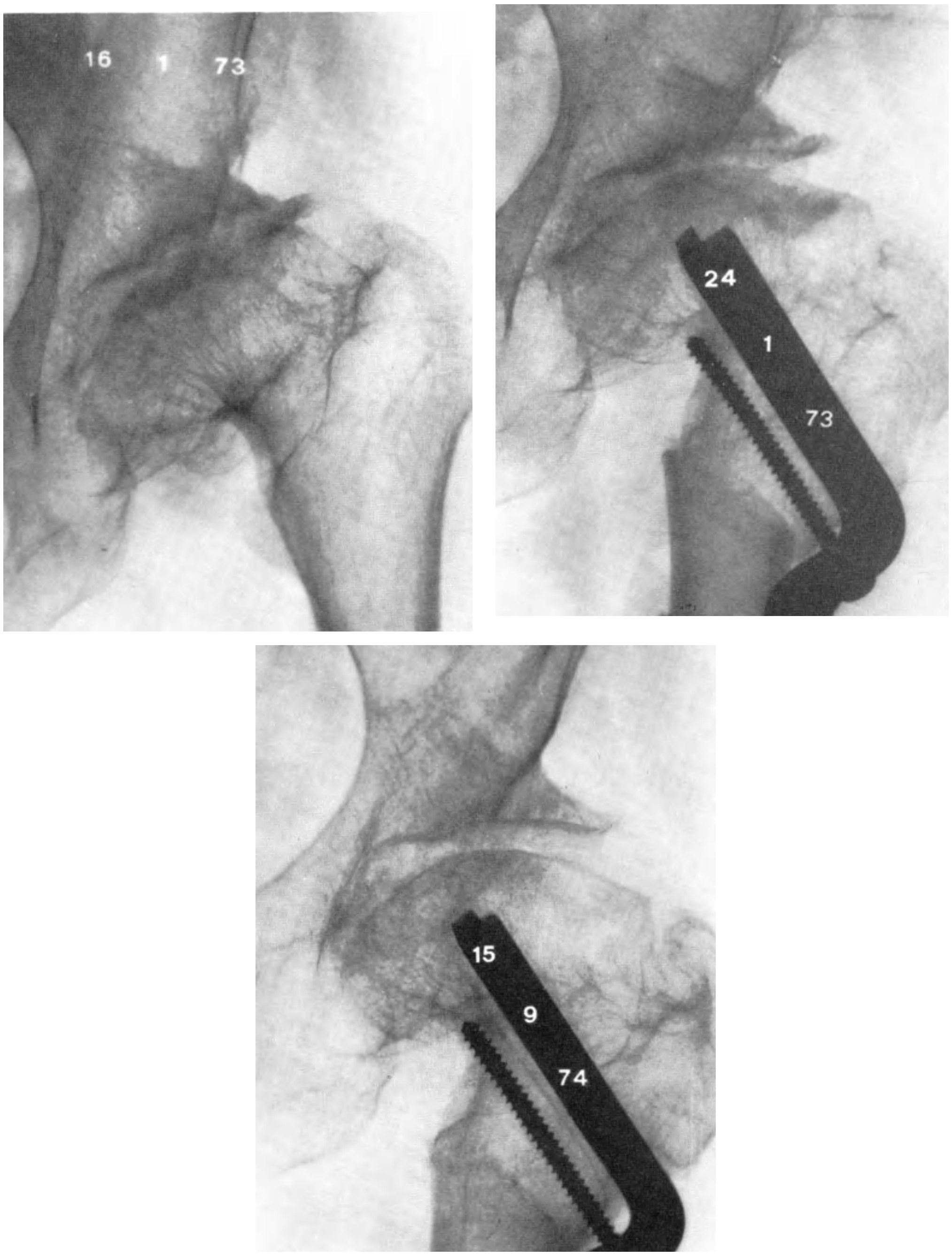
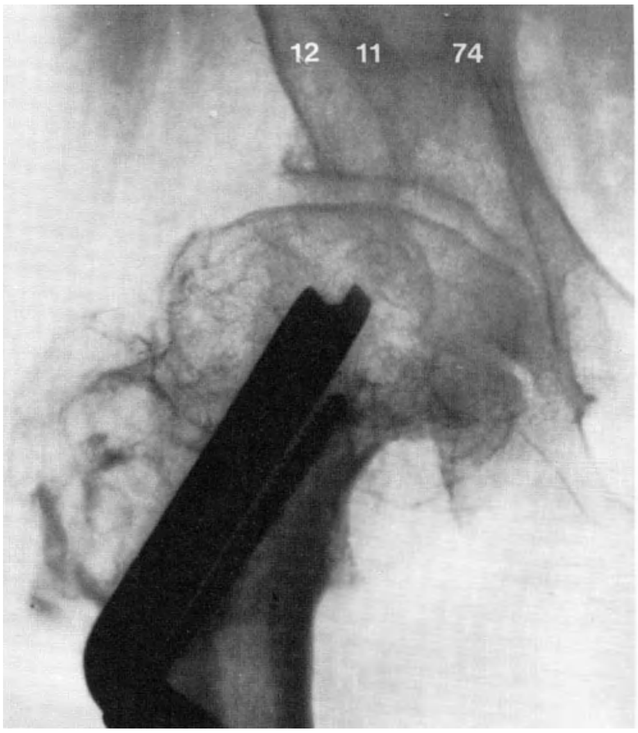


Fig. 46. B.G., age 46. Osteoarthritis of left hip secondary to presumed C.D.H. (Congenital Dislocation of the Hip). *16—1—73* Force *S* is present because of obliquity of joint surface. *24—1—73* X-ray 3 days after valgus osteotomy of 30°. Between capital drop and tent osteophyte we can see fulcrum of movement. Lateral joint space has been passively widened. *15—9—74* 20 months after operation. Joint has healed. Articular surfaces are congruent and a layer of fibrocartilagineous tissue covers osteophytes, which were acting as a fulcrum. They have ultimately worn out. The direction of the joint space is almost horizontal. Force *S* has disappeared and force *Q* has reappeared



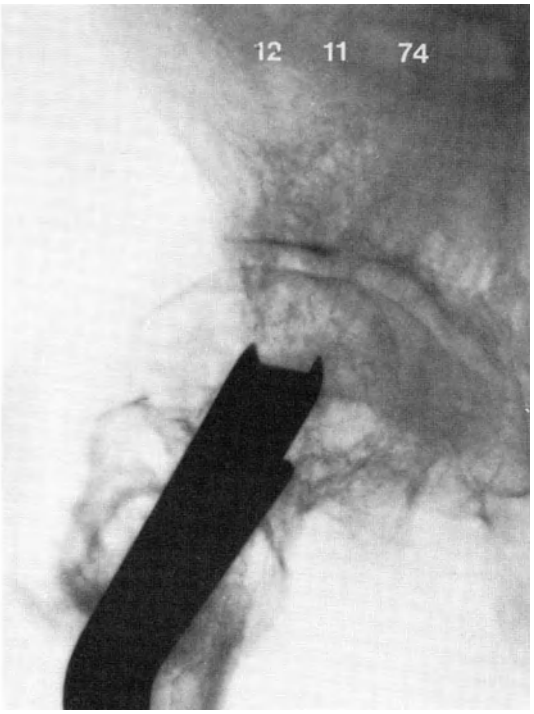


Fig. 47. T.M., age 69. *9–1–74* Primary osteoarthritis of right hip. X-ray shows large capital drop and inferior cervical osteophyte. The two osteophytes will soon fuse, forming mega-head. *12–11–74* 10 months after operation. Two osteophytes are building up pseudo head which helps to increase joint surface. The joint surface is regular. Patient is free from pain and walks without a stick

Fig. 48. Shock absorbing mechanisms. Severe arthritis following necrosis of head of femur. Weight-bearing joint surface is flat. Resultant force *R* is distributed over acetabulum and superior surface of head. After valgus osteotomy of 30°, acetabulum and surface of head are wide apart, except for their medial portions. Here the capital drop and tent osteophyte are in close contact. Increased joint space is filled by synovial fluid, which acts as a hydraulic mechanism, to absorb resultant force *R*. In fact, force *R* is now distributed over acetabulum, joint capsule, anterior, superior, posterior, and inferior parts of head and neck of femur. The medial fulcrum (capital drop and tent osteophyte) is not painful and, in time, with active joint movement, becomes molded. Ultimately a new large joint surface will appear. ▷

M.P., age 47. *2–3–72* Right osteoarthritis, probably secondary to necrosis of head of femur. Active movements are:

Fl./Ext.	20	0	0
Ab./Add.	0	0	20
Ex./Intr.	0	0	0
Shortening	2 cm		
Pain			

10–3–73 1 year after valgus osteotomy of 30°. Patient has been walking without any support for 6 months and works standing up all day long. The joint has improved. The active movements are:

Fl./Ext.	110	0	0
Ab./Add.	30	0	20
Ex./Intr.	0	0	0
No shortening			
No pain			

16–12–75 3 years, 9 months after operation. Patient is happy with his hip and leads a normal life. Note the wear and tear of fulcrum (capital drop and tent osteophyte), which has become covered with cartilage

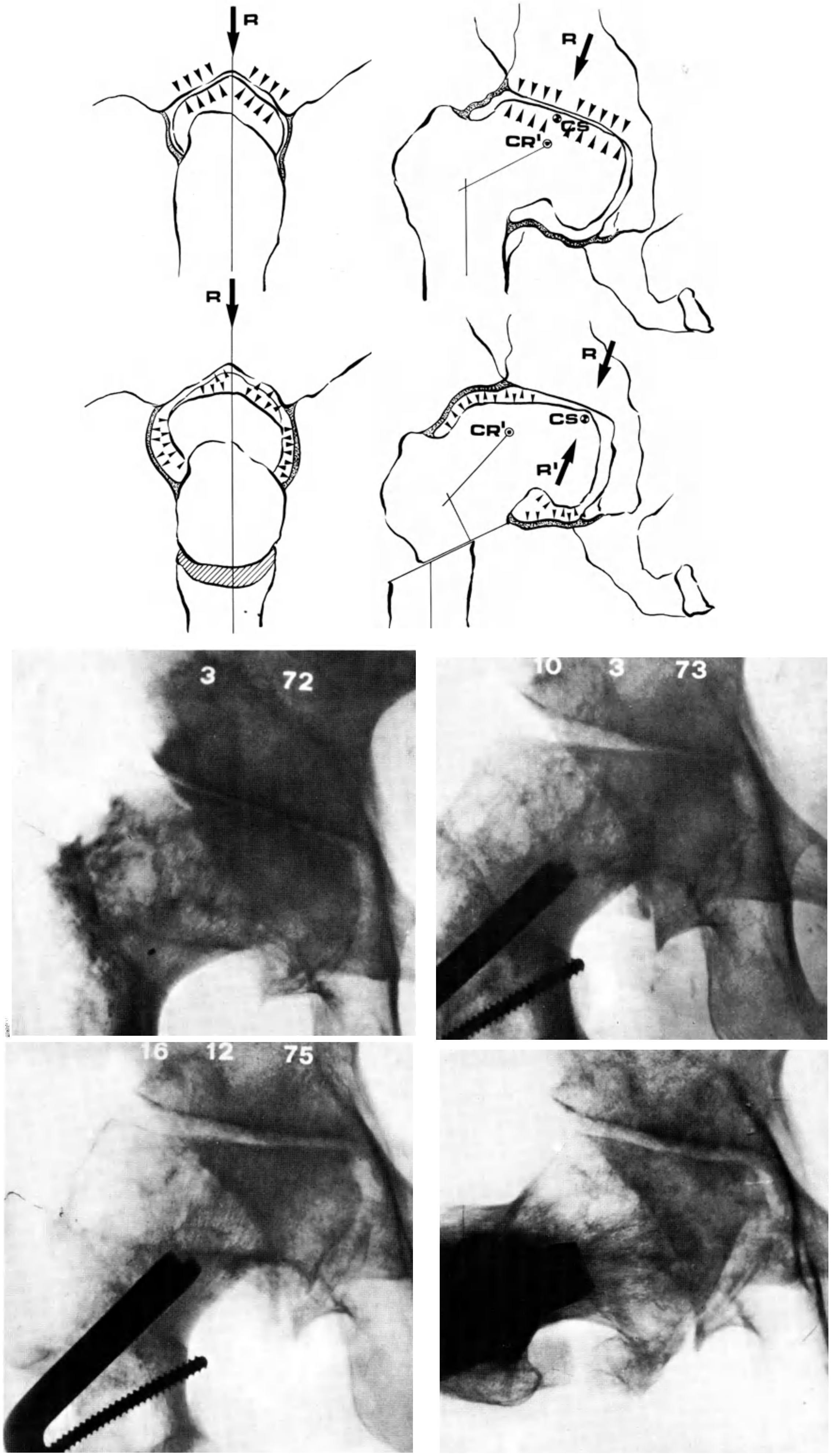
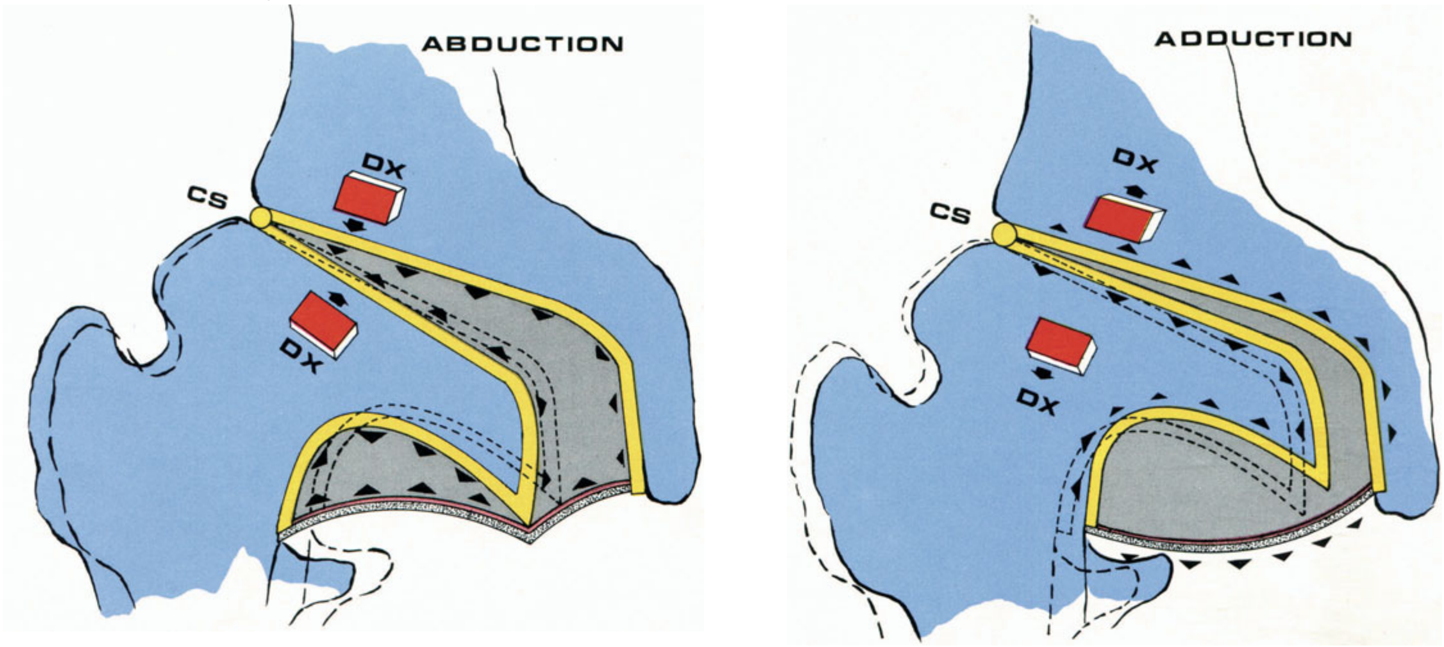


Fig. 48. Legend see opposite page

Before operation



After operation

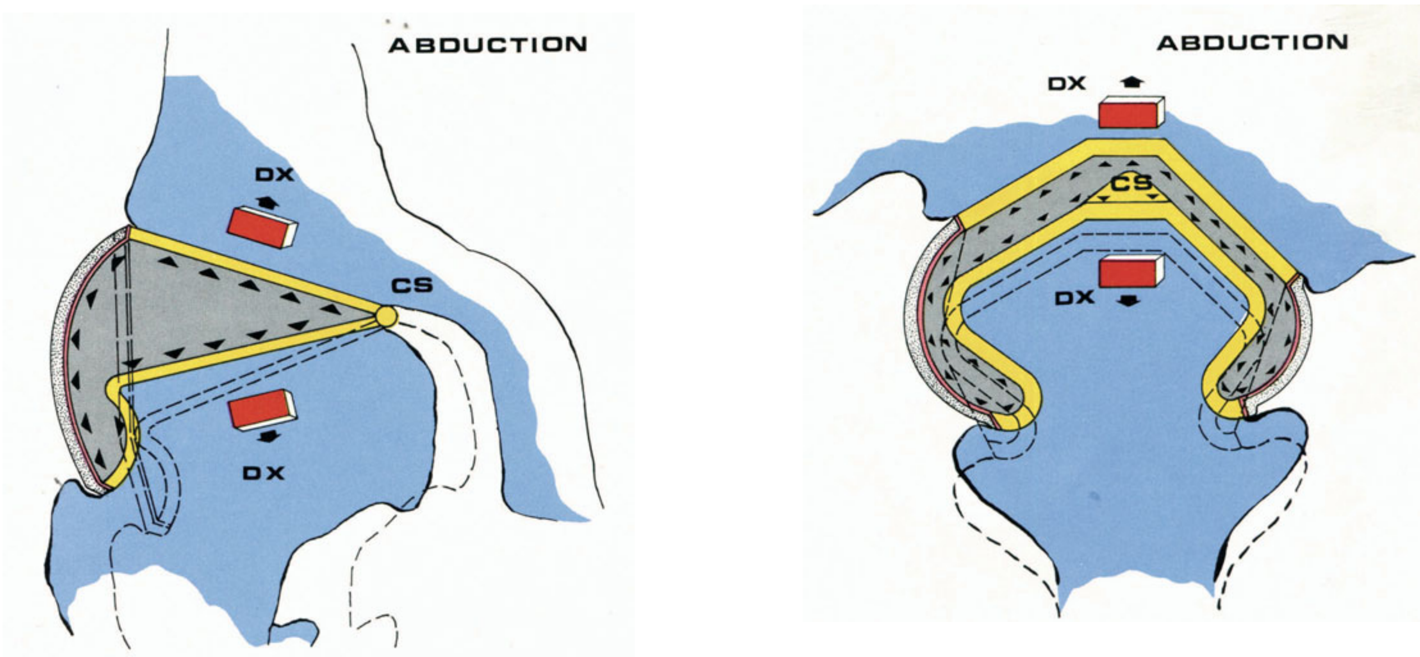


Fig. 49. Diagram shows how hip joint works before and after valgus osteotomy. *Before operation,* fulcrum of movement is located on sensitive cranioexternal edge of acetabulum. Abduction and adduction movements cause pain. Resultant force *R* has great magnitude because abductor lever arm is very short. *After operation,* the femur pivots both in abduction and in adduction on point *CS* (center of stress), which is located medially. CS is the restricted contact area of capital drop and tent osteophyte and acts as painless fulcrum (osteophytes have no nerves). *In abduction* the increased amount of synovial fluid is compressed against cartilage covering the socket, against whole surface of head, against intracapsular surface of neck of femur and against joint capsule, which becomes distended like a tire. Resultant force *R* is therefore distributed over a very wide area and unit pressure is greatly reduced. Also compression stress (*DX*) in adjacent bones is reduced. *In adduction* the increased joint space creates depression which sucks fluid from joint cartilage, deflates capsule, and reduces compression stress on adjacent bones. Alternation of *abduction* and *adduction* creates hydrodynamic massage on cartilage and bone, helping their healing. The *CS* (fulcrum) ultimately wears out because of tremendous pressure on it. It becomes molded into a more rounded surface (convex on head, concave on socket) covered by fibrocartilage. The progressive healing of the joint is also due to the fact that resultant force *R* is also reduced by the medial position of *CS*, which increases the length of abductor lever arm

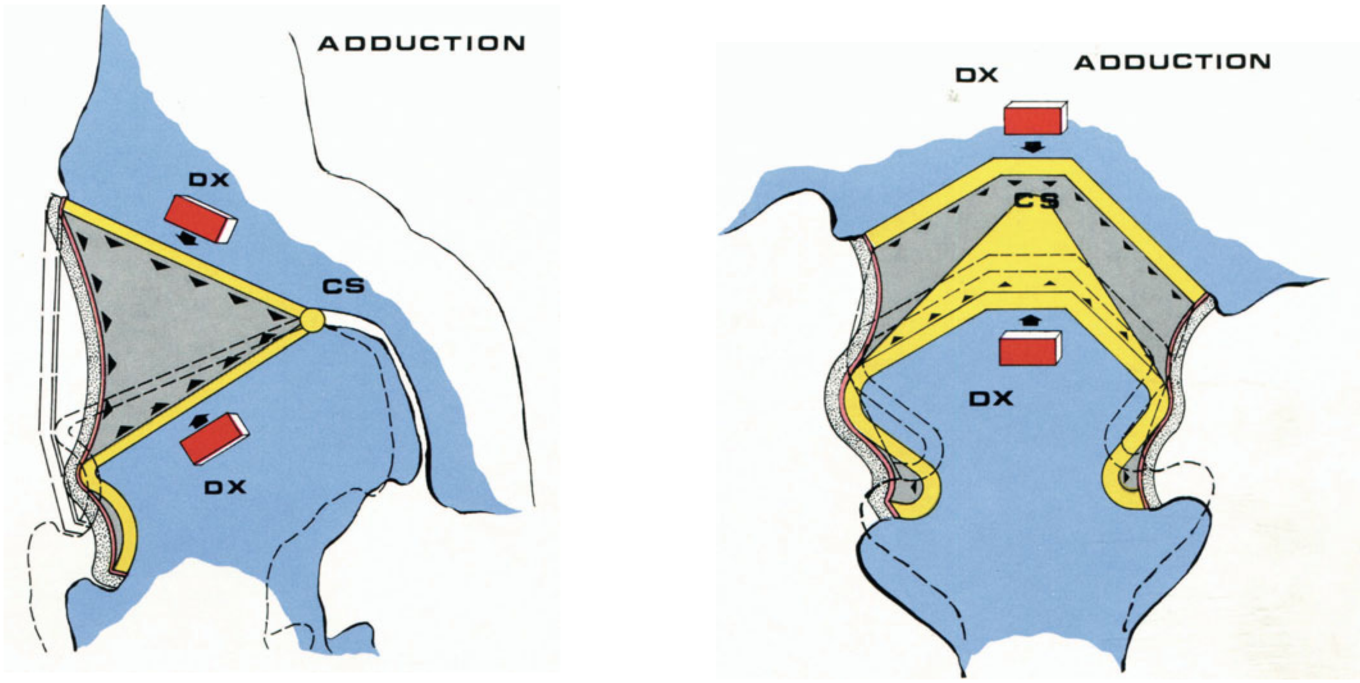


Fig. 49 (continued). Legend see opposite page

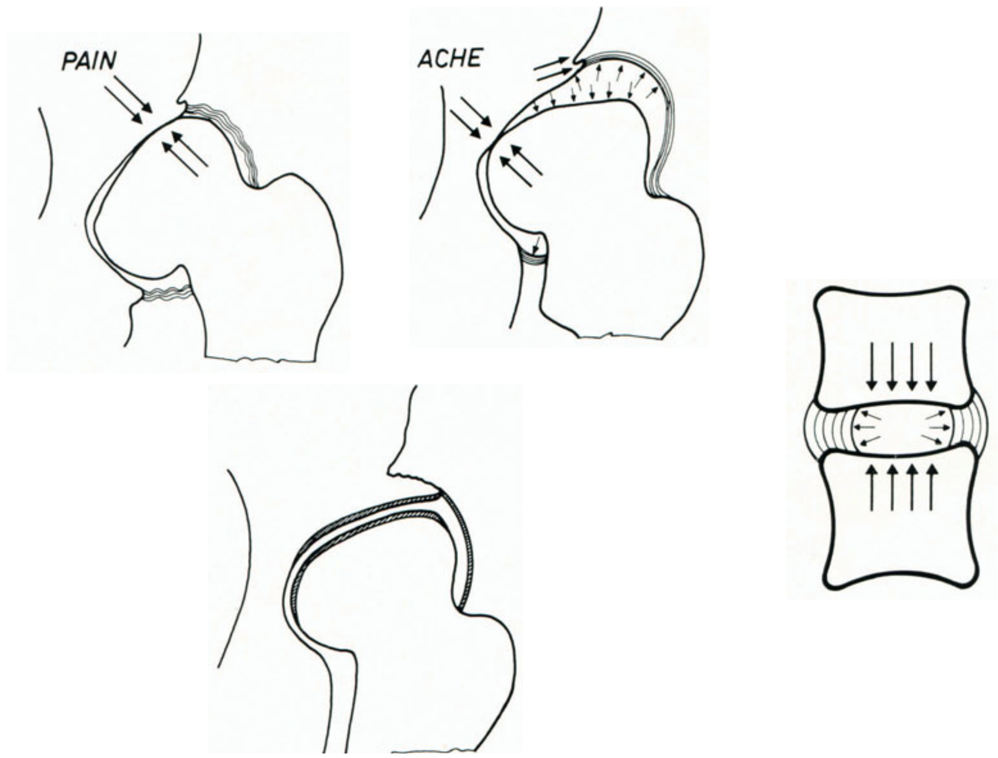


Fig. 50. The hydraulic mechanism, exploited by nature in a normal spine, is exaggerated in hip with osteoarthritis after valgus osteotomy of 30° or more. Nature repeats the physical phenomenon adopted in intervertebral disc. Excrutiating pain present before the operation, because joint surface is well innervated, changes to an inconstant ache after osteotomy. This is due to the fact that the new contact area is without innervation, being formed by osteophytes, which become the fulcrum of movement. Active movement rubs osteophytes against one another and they become round (one convex, the other concave). At the same time, new layers of fibrocartilage appears on head of femur and on acetabulum. A new joint is formed. The aim of a real biological arthroplasty is realized by the operation

2. Indication for Valgus-Extension Osteotomy

The femoral valgus-extension osteotomy is indicated in osteoarthritis of the hip when movement is still retained.

The term movement refers to a certain passive mobility of the hip joint, which can be obtained on the operating table, when the patient is anesthetized.

The amount of the active or passive movement available in the hip of a conscious patient is not decisive.

If we wish to increase a limited movement, a cautious, forced mobilization may be carried out.

With a passive movement of about 30° of flexion and of 15° of adduction of the hip, a valgus osteotomy may be performed. The absence of abduction is not a contra-indication.

When adduction is reduced because of one or more large osteophytes (capital drop, floor osteophyte, or inferior cervical osteophyte), it can be increased during the operation by removing the excessive part of the osteophytes.

The osteotomy is useless in the absence of movement or in the presence of an extremely restricted passive movement. In these cases spontaneous fusion, after an osteotomy, occurs (Fig. 90). When no movement is present, there are two solutions:

1. An arthrodesis, indicated if the correct conditions are present, particularly for young patients.
2. A total hip replacement, particularly in patients with a short life expectancy.

In our experience, in a developed osteoarthritis of the hip the valgus-extension osteotomy is "the operation" for two reasons:

1. When the disease starts at the superior part of the weight-bearing joint surface, in which force S is present, the valgus-extension osteotomy not only widens the area of the weight-bearing surface, increasing the volume of the osteophytes, but builds up or hypertrophies the roof osteophyte. This osteophyte makes the direction of the weight-bearing joint surface horizontal, causing the force S to disappear and the force Q to reappear. The roof osteophyte acts as a "stopper".

2. When patients, who have been operated on with an osteotomy, have not had good results, in most cases they were treated with a varus osteotomy. These patients, reoperated on with a valgus-extension osteotomy, are all healed (Fig. 51).

3. Evolution of the Technique of the Valgus Osteotomy

The technique we are using at the moment for the valgus-extension osteotomy is the result of about 13 years of experience. We started with the simple removal of bone wedge of 10 or 15°. Using a tracing of the head and socket outlines taken from X-rays, we chose the angle which would give congruence between the femoral head and the acetabulum.

(We had been taught this method by Pauwels, 1963–1973.) This angle was usually between 10° and 15°.

After the osteotomy, the superior part of the femur appeared shaped like a humerus. This was a mistake, because by doing so we decreased the muscular moment and therefore increased the resultant force R. A certain degree of valgus in the knee was not infrequent. Later on we realized two facts: *first* that congruence in the drawings of the two components of the joint was not important in the planning of the operation because congruence would normally result from the building up of osteophytes when a valgus of 30°–35° osteotomy was performed; *second* that the direction of force S is not only craniolateral, but also anterior, and the anterior direction makes the frontal part of the head press against the acetabulum.

For these reasons we started taking a bony wedge of 30°–35° with a larger posterior base in order to extend the head of the femur at the same time.

The constant appearance or increase in size of the capital drop, tent osteophyte, and roof osteophyte after such an osteotomy suggested to us the important roles played by the ligamentum teres, by the superior zone of the capsule, and by the synovial membrane.

The removal of a large wedge caused, in some cases, a lengthening of the limb. When the limbs had been equal before the operation we removed, in suitable cases, a part of the shaft, according to the magnitude of the angle of the wedge and the eomparative length of the limbs.

The greater trochanter was chiseled off and both the bony wedge and the ring-like fragments, taken from the shaft, were inserted under it to relax the medius gluteus and to increase as much as possible the muscular lever arm.

We have always considered solid internal fixation important because it allows early movement of the hip, ambulation of the patient, and easier nursing care, as well as self care. We have found that the AO angled osteotomy plates were the most effective because they permit not only the valgus but also the extension to be easily obtained at the same time. As we improved our technique, we realized that the 130° angled plate with a very long blade (85-90-100-110 mm) was the most suitable. The length of the blade permits the shaft to be shifted as laterally as possible. In this way we prevented valgus in the knee.

A long "cortical AO screw," gripping the cortex of the ADAM's arch, was also important to prevent the blade from slipping out.

4. Present Technique of Valgus-Extension Osteotomy

The technique must be precise and achieve these aims:

1. To reduce the resultant force *R*
2. To stimulate the building up of the capital drop, tent osteophyte, and roof osteophyte
3. To reduce the pressure on the anterocraniolateral part of the head of the femur
4. To avoid any lengthening of the femur
5. To exploit the hydraulic mechanism
6. To avoid a valgus in the knee.

The operation has to be carefully planned and carried out (Figs. 52, 62 and 63).

The patient is positioned flat on the operating table (an ordinary operating table without any special features). The positioning should be such that the fat and skin about the hip tend to "hang" a little over the side of the table.

The WATSON-JONES approach, with a skin incision of 30 cm in length is used. Detachment of vastus lateralis from the lateral intermuscular septum allows a wide inspection of the upper part of the femur.

Detachment of the greater trochanter with a chisel releases the gluteus medius, but care must be taken to preserve the anterior and the posterior fibres of this muscle. By doing so a pouch is created, into which, later on, the bone rings and the bone wedge of 30° or more that have been removed can be inserted.

Care must also be taken not to disturb the distal fibres of the superior capsule in order to obtain good tension on the acetabular roof later on (Fig. 53).

To allow the capital drop and the tent osteophyte to act as a fulcrum that holds the lateral part of the head and of the acetabulum wide apart, the adductor muscles must not be cut.

When using an AO 130° angled plate, the chisel for preparing the blade channel must be introduced into the neck of the femur at an angle, in the frontal plane, of 80° to the axis of the shaft, to obtain a valgus of 30°. To obtain extension the angle of the chisel must be 15°—20° in the sagittal plane, depending on the individual case (Fig. 54a).

This is the "essence" of the operation. The success or failure rests on the absolute perfection and precision of this step. To obtain a valgus osteotomy of planned value and to avoid differences in length of the limbs after the operation, we measure the length of the limbs before the operation under anesthesia. We then read from the table how much shortening or lengthening will be obtained from the operation (Figs. 55—60).

If it is calculated that after the operation a lengthening of 0.5—1—1.5—2 cm or more will be obtained, not only is the bone wedge but also a bone cylinder of corresponding amount, removed from the shaft. If possible, this cylinder is removed as two bone rings.

The tendon of the ileopsoas muscle is always divided to reduce the permanent tension.

When the AO plate is inserted, a long cortical screw, gripping the ADAM's arch, is fixed into the metaphysis, passing through a hole in the plate. The shaft is shifted downward and laterally and fixed with four screws after having been compressed against the metaphysis with the AO compression device. The long cortical screw prevents the blade from slipping out during the compression of the bony fragments. The bony wedge and bony rings are placed into the pouch of the detached greater trochanter. To keep the greater trochanter and the bony fragments in place, three or four stitches of Dacron or similar material in the vastus lateralis are enough. Sometimes, after removal of the bony wedge and the bony rings, before inserting the angled plate, it is necessary to chisel off superfluous parts of the capital drop and inferior cervical osteophyte, in order to allow the head to rotate.

We use three suction drains for 48 hours, but neither anticoagulants nor antibiotics on a prophylactic basis. The patient may move freely in bed the day after the operation and, after 5 days, he may walk with two crutches.

When he walks, he must set one foot directly in front of the other, like a mannequin. In this way he stretches the ligamentum teres and the superior zone of the joint capsule. The patient is encouraged to exercise the limb and the body as much as possible, avoiding full weight bearing for about 6 months by using two crutches and sometimes using one crutch for a further 2 or 3 months (Fig. 61).

How to Plan a Valgus-Extension Osteotomy

To calculate the amount of valgus and the amount of extension necessary and to calculate the length of the femur after the operation, it is recommended that the procedure be prepared exactly.

For the Valgus

From an anteroposterior X-ray of the hip, on which the axis of the shaft is dotted, an outline of the head, neck and metaphysis, and part of the shaft of the femur, is drawn on tracing paper marking the axis of the shaft.

The tracing of the head, superimposed on the original X-ray, is turned outwards in the socket till the capital drop comes into contact with the tent osteophyte of the socket. Now is determined the angle formed by the axis of the shaft on the X-ray and the axis of the shaft on the tracing: this is the necessary angle of valgus.

If congruence is not obtained, this is not a problem, because the joint surface of the acetabulum and of the femoral head will fit reciprocally after the operation.

For the Extension

From an axial X-ray of the hip (not always easy to get) on which the axis of the femoral head is dotted, an outline of the head, neck, and greater trochanter is drawn on tracing paper, marking the axis of the neck. The tracing of the head, superimposed on the original X-ray, is turned backward in the socket until the posterior part of the capital drop comes into contact with the posteroinferior part of the socket. The angle formed by the two axes is determined: this is the necessary extension angle.

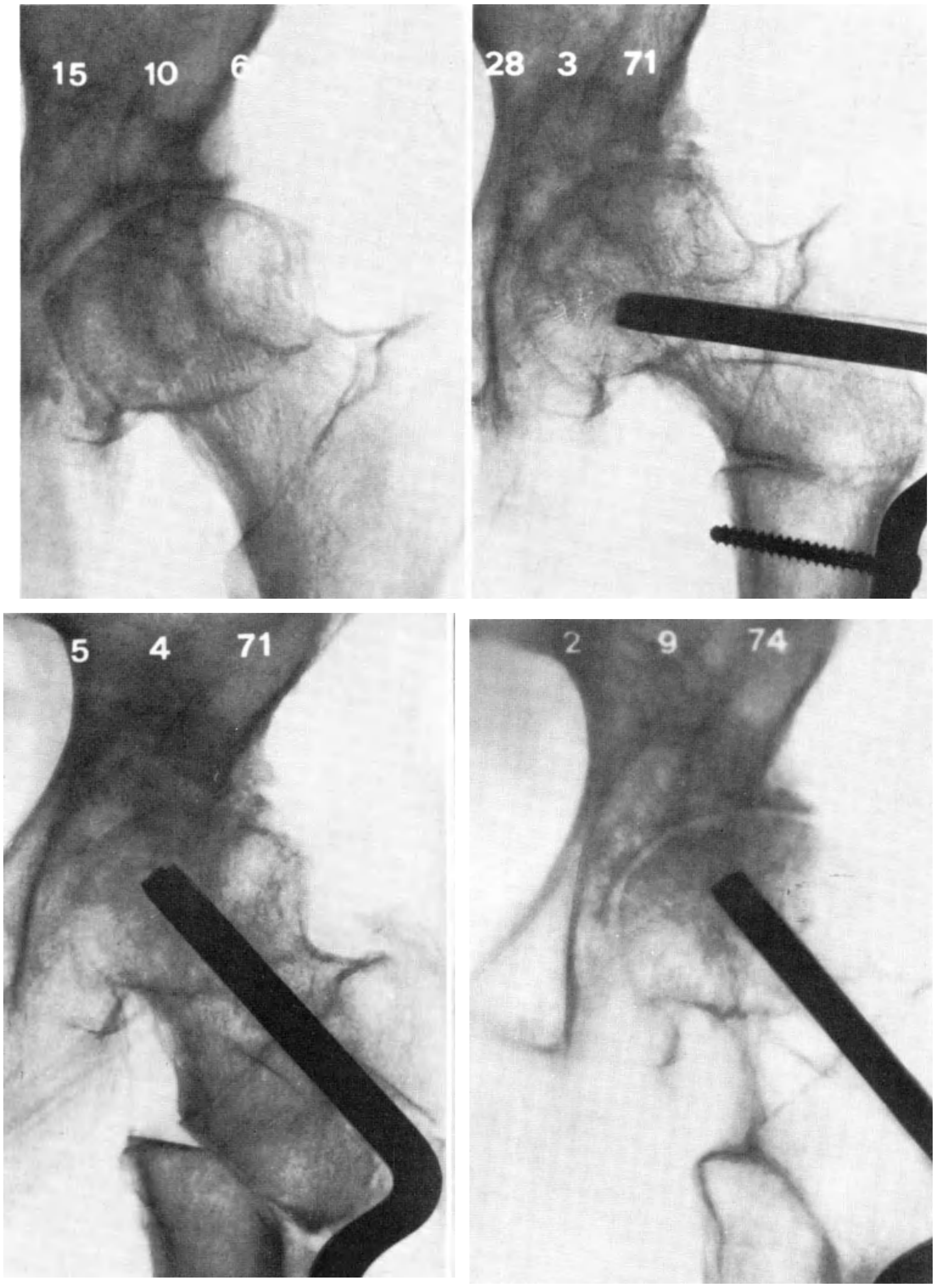
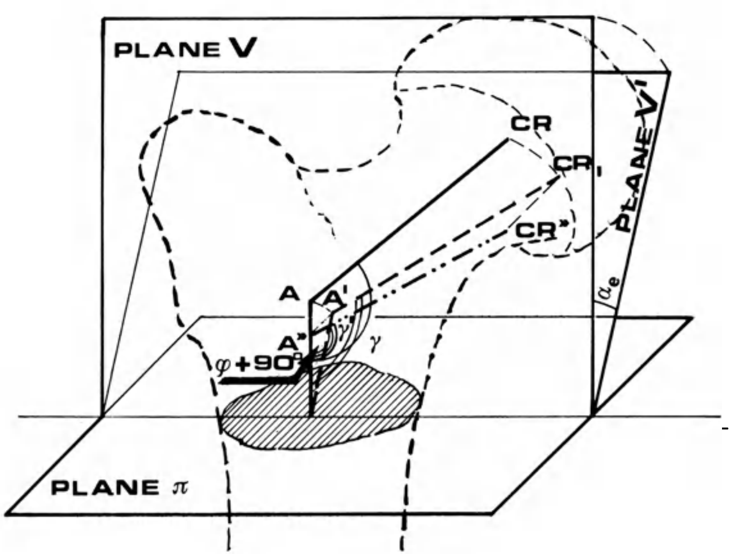
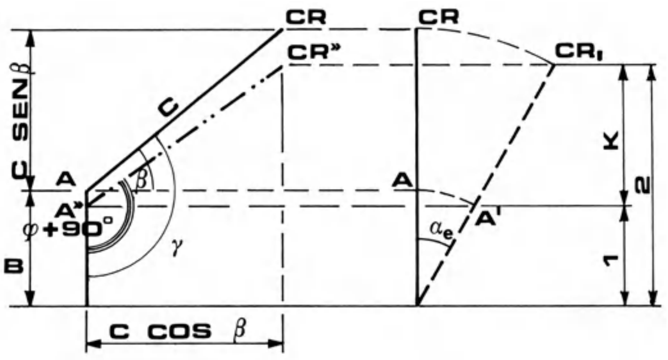


Fig. 51. Legend see opposite page

HOW EXTENSION AFFECTS THE SHAFT-NECK ANGLE





α_e = ANGLE OF EXTENSION

$$\operatorname{tg}\varphi = \operatorname{tg}\beta \cos\alpha_e$$

$$\beta = \gamma - 90^\circ$$

$$K = 2 - 1$$

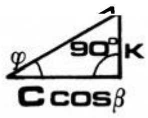
$$1 = B\cos\alpha_e$$

$$2 = (B + C\,\mathrm{sen}\,\beta)\cos\alpha_e$$

$$K = (B + C\,\mathrm{sen}\,\beta)\cos\alpha_e - B\cos\alpha_e$$

$$K = C\,\mathrm{sen}\,\beta\cos\alpha_e$$

$$\operatorname{tg}\varphi = \frac{C\,\mathrm{sen}\,\beta\cos\alpha_e}{C\cos\beta}$$



$$\operatorname{tg}\varphi = \frac{K}{C\cos\beta}$$

STARTING VALUE OF SHAFT-NECK ANGLE	FINAL VALUES OF SHAFT NECK ANGLE (φ+90°) AFTER EXTENSION										
0°	10°	15°	20°	25°	30°	40°	50°	60°	70°	80°	90°
160°	159° 43'	159° 21'	158° 50'	158° 07'	157° 12'	154° 35'	150° 29'	143° 57'	133° 13'	115° 30'	90°
150°	149° 37'	149° 08'	148° 26'	147° 30'	146° 19'	143°	138° 04'	130° 54'	120° 39'	106° 45'	90°
140°	139° 34'	139° 01'	138° 14'	137° 13'	135° 54'	132° 24'	127° 27'	120° 47'	112° 11'	101° 41'	90°
130°	129° 34'	129° 01'	128° 15'	127° 15'	126°	122° 44'	118° 20'	112° 46'	106°	98° 17'	90°
120°	119° 37'	119° 09'	118° 29'	117° 37'	116° 34'	113° 51'	110° 21'	106° 06'	101° 10'	95° 43'	90°
110°	109° 48'	109° 22'	108° 53'	108° 15'	107° 30'	105° 35'	103° 10'	100° 19'	97° 06'	93° 37'	90°
100°	99° 51'	99° 40'	99° 24'	99° 05'	98° 41'	97° 41'	96° 28'	95° 02'	93° 27'	91° 45'	90°

Fig. 52. By doing combined valgus and extension osteotomy, a valgus correction, which is less than we intended, is obtained. This is due to the fact that extension causes at the same time a reduction of CCD angle. To overcome this difference we must perform a more accentuated valgus varying the angle, according to angle of extension performed. We have a table available, from which we can obtain the amount of loss of valgus, according to amount of extension. For instance, before the operation CCD angle is 120° and it is necessary to perform a 30° valgus-30° extension osteotomy. In the end actual CCD angle is 146.19°, not 150°, losing about 4° of valgus. Therefore a valgus of 34° is necessary

---

◁ **Fig. 51.** R.P., age 58. *15–10–68* Osteoarthritis of left hip. *28–3–71* 2 years, 5 months after varus osteotomy of 20°. The result is disappointing, because head was not spherical. Disease has progressed; hip is stiff and painful. *5–4–71* 1 week after valgus osteotomy of 35°. *2–9–74* 3 years, 6 months after operation. Hip is not painful and has full movement. Patient walks normally.
Varus osteotomy has pivoted head on a fulcrum in the more painful joint area (superolateral surface) of acetabulum. Whereas, in contrast, joint space in inferior-medial zone has widened. This is due to the fact that the head was not perfectly spherical. The valgus osteotomy, instead, stretching ligamentum teres, has increased capital drop and formed tent osteophyte and, stretching superior part of capsule and its synovial membrane, has hypertrophied roof osteophyte

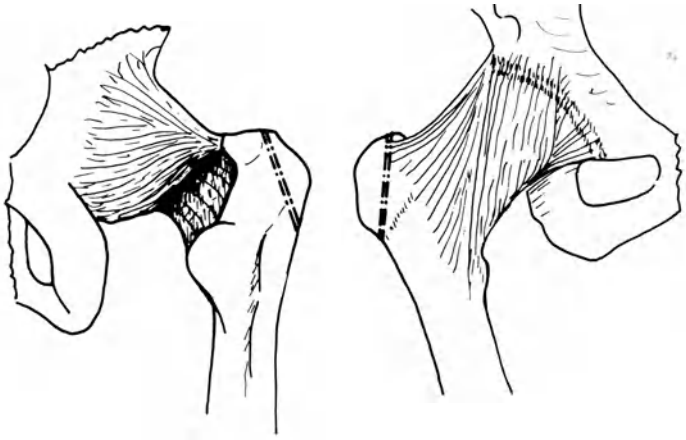


Fig. 53. How to resect the greater trochanter. Superior distal capsular fibres must be left undisturbed when greater trochanter is chiselled off. In this way, after osteotomy, fibres of superior zone of capsule become tense and build up roof osteophyte

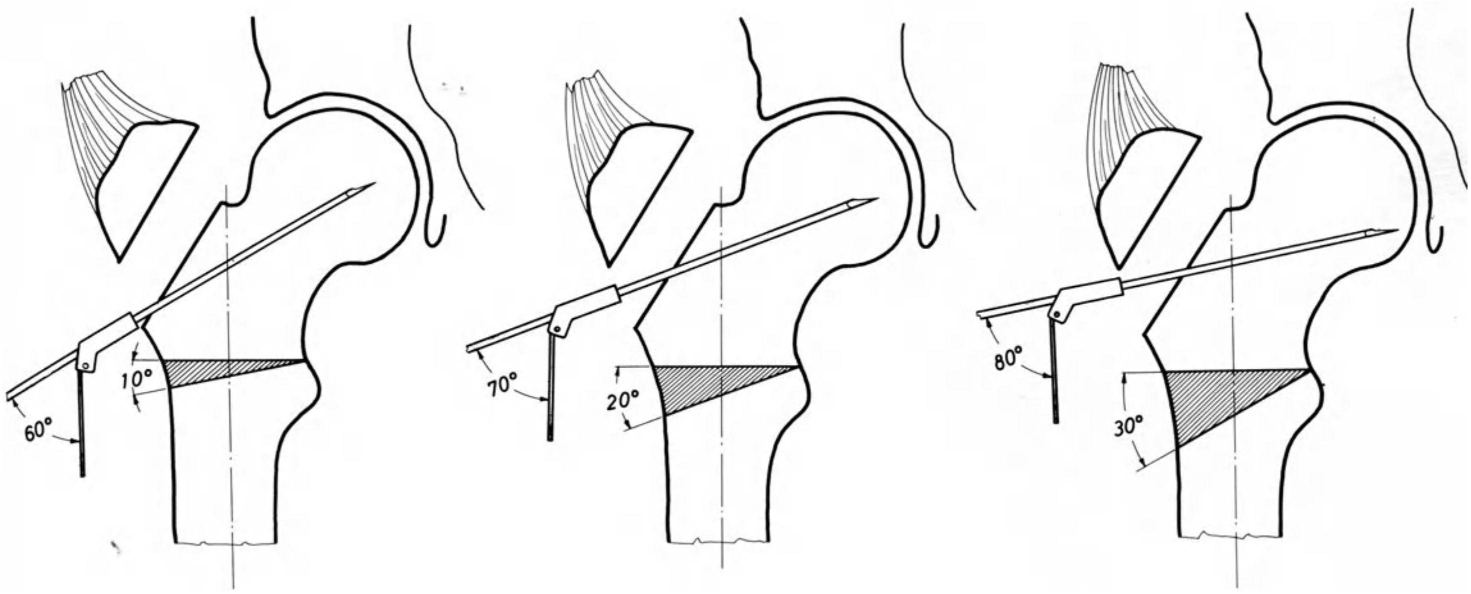


Fig. 54a. This figure shows how to insert the chisel to prepare the blade channel in valgus osteotomy using an AO angle plate of 130°. Angle formed by direction of chisel and shaft of femur must be: supplementary angle (50°) plus angle of bone wedge to be removed.

For a valgus of 30° the chisel-shaft angle must be 50° + 30° = 80°
For a valgus of 20° the chisel-shaft angle must be 50° + 20° = 70°
For a valgus of 10° the chisel-shaft angle must be 50° + 10° = 60°

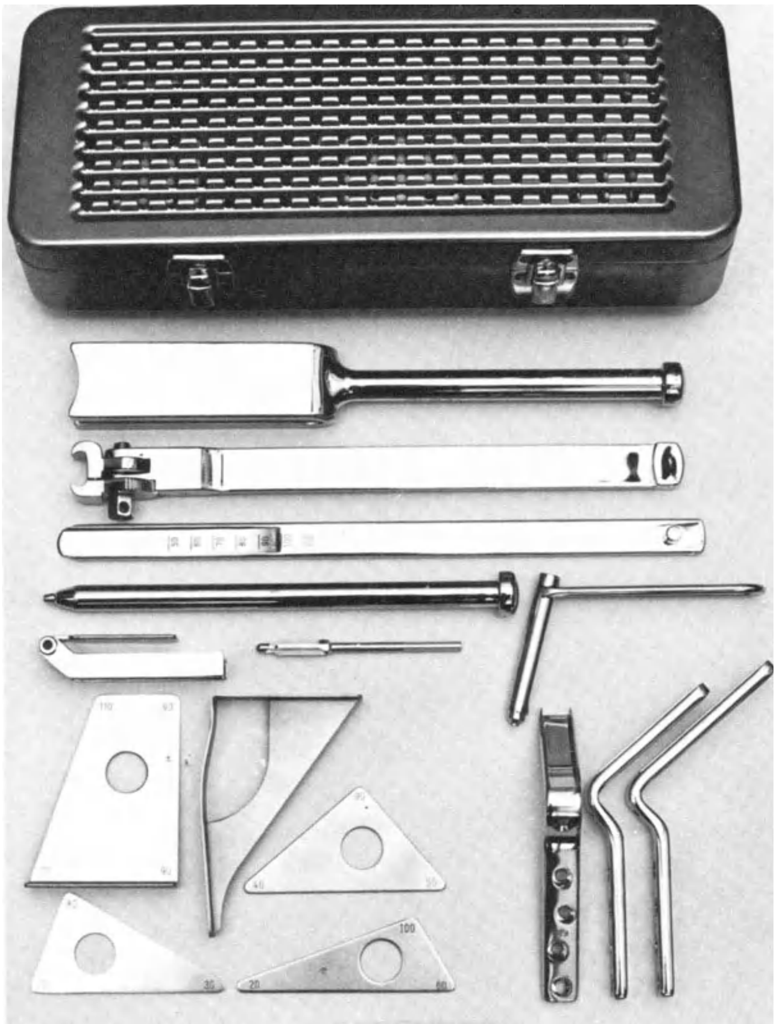


Fig. 54b. Instruments used by us and considered to be most suitable for such an operation are AO instruments illustrated shown here

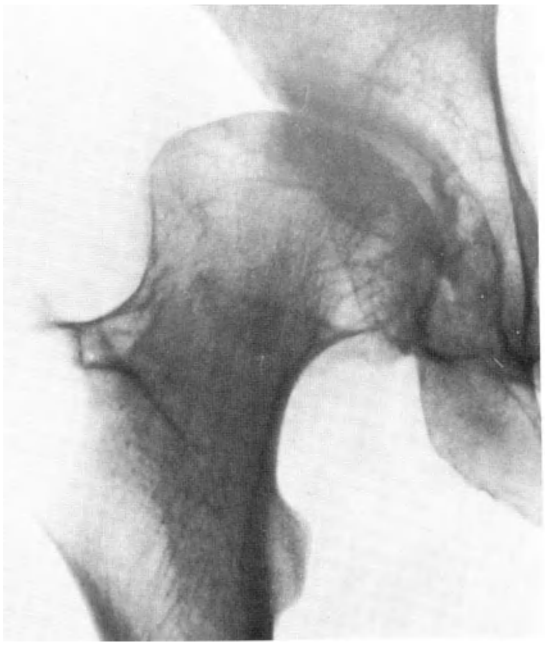
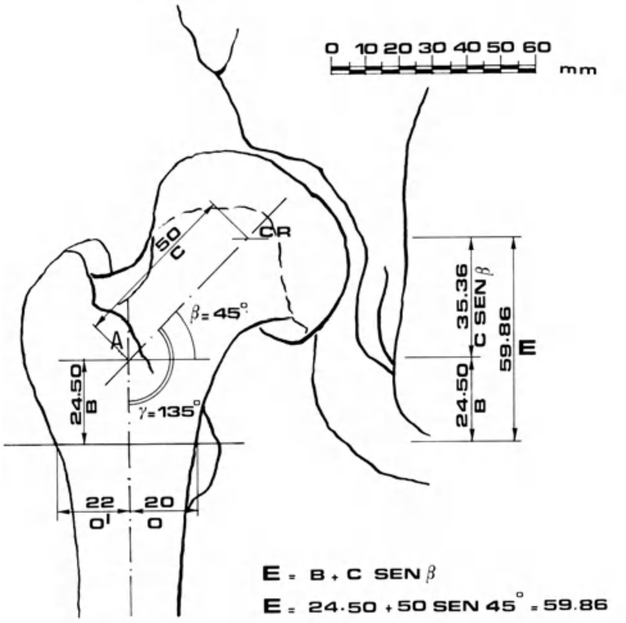


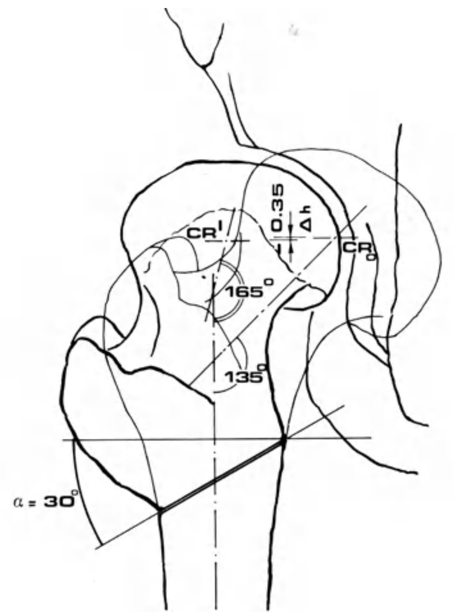
Fig. 55. Mathematical formulae are available to calculate length of the femur after the operation. On tracing paper is drawn the outline of the proximal part of femur, taken from anteroposterior X-ray. Center of rotation of femoral head *CR* is determined. We consider femoral head previous to the process of osteoarthritis. In fact, looking attentively at anteroposterior X-ray, the outline of original head looms out. Axes of the shaft and neck are marked, which at their point of intersection (*A*) form an angle γ, which is called CCD angle. About 2.5 cm below (*B*), the horizontal cut of osteotomy is traced. Length of the neck is called C. This is the distance between points *A* and *CR*. Angle γ less 90° is called β. Angle of valgus previously calculated with our tracing is called α. *E* is vertical distance between *CR* and plane through horizontal cut osteotomy. O'' is width of metaphysis at the level of horizontal cut. Usually axis of shaft cuts this width into two different parts O' and O. D'' is thickness of metaphysis at the level of horizontal cut. D' and D are two different parts of D''. Figure helps us to fix key-points of our hip and to use formulae according to type of valgus osteotomy. Removing a complete bony wedge, we can either displace shaft of femur laterally or not. From formulae we can calculate $E\alpha$ – that is the new vertical distance between *CR* and the plane through horizontal cut of osteotomy. The previous distance *E* is compared to $E\alpha$ and difference in height Δh is obtained.
X-ray is taken at 1 m distance: focus/film and at 20 cm of distance: femur/film. With these distances the magnification rate is 1.125:1. Final result Δh must, therefore, be divided for 1.125
Table. Symbols and values used in the graphs and when calculating Δh (difference in height of the centres of rotation)



$E = B + C \text{ SEN } \beta$

$E = 24.50 + 50 \text{ SEN } 45^\circ = 59.86$

NO SHAFT DISPLACEMENT



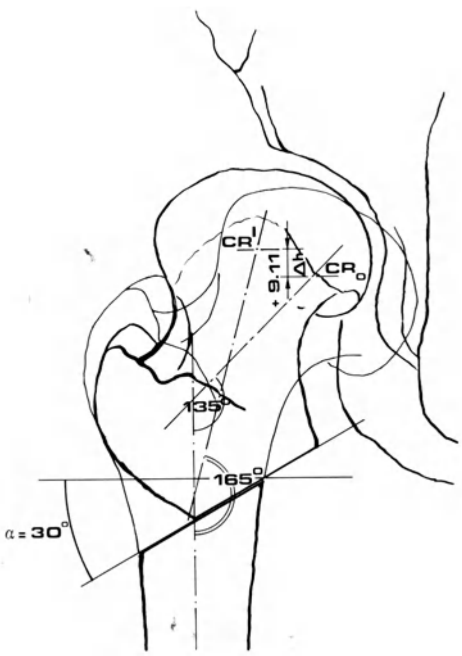
$E\alpha = B \text{ COS } \alpha + C \text{ SEN}(\beta + \alpha) - O \text{ SEN } \alpha$

$E\alpha = 24.5 \text{ COS } 30^\circ + 50 \text{ SEN } (45^\circ + 30^\circ) -$

$- 20 \text{ SEN } 30^\circ = 59.51$

$\Delta h = 59.51 - 59.86 = -0.35$

1/2 SHAFT DISPLACEMENT



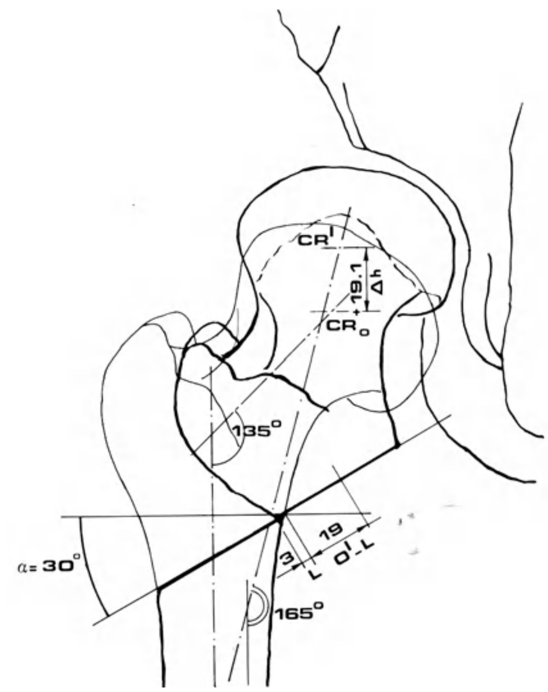
$E\alpha = B \text{ COS } \alpha + C \text{ SEN}(\beta + \alpha) + O' \text{ SEN } \alpha - O \text{ TG } \alpha$

$E\alpha = 24.5 \text{ COS } 30^\circ + 50 \text{ SEN}(45^\circ + 30^\circ) +$

$+ 22 \text{ SEN } 30^\circ - 20 \text{ TG } 30^\circ =$

$\Delta h = 68.97 - 59.86 = +9.11$

COMPLETE SHAFT DISPLACEMENT



$E\alpha = B \text{ COS } \alpha + C \text{ SEN}(\beta + \alpha) + (O' - L) \text{ SEN } \alpha$

$E\alpha = 24.5 \text{ COS } 30^\circ + 50 \text{ SEN}(45^\circ + 30^\circ) +$

$+ (22 - 3) \text{ SEN } 30^\circ = 79.01$

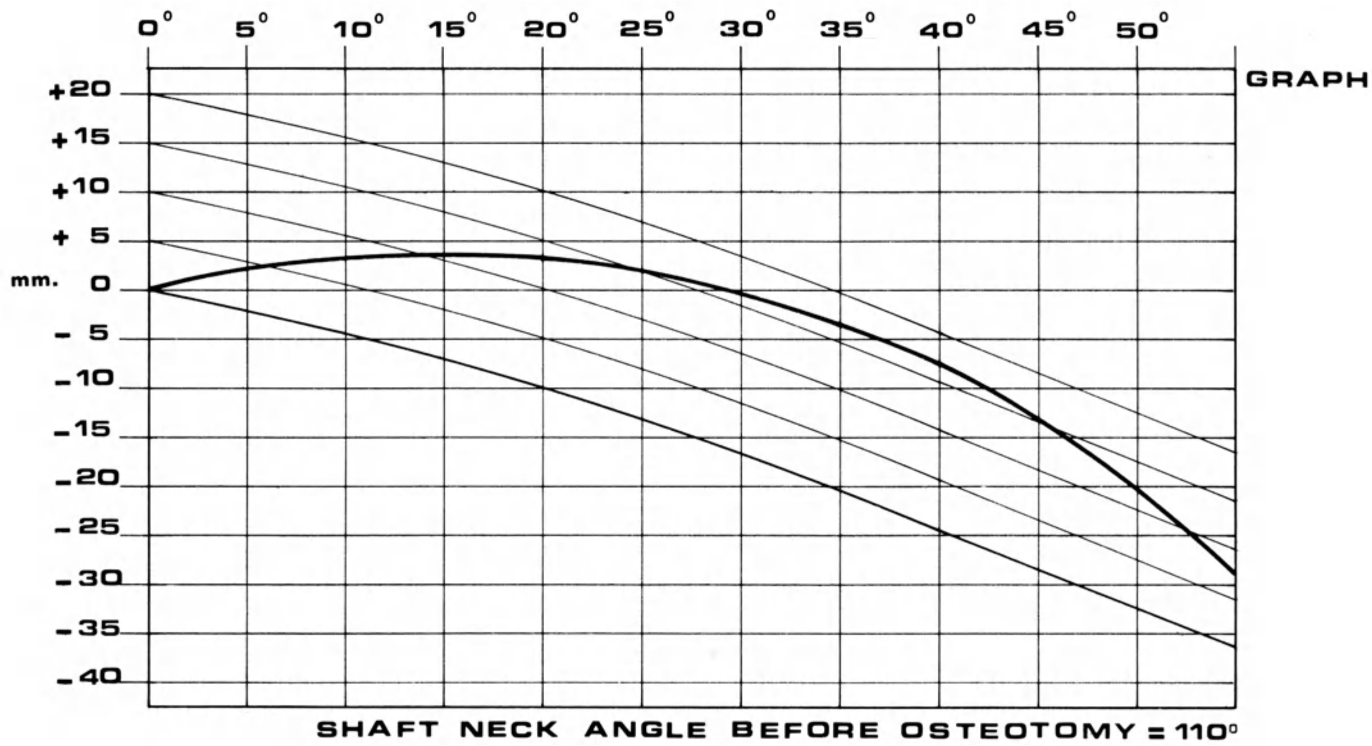
$\Delta h = 79.01 - 59.86 = +19.15$

Fig. 55 (continued). Legend see opposite page

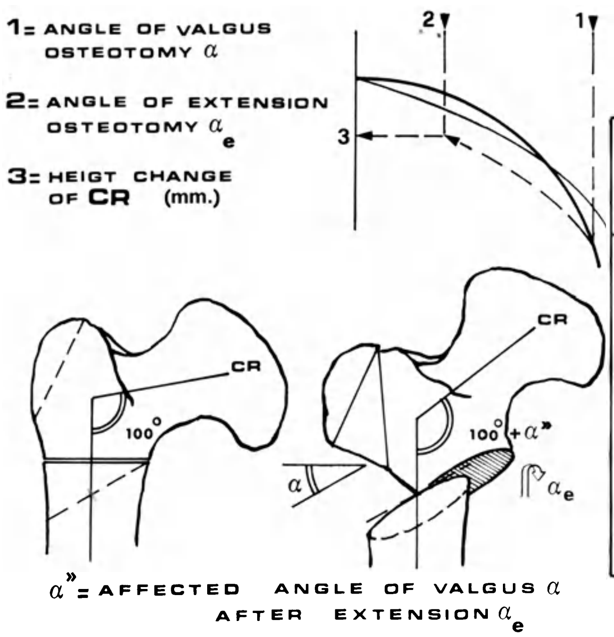
TABLE OF NATURAL FUNCTIONS			
DEGREES	SINE	COSINE	TANGENT
0°	0.00000	1.00000	0.00000
5°	0.08716	0.99619	0.08749
10°	0.17365	0.98481	0.17633
15°	0.25882	0.96593	0.26795
20°	0.34202	0.93969	0.36397
25°	0.42262	0.90631	0.46631
30°	0.50000	0.86603	0. 57735
35°	0.57358	0.81915	0.70021
40°	0.64279	0.76604	0.83910
45°	0.70711	0.70711	1.00000

TABLE OF NATURAL FUNCTIONS			
DEGREES	SINE	COSINE	TANGENT
45°	0.70711	0.70711	1.00000
50°	0.76604	0.64279	1.19175
55°	0.81915	0.57358	1.42815
60°	0.86603	0.50000	1.73205
65°	0.90631	0.42262	2.14451
70°	0.93969	0.34202	2.74748
75°	0.96593	0.25882	3.73205
80°	0.98481	0.17365	5.67128
85°	0.99619	0.08716	11.43006
90°	1.00000	0.00000	∞

Fig. 55 (continued). Legend see page 66



HOW TO READ THE GRAPH

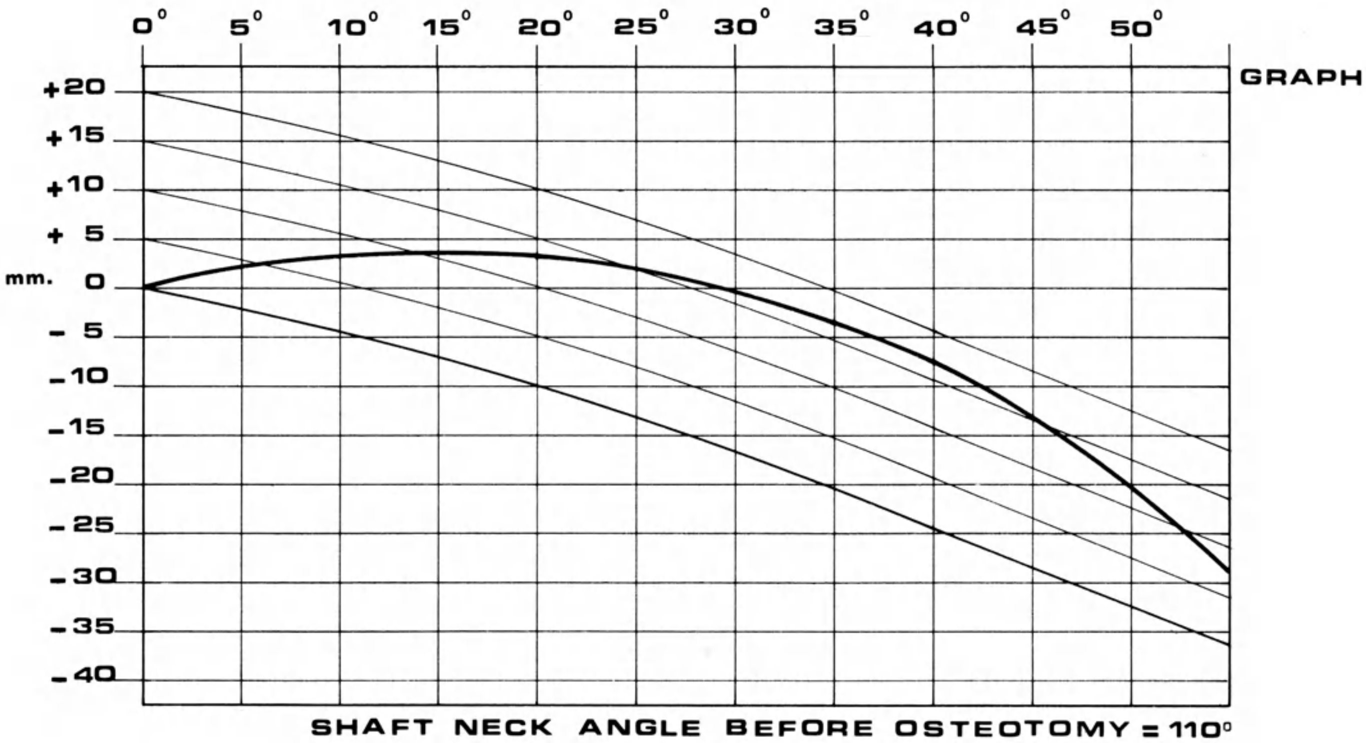


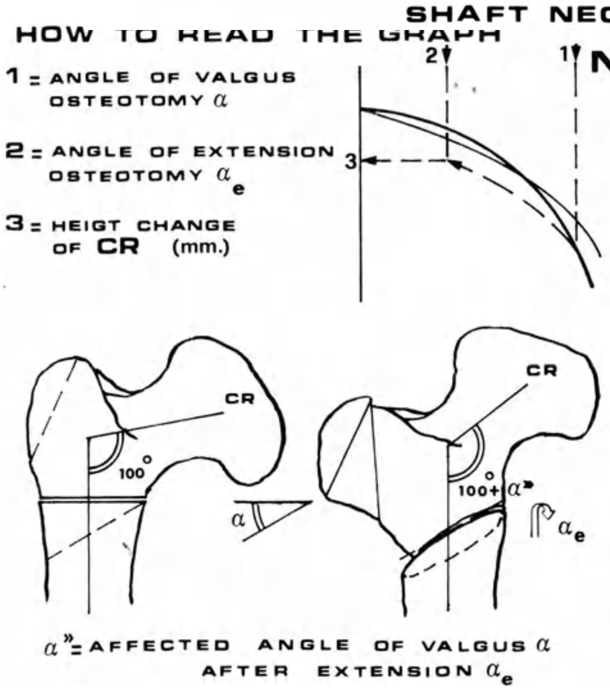
1/2 SHAFT DISPLACEMENT

TABLE

γ = 100°		ANGLE OF EXTENSION OSTEOTOMY						
		0°	10°	15°	20°	30°	40°	50°
ANGLE OF VALGUS OSTEOTOMY	0°	0.00	– 4.34	– 6.87	– 9.61	–15.63	–22.22	– 29.19
	10°	+ 8.30	+ 3.96	+ 1.43	– 1.31	– 7.33	–13.92	– 20.89
	15°	+11.87	+ 7.53	+ 5.00	+ 2.26	– 3.76	–10.35	– 17.32
	20°	+14.93	+10.59	+ 8.04	+ 5.32	– 0.70	– 7.29	– 14.26
	30°	+19.25	+14.91	+12.38	+ 9.64	+ 3.62	– 2.97	– 9.94
	40°	+20.49	+16.15	+13.62	+10.88	+ 4.86	– 1.73	– 8.70
	50°	+17.49	+13.15	+10.62	+ 7.88	+ 1.86	– 4.73	– 11.70

Fig. 56a. Alteration in length of the femur are shown with CCD angle of 100° by combined valgus-extension osteotomy when the shaft is laterally displaced for one-half of its width. Lateral displacement not only prevents valgus in the knee, but lengthens the femur. The greatest lengthening (20.49 mm) is obtained by simple valgus osteotomy of 40°. Without displacement of the shaft lengthening is 12.59 mm



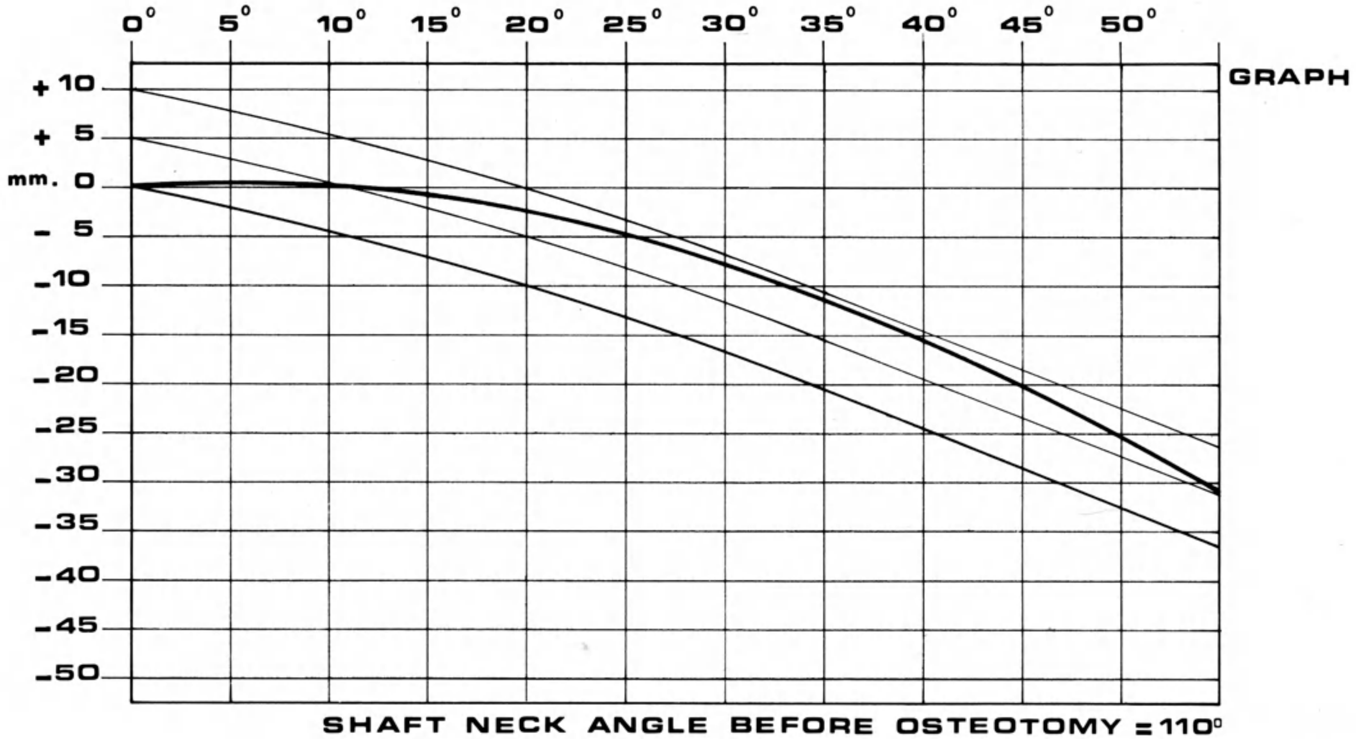


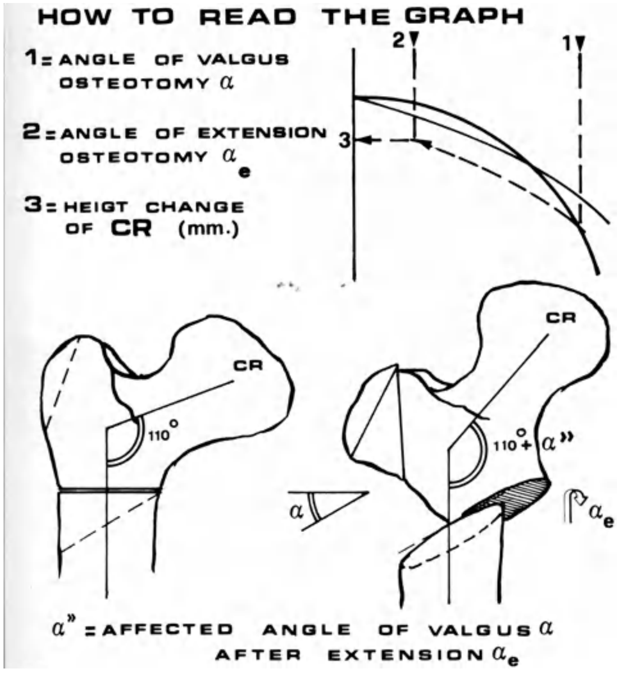
NO SHAFT DISPLACEMENT

TABLE

ANGLE OF VALGUS OSTEOTOMY (γ=100°)	ANGLE OF EXTENSION OSTEOTOMY 0°	10°	15°	20°	30°	40°	50°
0°	0.00	− 4.34	− 6.87	− 9.61	−15.63	−22.22	−29.19
10°	+ 5.06	+ 0.72	− 1.81	− 4.55	−10.57	−17.16	−24.13
15°	+ 7.15	+ 2.81	+ 0.28	− 2.46	− 8.48	−15.07	−22.04
20°	+ 8.92	+ 4.58	+ 2.05	− 0.69	− 6.71	−13.30	−20.27
30°	+ 11.45	+ 7.11	+ 4.58	+ 1.84	− 4.18	−10.77	−17.74
40°	+ 12.59	+ 8.25	+ 5.72	+ 2.98	− 3.04	− 9.63	−16.60
50°	+ 12.30	+ 7.96	+ 5.43	+ 2.69	− 3.33	− 9.92	−16.89

Fig. 56b. This figure shows alterations in length of the femur with CCD angle of 100° by combined valgus-extension osteotomy, when the shaft is not displaced. It is evident how much the extension causes shortening. For example: simple valgus osteotomy of 40° lengthens femur by 12.59 mm, but, when it is associated with extension of 30°, femur is shortened by 3.04 mm. The greatest lengthening (12.59 mm) is obtained by simple valgus of 40°. Zone of lengthening is marked in grey



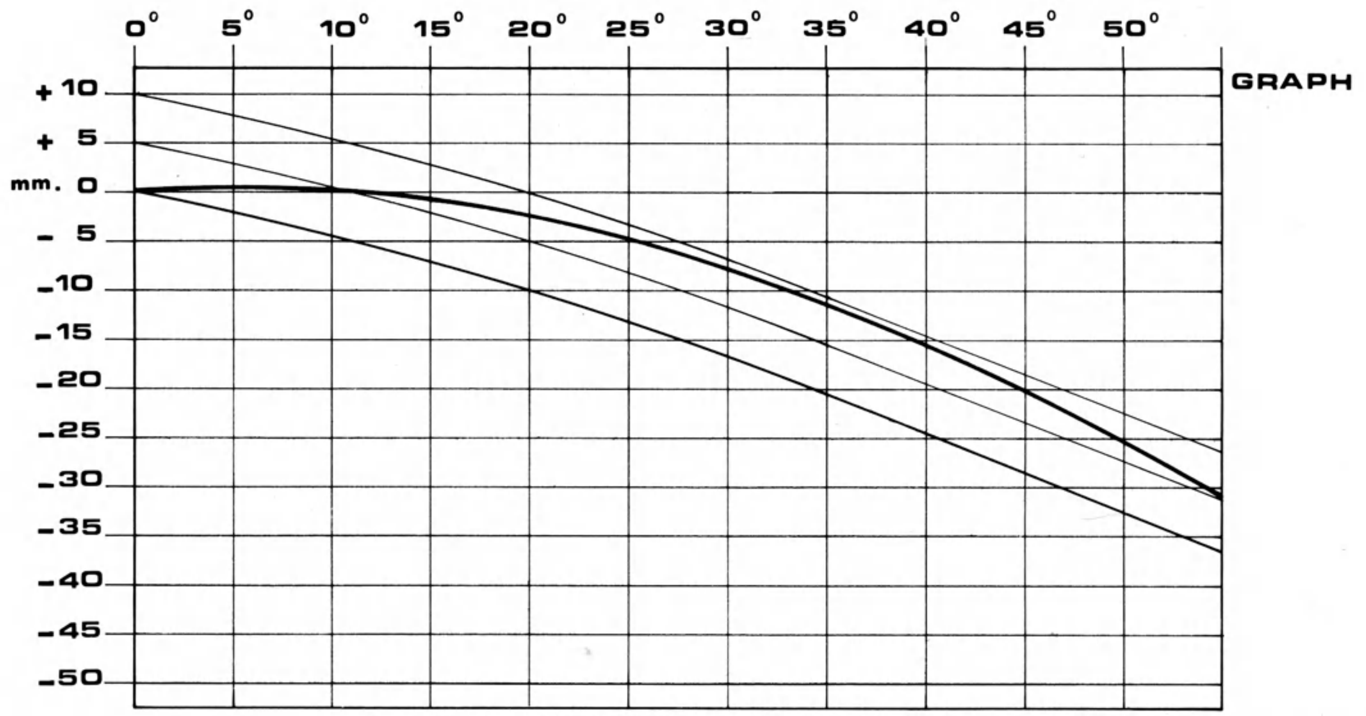


1/2 SHAFT DISPLACEMENT

TABLE

γ = 110°		ANGLE OF EXTENSION OSTEOTOMY						
		0°	10°	15°	20°	30°	40°	50°
ANGLE OF VALGUS OSTEOTOMY	0°	0.00	– 4.48	– 7,19	–10.17	–16.87	–24.39	–32.50
	10°	+ 7.73	+ 3.25	+ 0.54	– 2,44	– 9.14	–16.66	–24.77
	15°	+10.91	+ 6.43	+ 3.72	+ 0.74	– 5,96	–13.48	–21,59
	20°	+13.53	+ 9.05	+ 6.34	+ 3.36	– 3,34	–10.86	–18.97
	30°	+16.77	+12.29	+ 9.58	+ 6.60	– 0.10	– 7.62	–15.73
	40°	+16.73	+12.25	+ 9.54	+ 6.20	– 0.14	– 7.66	–15.77
	50°	+12.28	+ 7.80	+ 5.09	+ 2.11	– 4.59	–12.11	– 20.22

Fig. 57a. Alterations in length of the femur are shown with CCD angle of 110° by combined valgus-extension osteotomy when the shaft is laterally displaced for one-half of its width. The greatest lengthening (16.77 mm) is obtained by simple valgus osteotomy of 30°

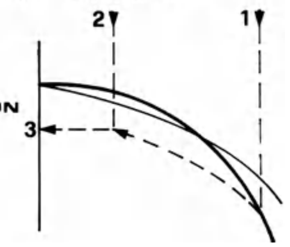


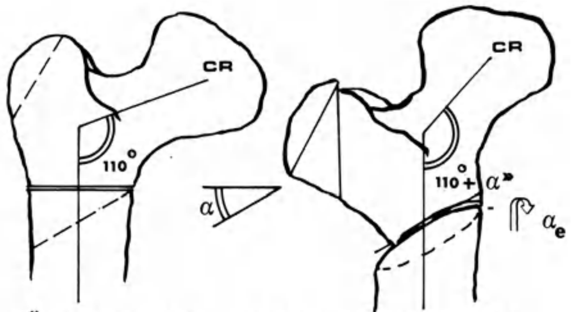
HOW TO READ THE GRAPH

1 = ANGLE OF VALGUS OSTEOTOMY α

2 = ANGLE OF EXTENSION OSTEOTOMY α_e

3 = HEIGT CHANGE OF CR (mm.)





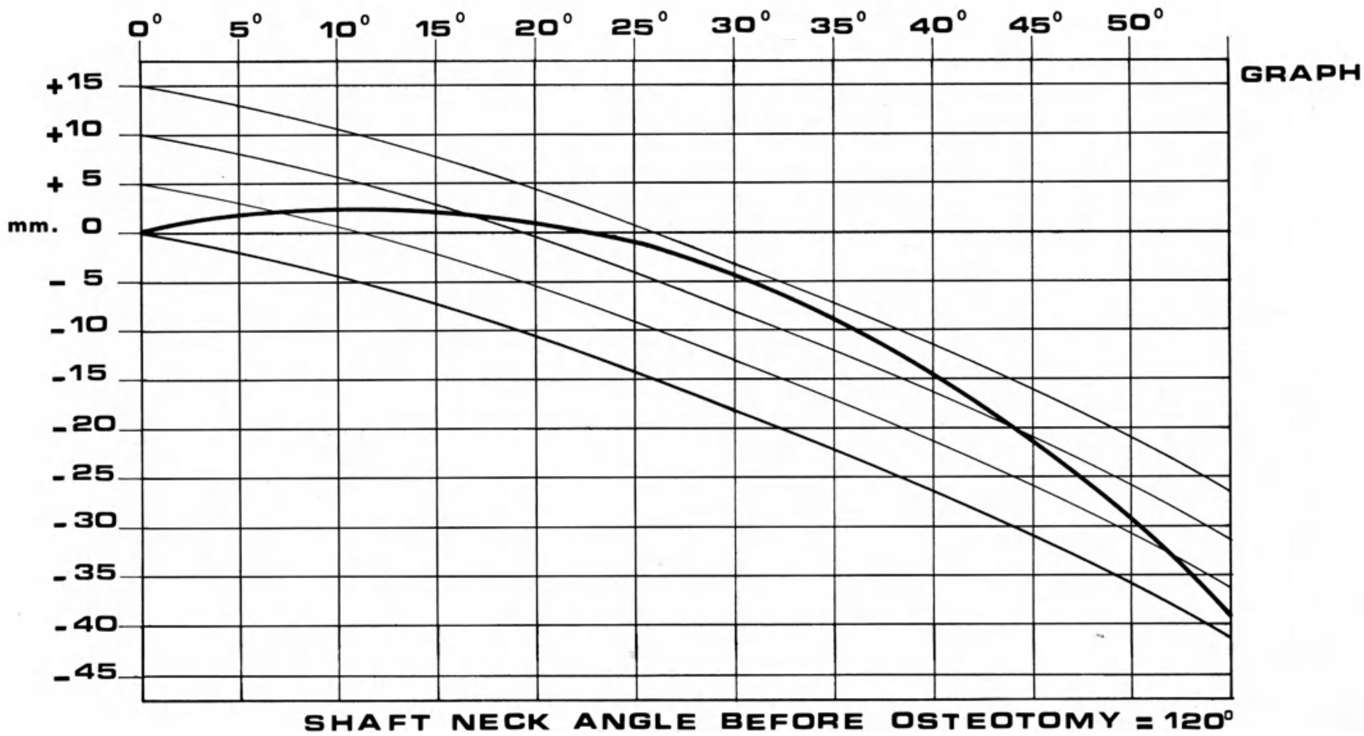
α" = AFFECTED ANGLE OF VALGUS α AFTER EXTENSION α_e

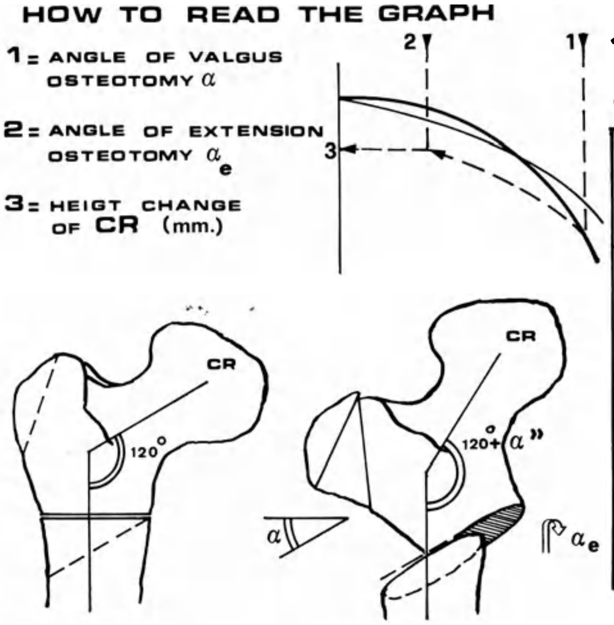
NO SHAFT DISPLACEMENT

TABLE

γ = 110		ANGLE OF EXTENSION OSTEOTOMY						
		0°	10°	15°	20°	30°	40°	50°
ANGLE OF VALGUS OSTEOTOMY	0°	0.00	– 4.48	– 7.19	–10.17	–16.87	–24.39	–32.50
	10°	+ 4.49	+ 0.01	– 2.70	– 5.68	–12.38	–19.90	– 28.01
	15°	+ 6.19	+ 1.71	– 1.00	– 3.98	–10.68	–18.20	– 26.31
	20°	+ 7.51	+ 3.03	+ 0.32	– 2.66	– 9 36	–16.88	– 24.99
	30°	+ 8.97	+ 4.49	+ 1.78	– 1.20	– 7.90	–15.42	– 23.53
	40°	+ 8.83	+ 4.35	+ 1.64	– 1.34	– 8,04	–15.56	– 23.67
	50°	+ 7.09	+ 2.61	– 0.10	– 3.08	– 9.78	–17.30	– 25.41

Fig. 57b. Alterations in length of the femur are shown with CCD angle of 110° by combined valgus-extension osteotomy, when the shaft is not displaced. The greatest lengthening (8.97 mm) is obtained by simple valgus osteotomy of 30°



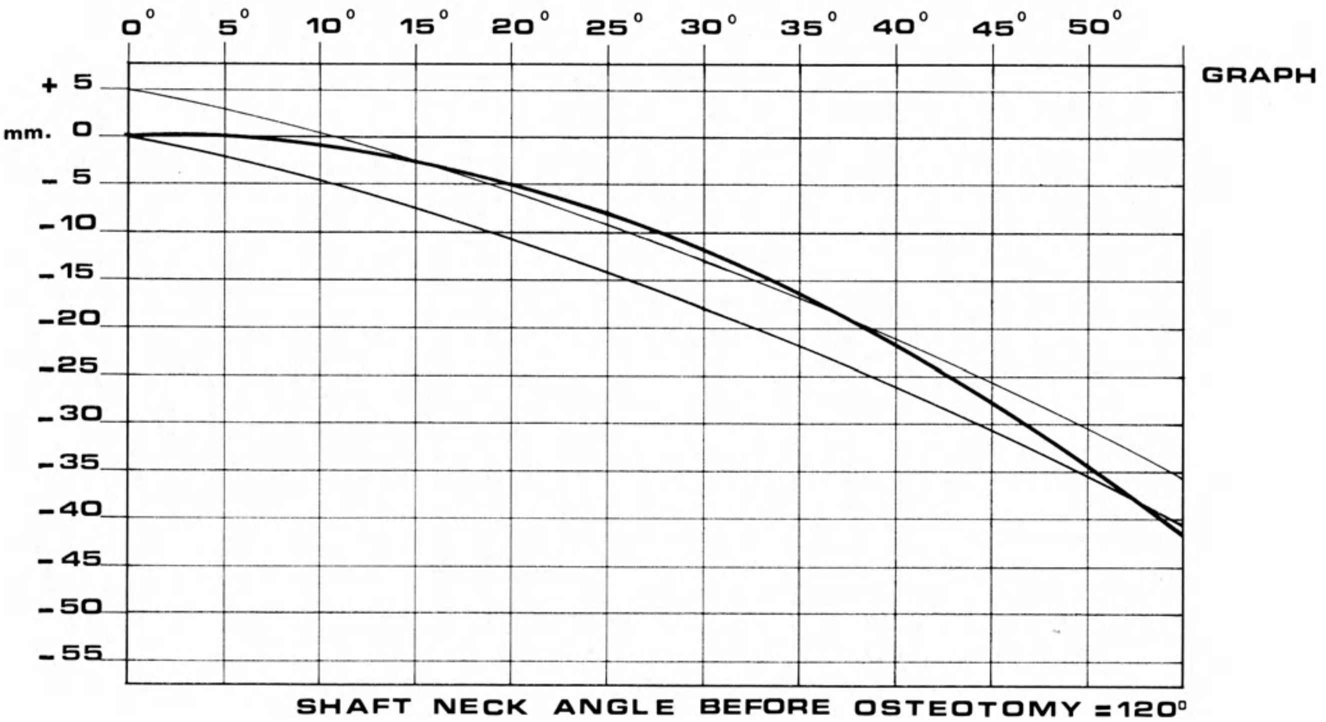


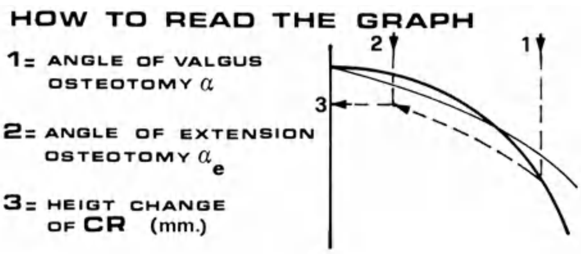
1/2 SHAFT DISPLACEMENT

TABLE

γ = 120°		ANGLE OF EXTENSION OSTEOTOMY						
		0°	10°	15°	20°	30°	40°	50°
ANGLE OF VALGUS OSTEOTOMY	0°	0.00	– 4.62	– 7.48	–10.69	–18.03	–26.42	–35.61
	10°	+ 6.89	+ 2.27	– 0.59	– 3.80	–11.14	–19.53	–28.72
	15°	+ 9.56	+ 4.94	+ 2.08	– 1.13	– 8.47	–16.86	–26.05
	20°	+11.62	+ 7.00	+ 4.14	+ 0.93	– 6.40	–14.80	–23.99
	30°	+13.58	+ 8.96	+ 6.10	+ 2.89	– 4.45	–12.84	–22.03
	40°	+12.09	+ 7.47	+ 4.61	+ 1.40	– 5.94	–14.33	–23.52
	50°	+ 6.07	+ 1.45	– 1.41	– 4.62	–11.96	– 20.35	–29.54

Fig. 58a. Alterations in length of the femur are shown with CCD angle of 120° by combined valgus-extension osteotomy when the shaft is laterally displaced for one-half of its width. The greatest lengthening (13.58 mm) is obtained by simple valgus osteotomy of 30°





NO SHAFT DISPLACEMENT

TABLE

γ = 120°		ANGLE OF EXTENSION OSTEOTOMY						
		0°	10°	15°	20°	30°	40°	50°
ANGLE OF VALGUS OSTEOTOMY	0°	0.00	–4.62	–7.48	–10.69	–18.03	–26.42	–35.61
	10°	+3.65	–0.97	–3.83	– 7.04	– 14.38	–22.77	– 31.96
	15°	+4.85	+0.23	– 2.63	– 5.84	–13.18	–21.57	– 30.76
	20°	+5.60	+0.98	– 1.88	– 5.09	–12.43	–20.82	– 15.22
	30°	+5.78	+1.16	– 1.70	– 4.91	–12.25	–20.64	– 29.83
	40°	+4.19	–0.43	– 3.29	– 6.50	–13.84	–22.23	– 31.42
	50°	+0.88	–3.74	–6.60	– 9.81	–17.15	–25.54	– 34.73

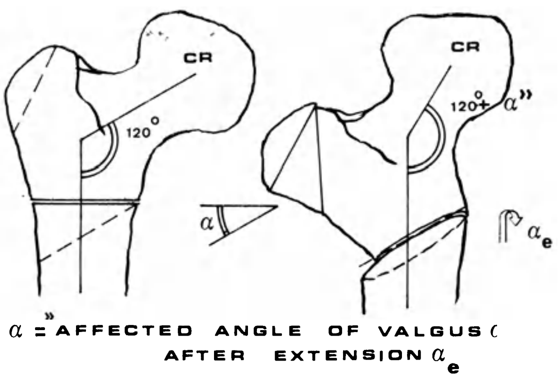
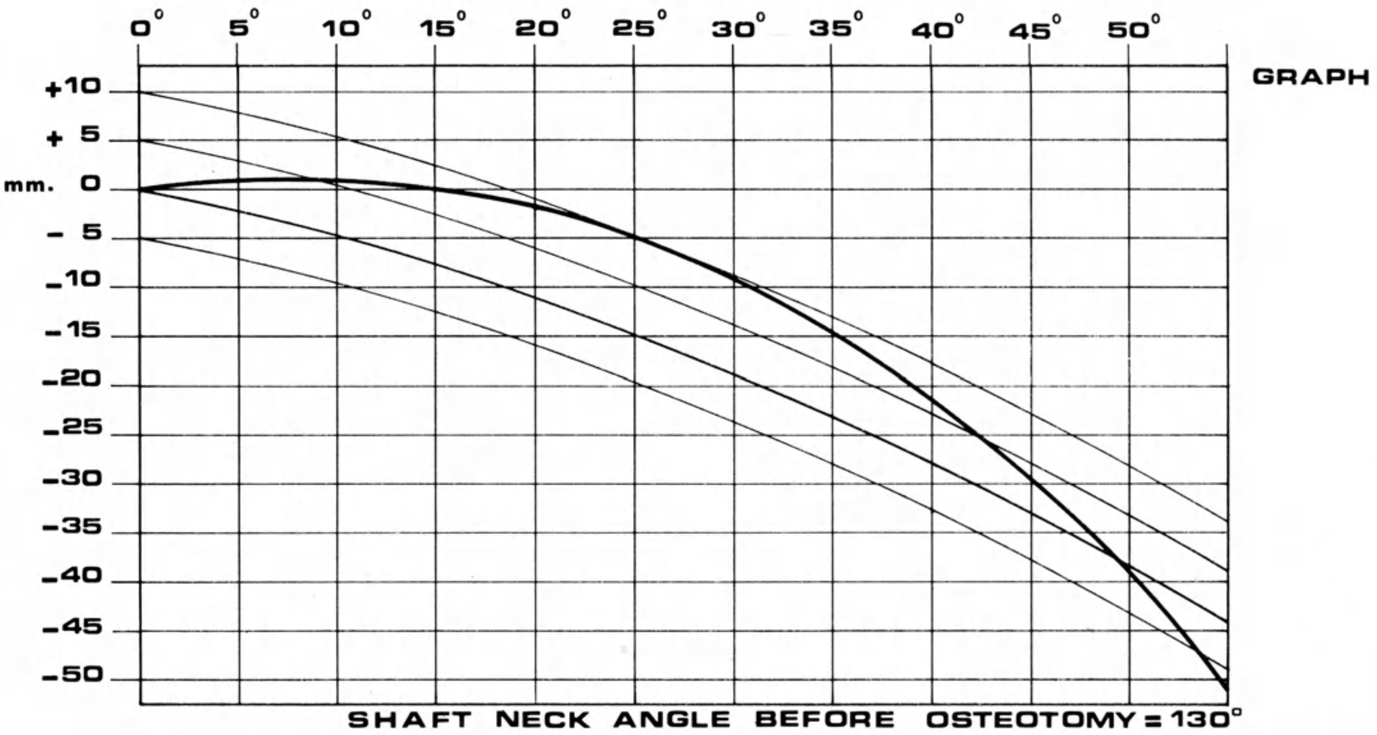
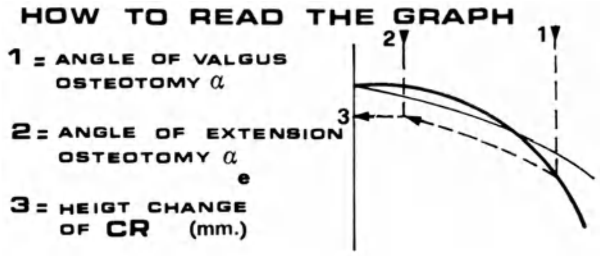


Fig. 58b. Alterations in length of the femur are shown with CCD angle of 120° by combined valgus-extension osteotomy, when the shaft is not displaced. The greatest lengthening 5.78 mm is obtained by simple valgus osteotomy of 30°

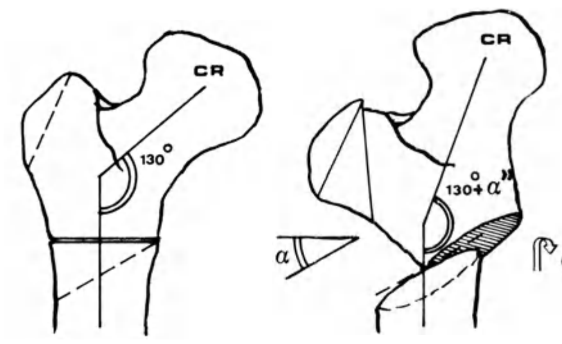




1/2 SHAFT DISPLACEMENT

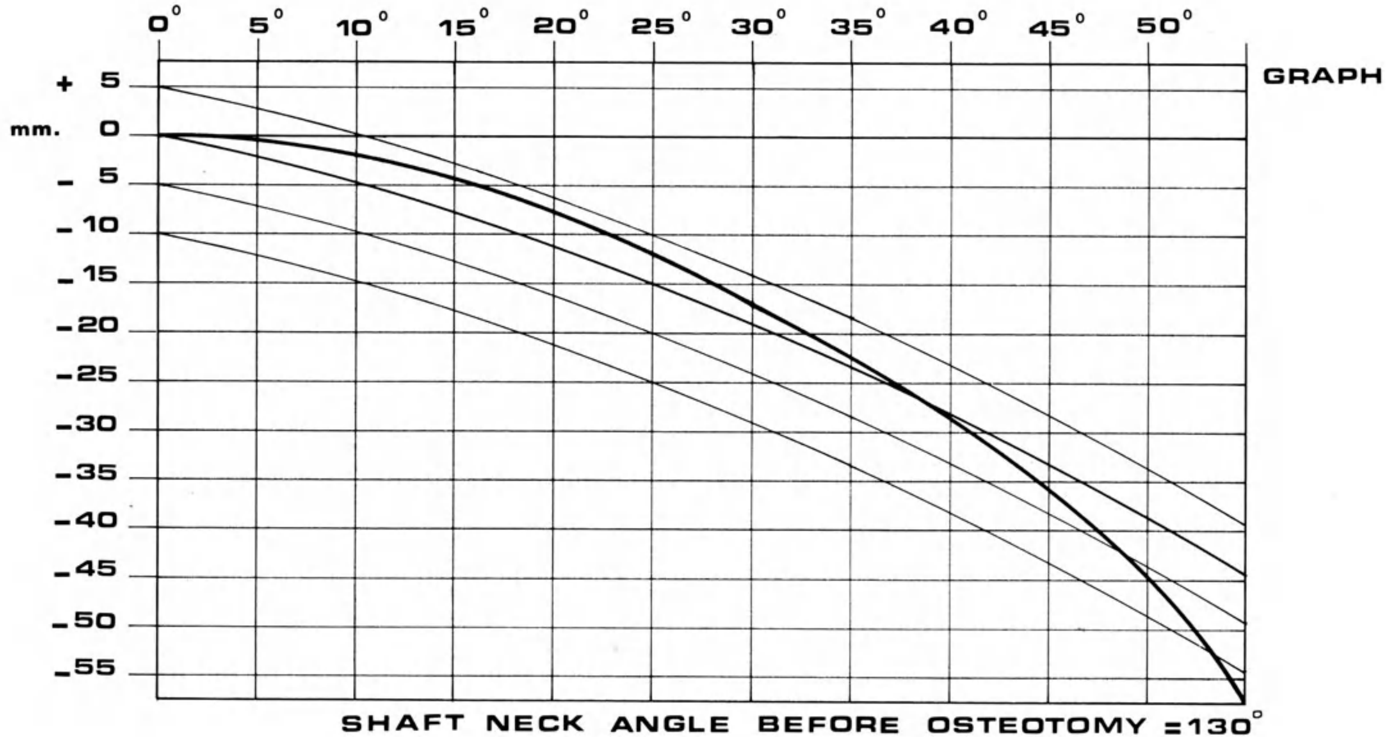
TABLE

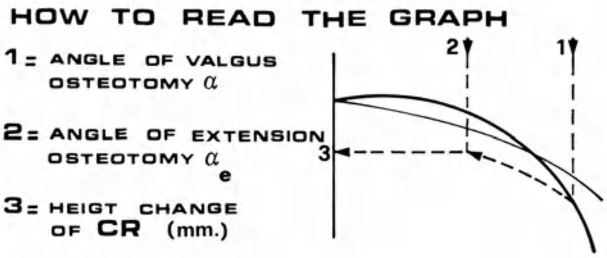
γ = 130°		ANGLE OF EXTENSION OSTEOTOMY						
		0°	10°	15°	20°	30°	40°	50°
ANGLE OF VALGUS OSTEOTOMY	0°	0.00	– 4.74	– 7.75	– 11.16	– 19.09	– 28.26	– 38.41
	10°	+ 5.82	+ 1.08	– 1.93	– 5.34	– 13.27	– 22.44	– 32.59
	15°	+ 7.87	+ 3.13	+ 0.12	– 3.29	– 11.22	– 20.39	– 30.54
	20°	+ 9.26	+ 4.52	+ 1.51	– 1.90	– 9.83	– 19.00	– 29.15
	30°	+ 9.78	+ 5.04	+ 2.03	– 1.38	– 9.31	– 18.48	– 28.63
	40°	+ 6.72	+ 1.98	– 1.03	– 4.44	– 12.37	– 21.54	– 31.69
	50°	– 0.95	– 5.69	– 8.70	– 12.11	– 20.05	– 29.21	– 39.36



α = AFFECTED ANGLE OF VALGUS α AFTER EXTENSION $α_e$

Fig. 59a. Alterations in length of the femur are shown with CCD angle of 130° by combined valgus-extension osteotomy when the shaft is laterally displaced for one-half of its width. The greatest lengthening (9.78 mm) is obtained by simple valgus osteotomy of 30°. Compare the figure where shaft is not displaced. The greatest lengthening is obtained by simple valgus osteotomy of 20° and is only 3.25 mm





NO SHAFT DISPLACEMENT

TABLE

γ = 130°		ANGLE OF EXTENSION OSTEOTOMY						
		0°	10°	15°	20°	30°	40°	50°
ANGLE OF VALGUS OSTEOTOMY	0°	0.00	– 4.74	– 7.75	– 11.16	– 19.09	– 28.26	– 38.41
	10°	+ 2.58	– 2.16	– 5.17	– 8.58	– 16.51	– 25.68	– 35.83
	15°	+ 3.16	– 1.58	– 4.59	– 8.00	– 15.93	– 25.10	– 35.25
	20°	+ 3.25	– 1.49	– 4.50	– 7.91	– 15.84	– 25.01	– 35.16
	30°	+ 1.98	– 2.76	– 5.77	– 9.18	– 17.11	– 26.28	– 36.43
	40°	– 1.18	– 5.92	– 8.93	– 12.34	– 20.27	– 29.44	– 39.59
	50°	– 6.13	– 10.87	– 13.88	– 17.29	– 25.22	– 34.39	– 44.54

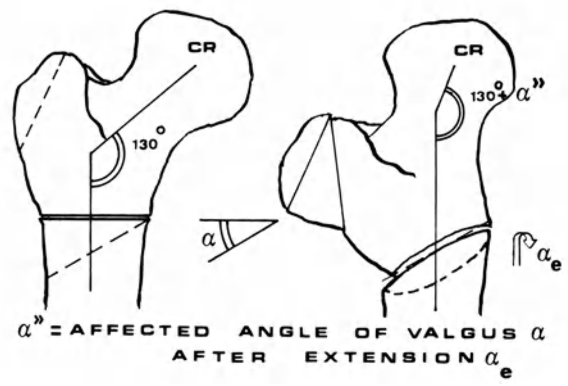
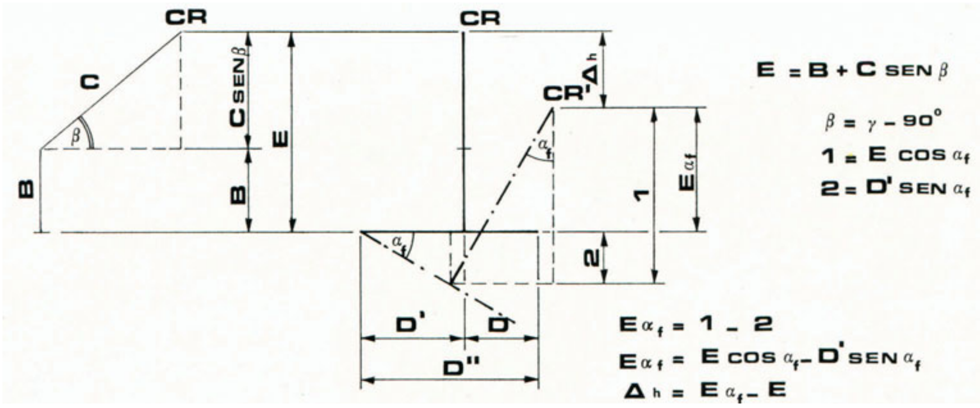
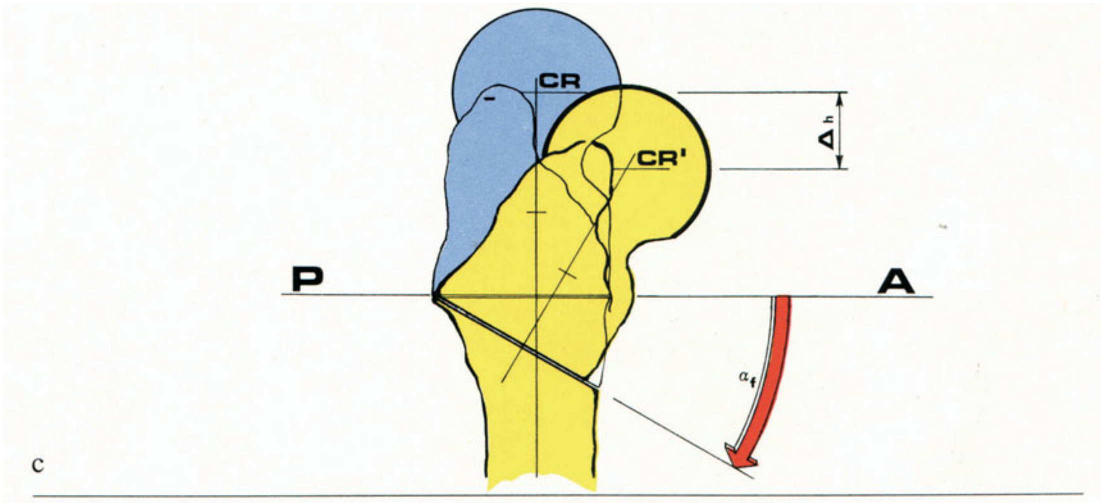
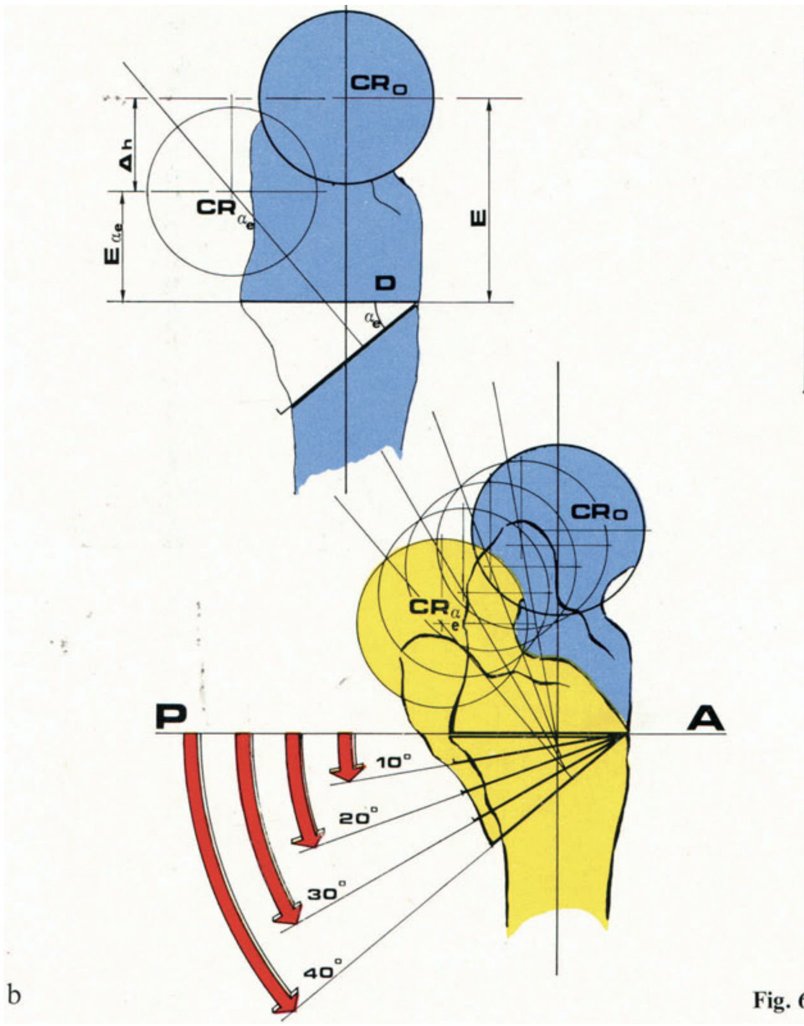


Fig. 59b. Alterations in length of the femur are shown with CCD angle of 130° by combined valgus-extension osteotomy, when shaft is not displaced. Femur is lengthened only by simple valgus osteotomy of 10°–20°–30°. When the simple valgus osteotomy is more than 30° or extension is combined with it, the femur is shortened. The greatest lengthening (3.25 mm) is obtained by simple valgus osteotomy of 20°





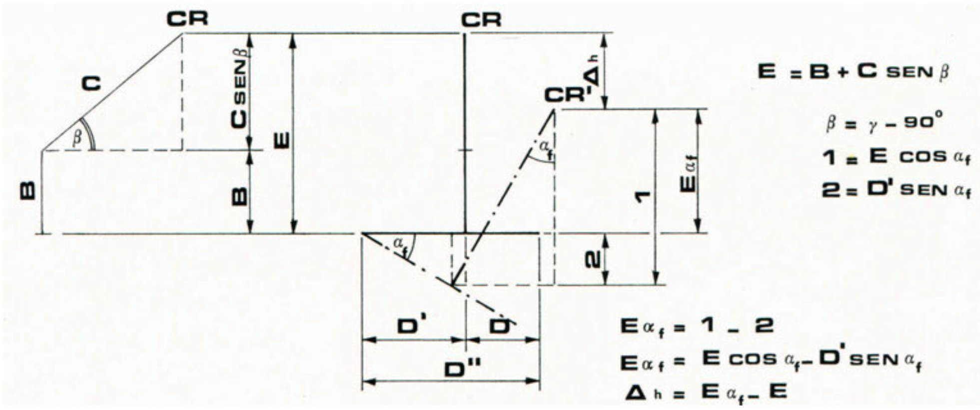
c

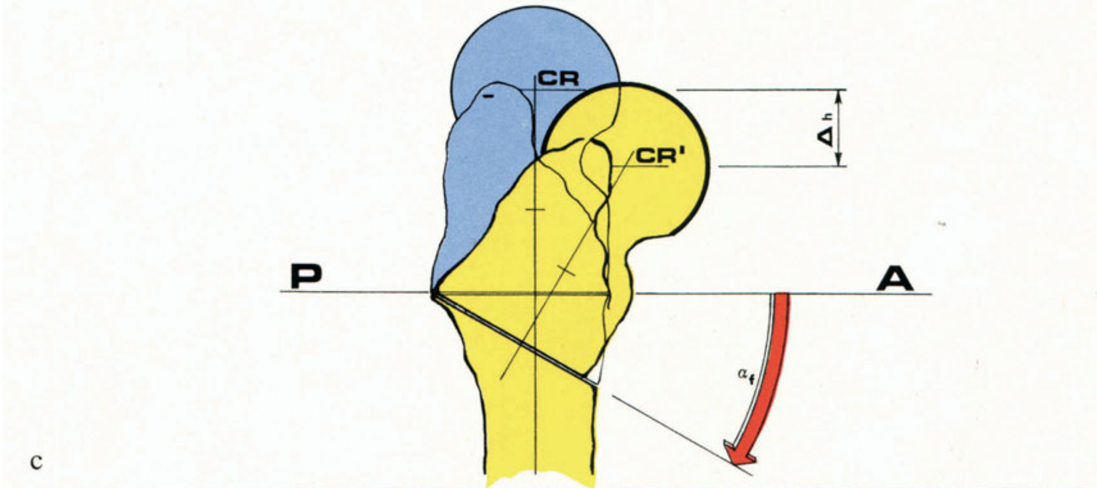


	D = 22	
α_e	$E_{\alpha e}$	Δ h mm
0°	60.35	± 0.00
10°	55.61	− 4.74
15°	52.60	− 7.75
20°	49.19	−11.16
30°	41.26	−19.09
40°	32.09	−28.26
50°	21.94	−38.41
$E\alpha_e$=E COS α_e−D SEN α_e		

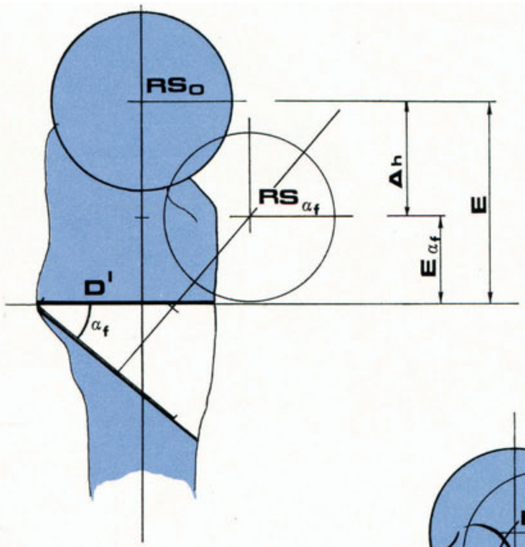
b

Fig. 60a and b. Loss of height with extension osteotomy

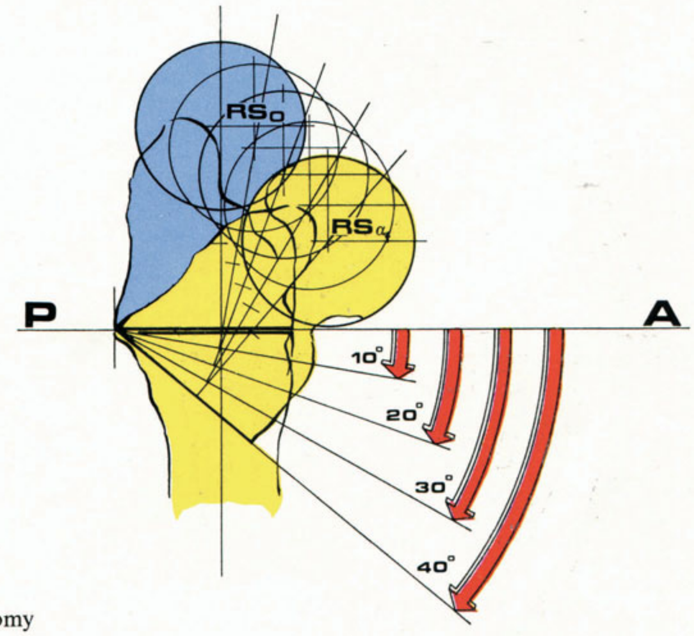




c



D = 31		
α_f	$E\alpha_f$	Δh mm
0°	60.35	± 0.00
10°	54.04	– 6.31
15°	50.27	–10.08
20°	46.11	–14.24
30°	36.76	–23.59
40°	26.30	–34.05
50°	15.05	–45.30
$E\alpha_f = E \cos\alpha_f - D' \,\mathrm{SEN}\, \alpha_f$		



d

Fig. 60c and d. Loss of height with flexion osteotomy

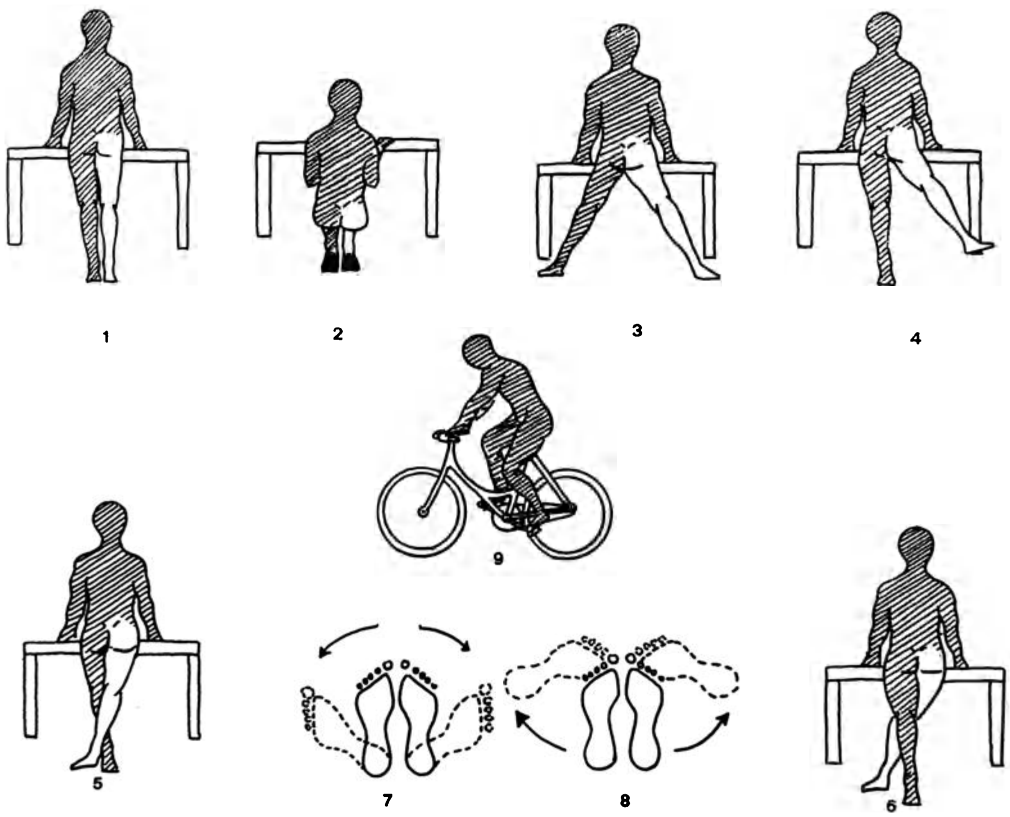


Fig. 61. Patients are advised to carry out active exercises. They must be repeated many times a day. Exercises mold osteophytes already present and stimulate some of them to hypertrophy (roof osteophyte, capital drop, tent osteophyte)

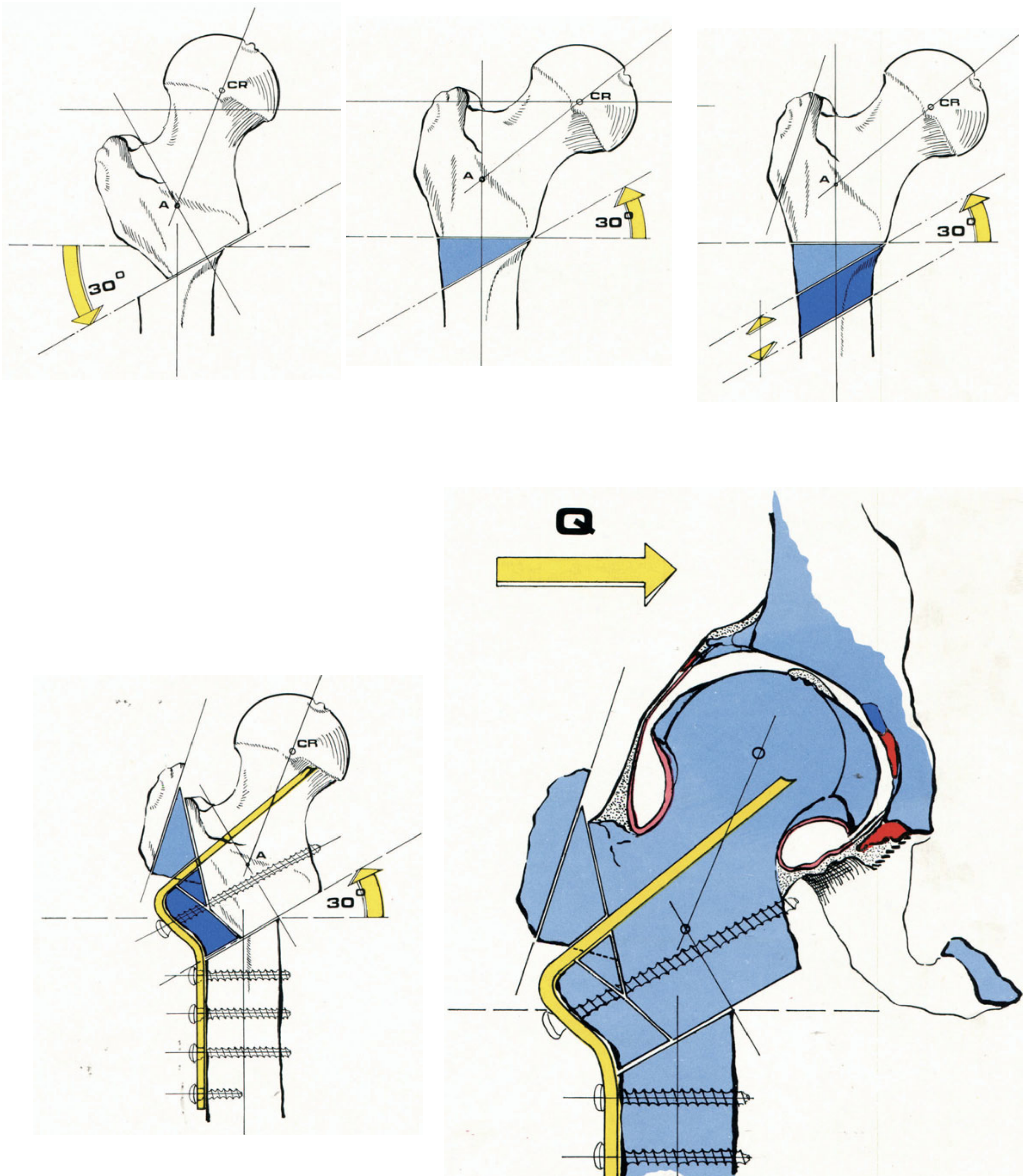


Fig. 62. Simple valgus osteotomy of 30°

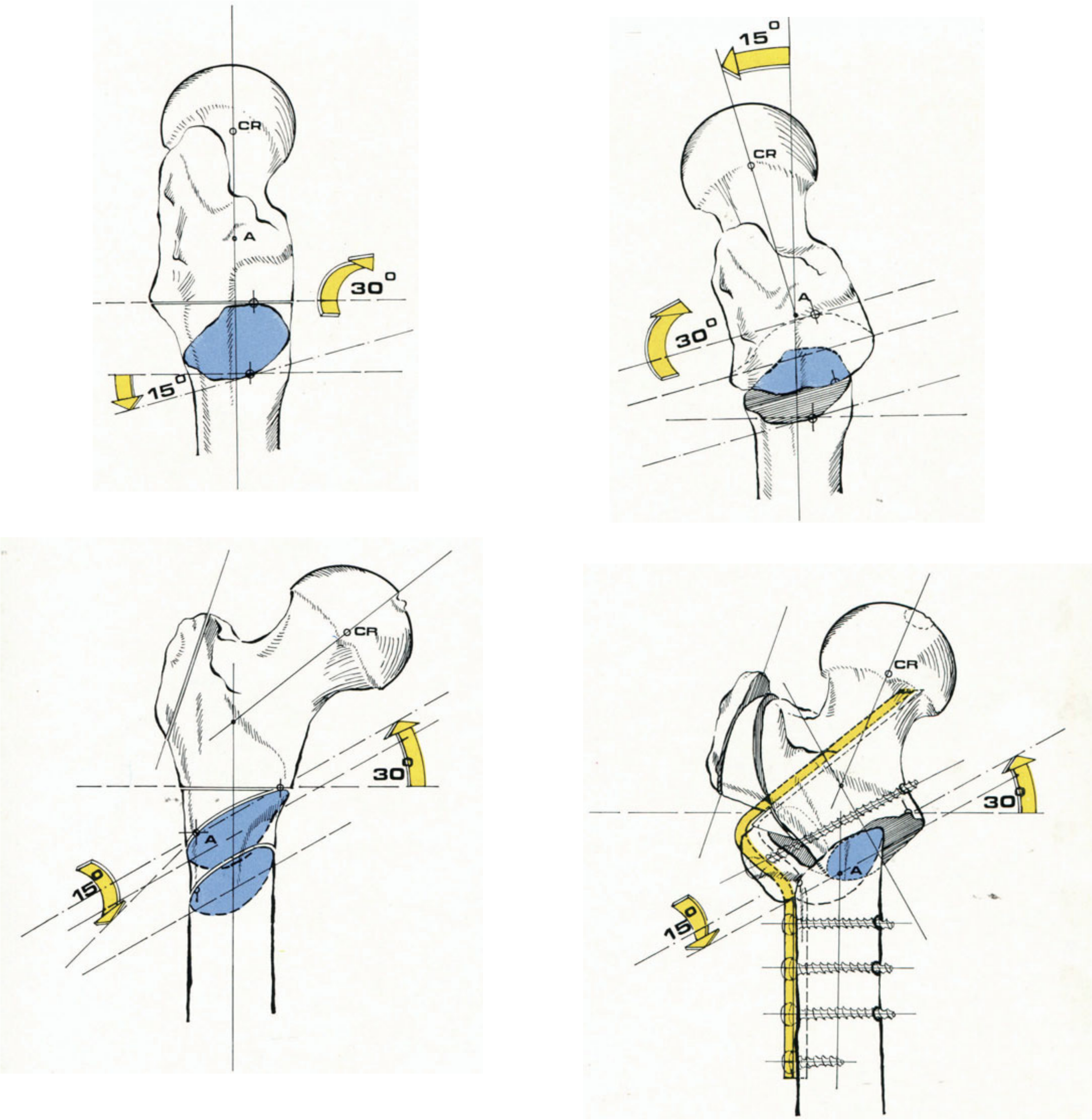
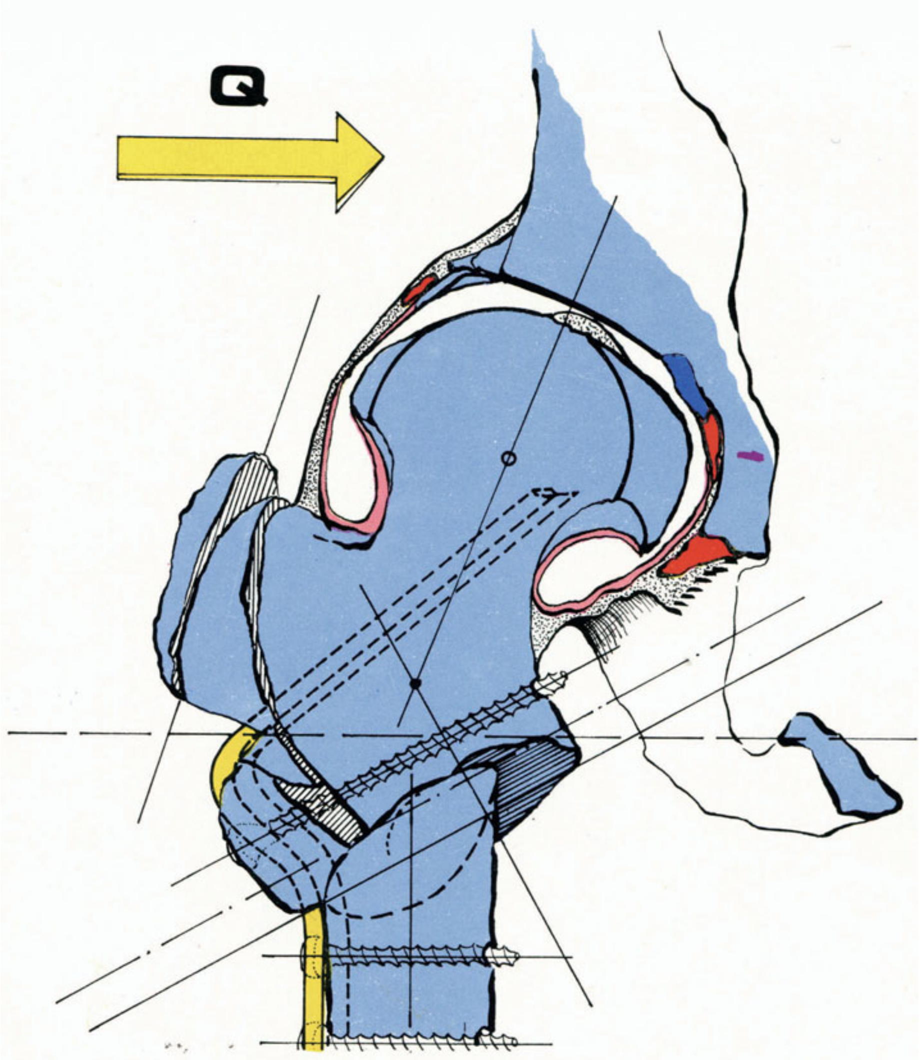


Fig. 63. Osteotomy of combined valgus 30° and extension 15°



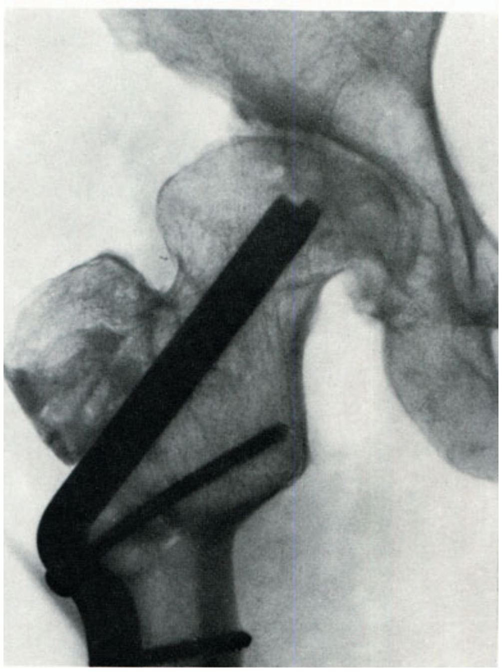


Fig. 63 (continued). Legend see page 81

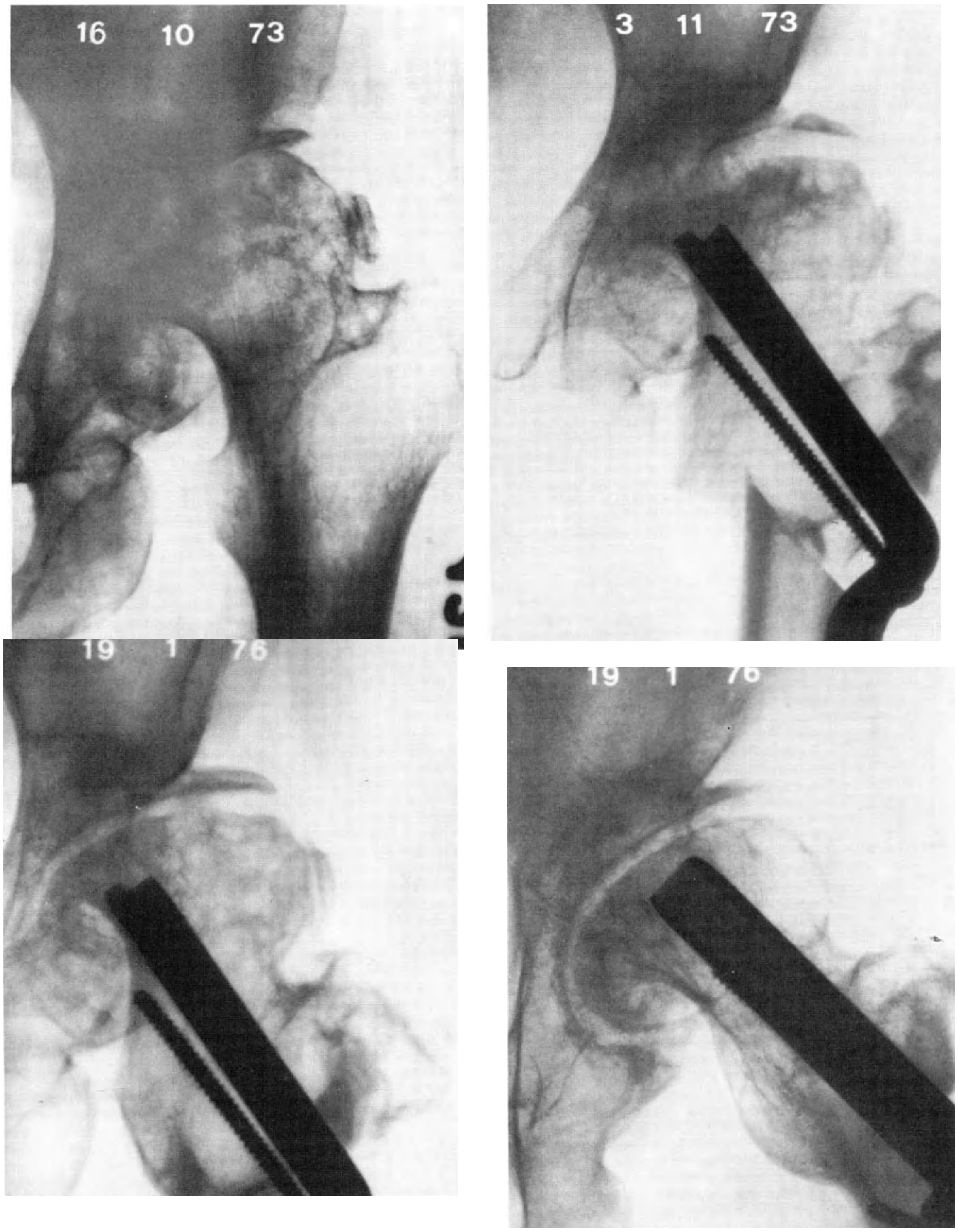


Fig. 64. S.R., age 47. *16–10–73* Left secondary osteoarthritis. *3–11–73* 2 weeks after osteotomy of valgus 35° extension 20°, shortening 1 cm. Fulcrum of movement is located on medial side of joint. Synovial fluid in wide open joint acts as buffer cushion. The taut superior part of capsule has broken oblique roof osteophyte. *19–1–76* 2 years, 3 months after operation. Disease has healed. The joint space is regular. Roof osteophyte has healed. It is now horizontal and acts as "block" to force *S*

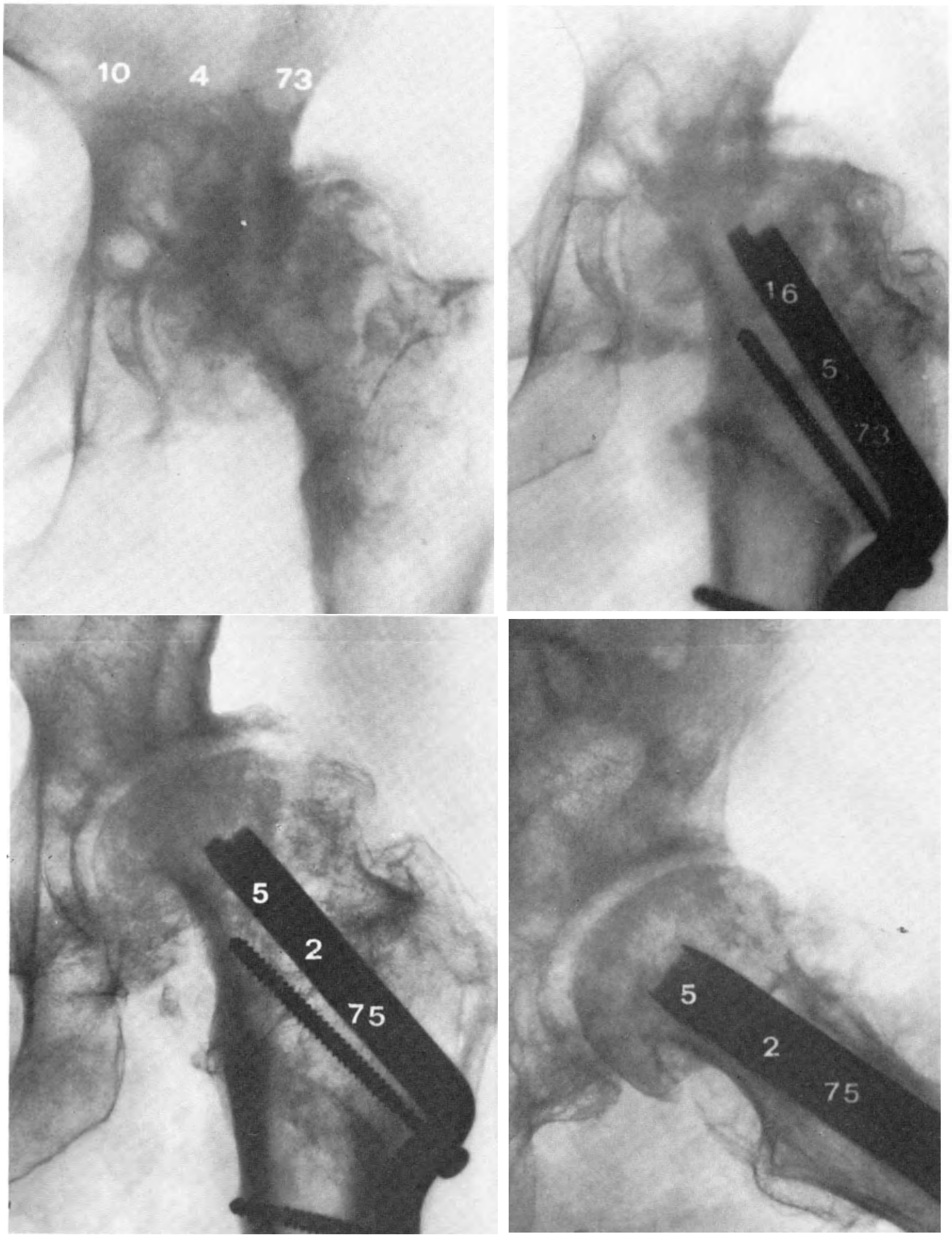


Fig. 65. A.M., age 76. *10–4–73* Primary osteoarthritis of left hip. *16–5–73* 1 month after valgus osteotomy of 30°. Lateral part of joint surface has become wider because hydraulic mechanism is in action. *5–2–75* About 2 years after operation. The joint space is regular and horizontal. Force *S* has disappeared. Roof osteophyte is stouter. Disease has healed

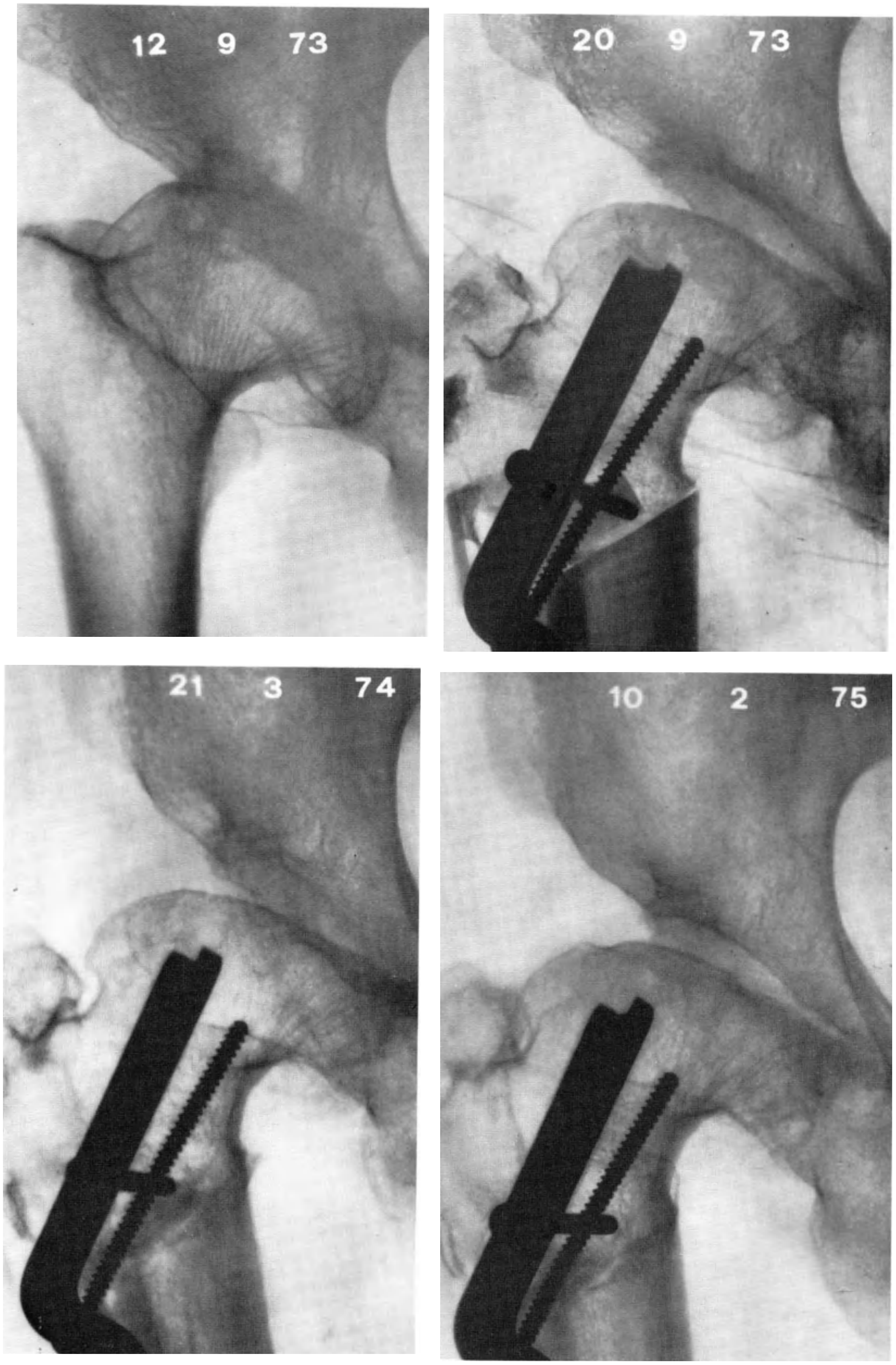


Fig. 66. R.Z., age 52. *12–9–73* right osteoarthritis secondary to C.D.H. (Congenital Dislocation of the Hip). *20–9–73* Intertrochanteric valgus osteotomy of 30°, X-ray result just after operation. Two medial osteophytes: capital drop and tent osteophyte are the fulcrum of the joint. An increased joint space, filled by synovial fluid, is formed by withdrawal of head of femur from acetabulum caused in the vertical position by weight of the limb. Synovial fluid acts as hydraulic mechanism absorbing resultant force *R*. *21–3–74* Result after 6 months. The joint space widens. Patient can walk free from pain. *10–2–75* Result after 17 months. Fulcrum (capital drop and tent osteophyte) is being molded and widened. A cover of fibrocartilage has appeared on osteophytes

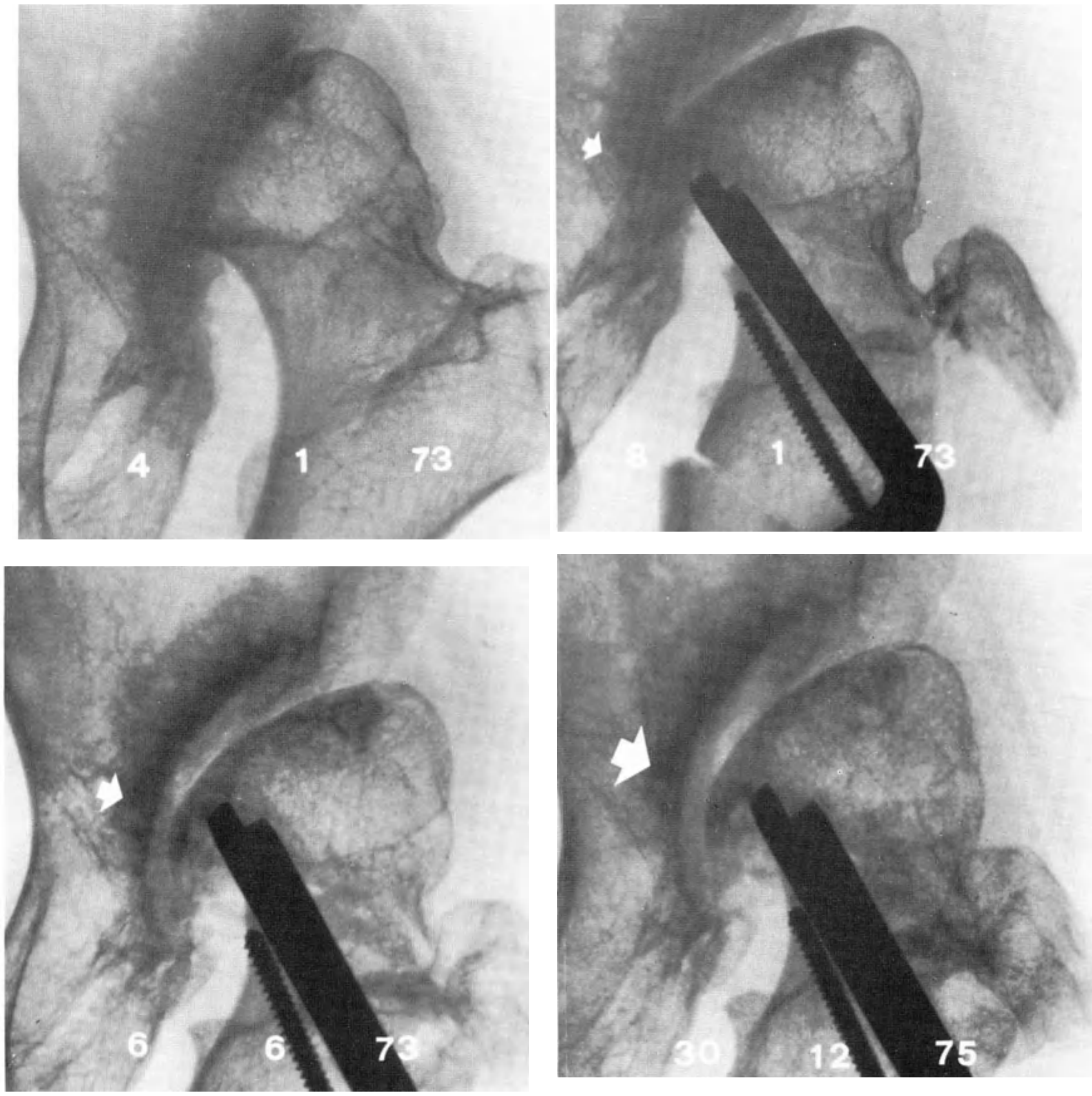


Fig. 67. B.V., age 53. *4–1–73* Left osteoarthritis secondary to C.D.H. *8–1–73* X-ray appearance just after valgus osteotomy of 30°. Capital drop and tent osteophyte are touching. Lateral part of joint space has widened due to passive withdrawal of the head. *6–6–73* X-ray 5 months after operation. The two touching osteophytes have been molded and their covering cartilage has thickened. All the joint space has appeared and has a more or less normal shape, although it is still slanting in craniolateral direction. *30–12–75* 3 years after operation. The joint space has widened even more. Disease has not yet healed because roof osteophyte, which must make joint space horizontal and therefore eliminate force *S*, has not yet made its appearance

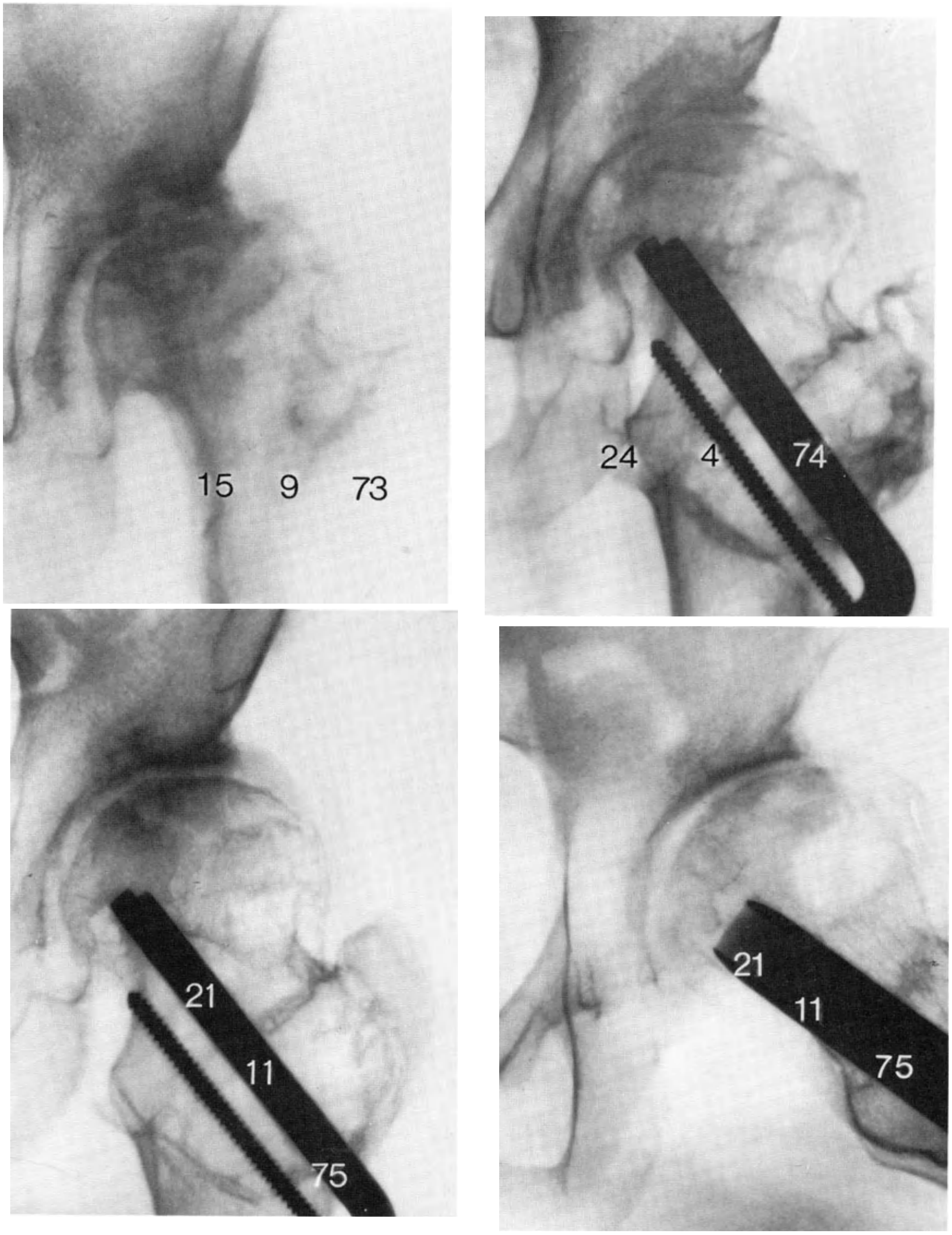


Fig. 68. F.L., age 61. *15–9–73* Primary osteoarthritis of left hip. *24–4–74* 7 months after valgus osteotomy of 30°. Head is becoming spherical. Roof osteophyte has increased and is no longer oblique. *21–11–75* 2 years, 2 months after operation. No pain. The weight-bearing joint surface is horizontal. Force *S* has disappeared. The hip shape and function have become normal

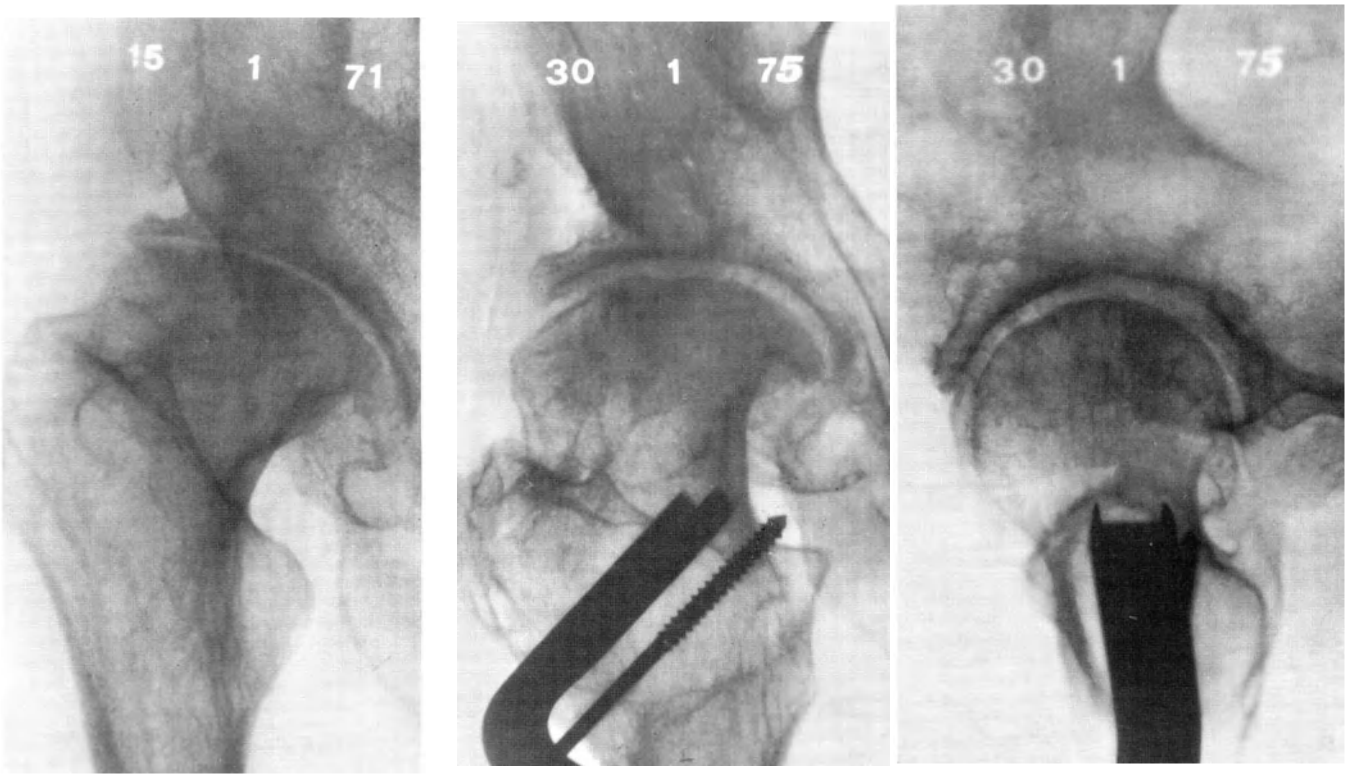


Fig. 69. M.L., age 44. *15–1–71* Right osteoarthritis secondary to C.D.H. The weight-bearing joint surface is oblique and force *S* is responsible for appearance of roof osteophyte, capital drop, and tent osteophyte. *30–1–75* 4 years after valgus osteotomy of 30°. The joint surface is now horizontal, thanks to the alignment of the roof osteophyte. Force *S* has therefore disappeared. The joint space is uniform and nearly normal. Patient is free from pain and walks normally. All movements are full

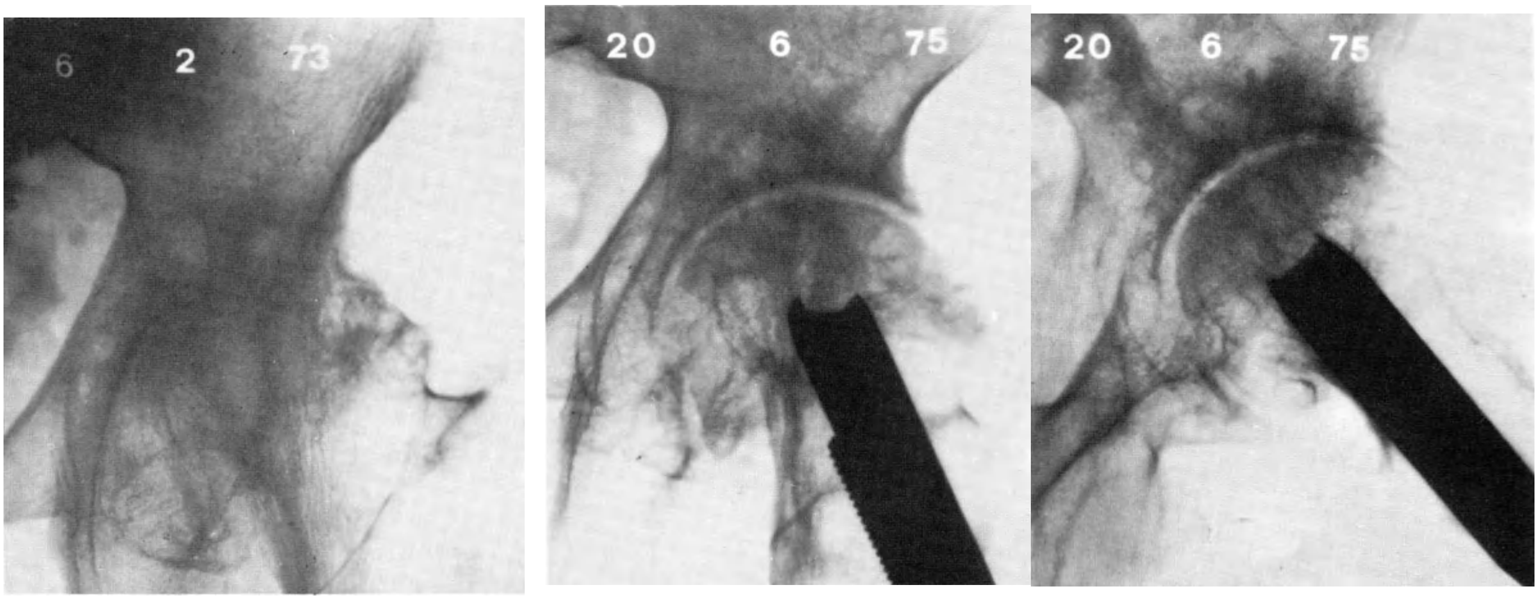


Fig. 70. R.A., age 69. *6–2–73* Primary osteoarthritis of left hip. *20–6–75* 2 years, 4 months after osteotomy of valgus 30° extension 10°. The joint space is visible. Head is taking a normal shape and its volume is increased, due to capital drop. Bone structure is improving, but not yet normal. Patient walks without a stick; he has no limp and no pain

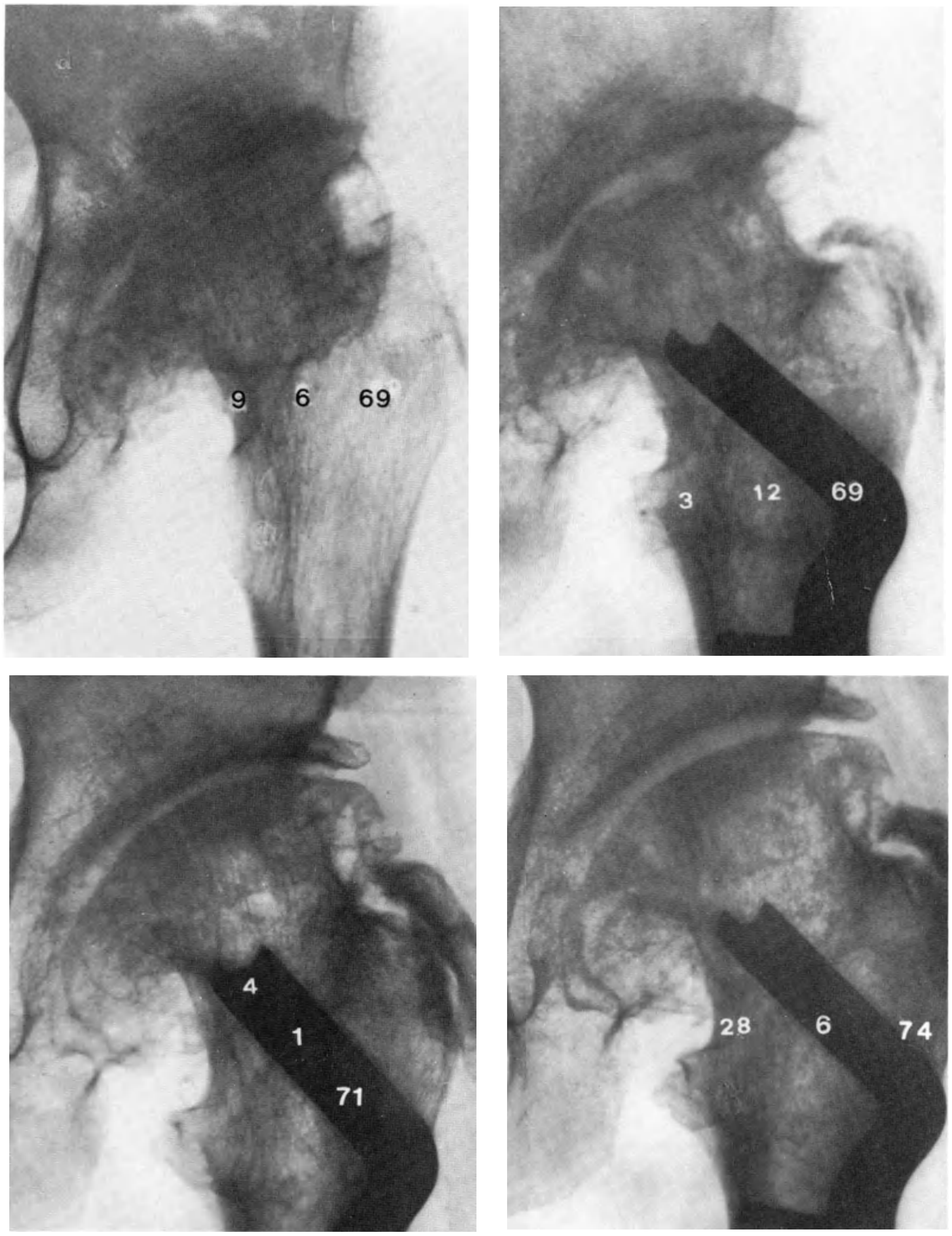


Fig. 71. T.MP., age 60. *9—6—69* Primary osteoarthritis of left hip. *3—12—69* 6 months after valgus osteotomy of 30°. The joint space is reappearing. An active alteration in bones is present. Patient is free from pain and walks with one stick. *4—1—71* 1 year, 6 months after operation. The remodeling activity is still proceeding. The joint space is clear. Roof osteophyte is well formed. Force *Q* is present. Patient works all day as a nun in an X-ray department. *28—6—74* 5 years after operation. The joint surface has become wider and regular; bone structure is nearly normal; movement is full. The osteotomy has achieved a real biological arthroplasty

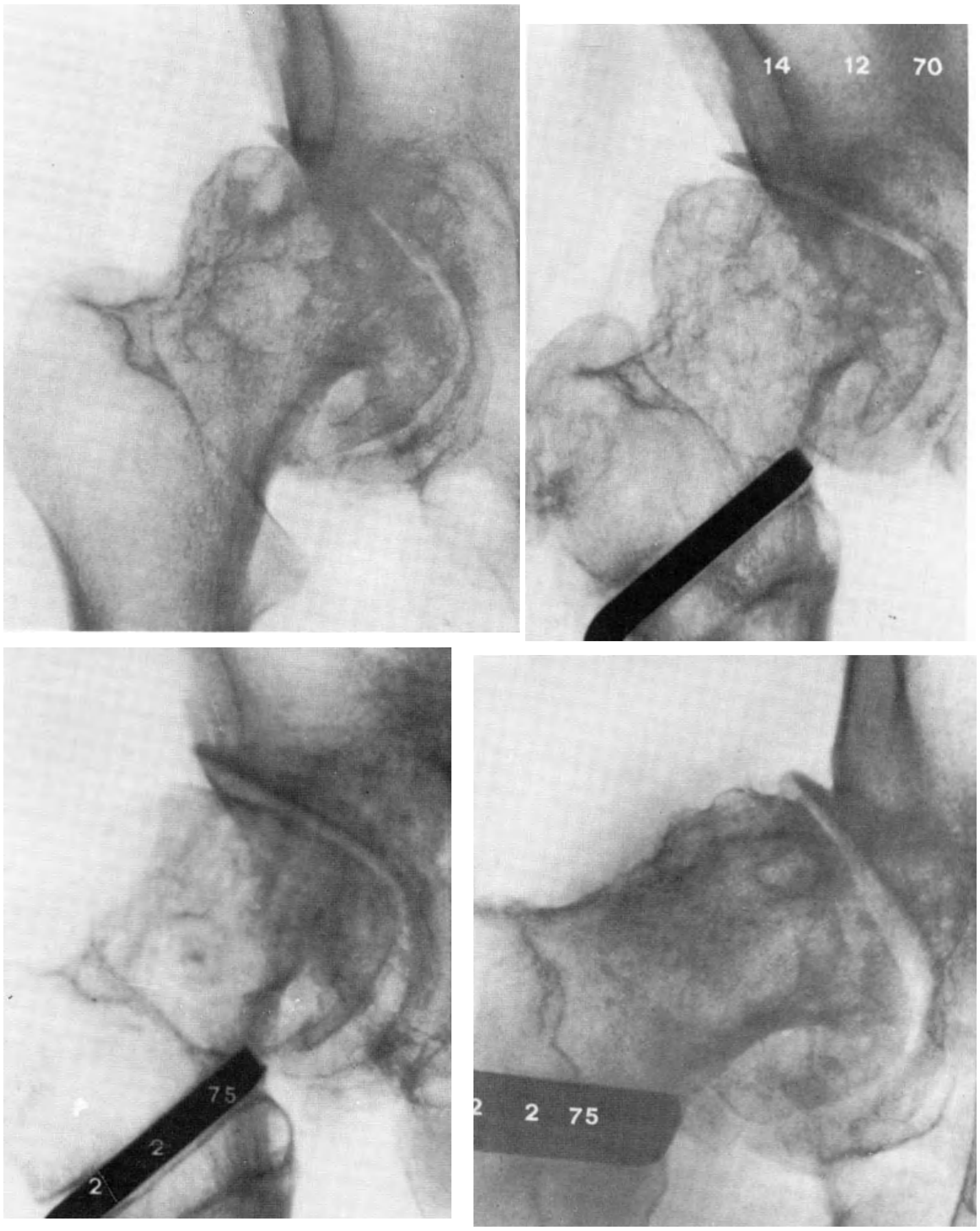


Fig. 72. P.M.L., age 32. *5—5—70* Secondary osteoarthritis of right hip. *14—12—70* 7 months after valgus osteotomy of 30°. The joint is reappearing. *2—2—75* 4 years, 9 months after operation. Patient leads a normal life. No pain and no limping, only the external and internal rotation of hip are reduced to one-half

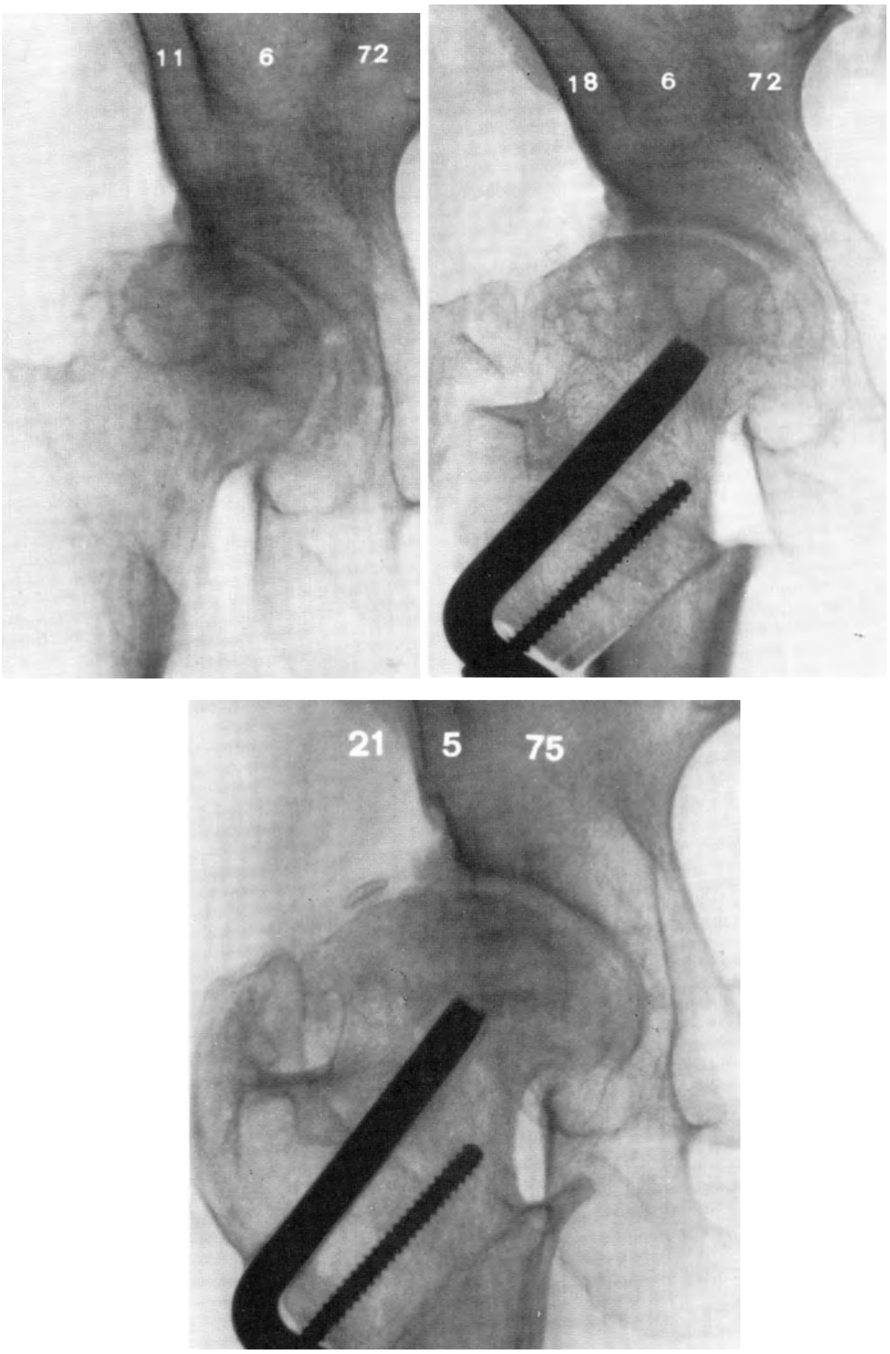


Fig. 73. B.M., age 63. *11–6–72* Secondary osteoarthritis of right hip. *18–6–72* 1 week after valgus osteotomy of 30°. *21–5–75* 3 years after operation. Roof osteophyte has appeared. Ossification in superior part of capsule, already present before the operation, has increased. This is the consequence of the stretching of the capsule caused by valgus rotation of head. Patient has a normally functioning hip

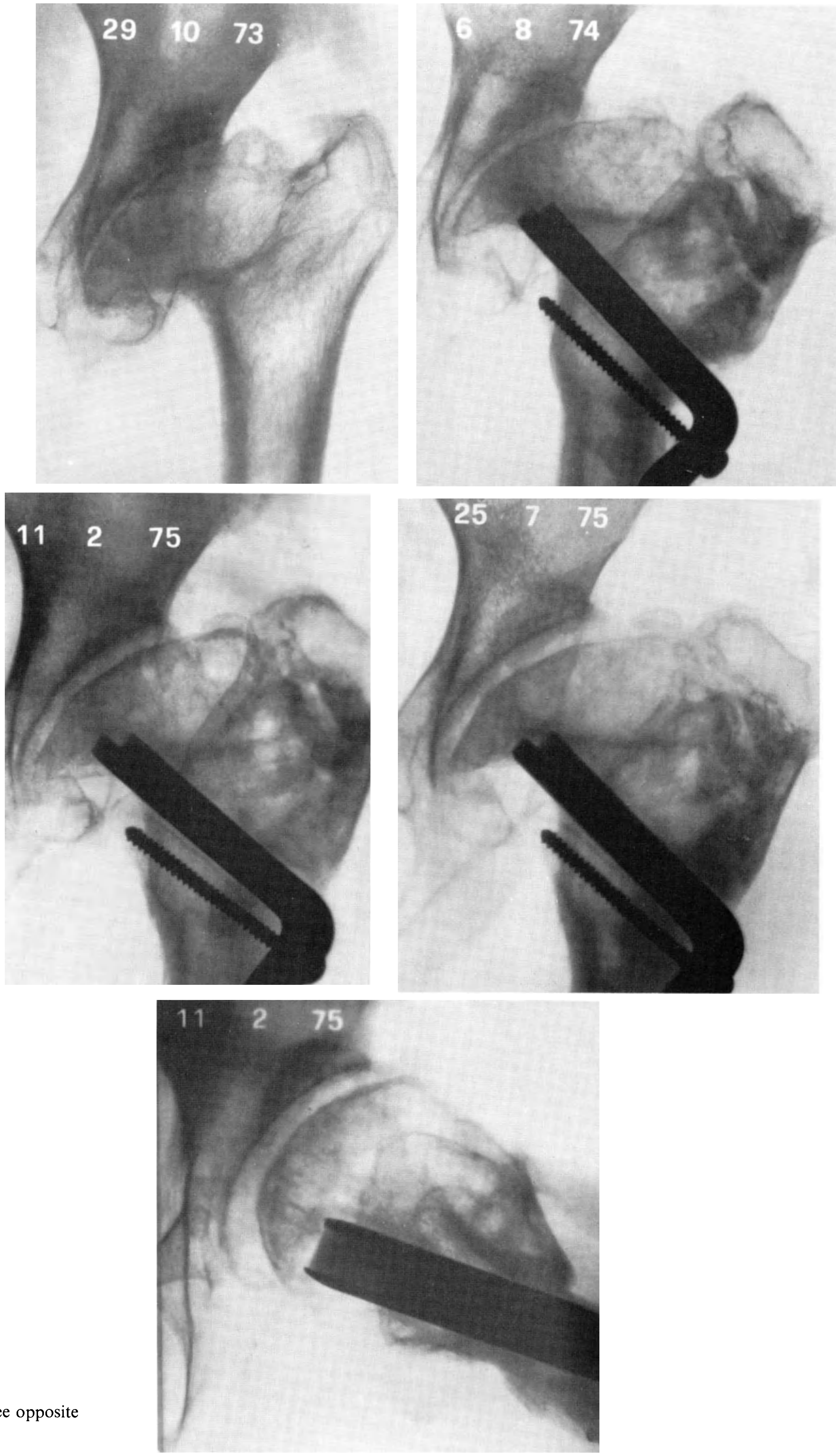


Fig. 74. Legend see opposite page

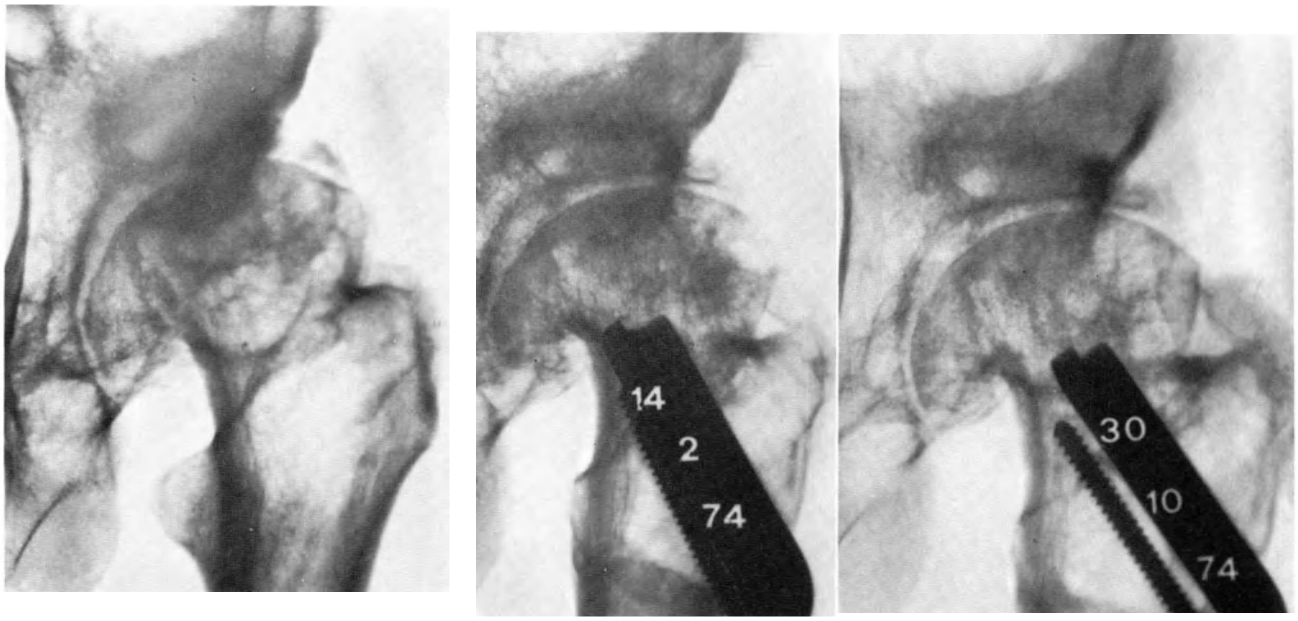


Fig. 75. D.R.M., age 54. *13–1–73* Primary osteoarthritis of left hip. Force *S* is present. Roof osteophyte is appearing; capital drop and tent osteophyte are well developed. The socket and head, corresponding to small weight-bearing joint zone, are sclerotic and partially cystic. *14–2–74* 1 year after valgus osteotomy of 30°. Joint has full movement. Patient is free from pain and walks without a stick. *30–10–74* 21 months after operation. The head is well shaped; joint space is wider and regular; bone structure is taking a normal shape; cyst is disappearing; roof osteophyte is horizontal and stout

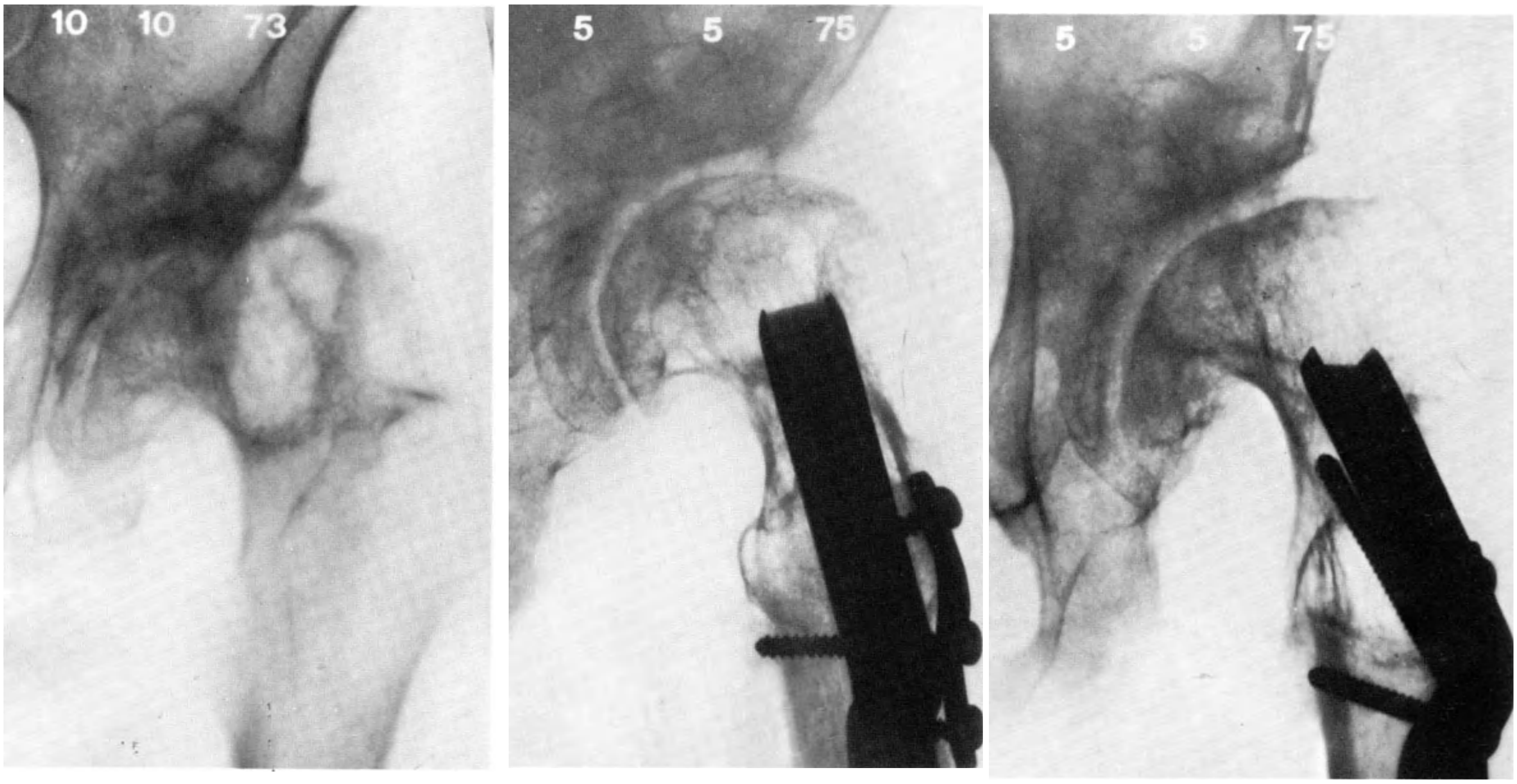


Fig. 76. R.A., age 59. *10–10–73* Secondary osteoarthritis of left hip. *5–5–75* 1 year, 7 months after valgus osteotomy of 30°. Hip has changed both in shape and in structure. A wide, even joint space has appeared. Cysts are filling up. Hip has full active and passive movement. Patient walks without a stick

---

◁ **Fig. 74.** C.E., age 45. *29–10–73* Left osteoarthritis secondary to coxa plana. *6–8–74* 9 months after operation (valgus osteotomy of 30°). Capital drop and tent osteophyte are congruent. The joint space is regular. Patient walks with a stick but without pain. *11–2–75* 16 months after operation. The joint space is wider and regular. A very tiny roof osteophyte has made its appearance. Hip has full active and passive movement. Patient walks without a stick. *25–7–75* 21 months after operation. The joint space has ultimately widened. Zones of increased bone density are disappearing

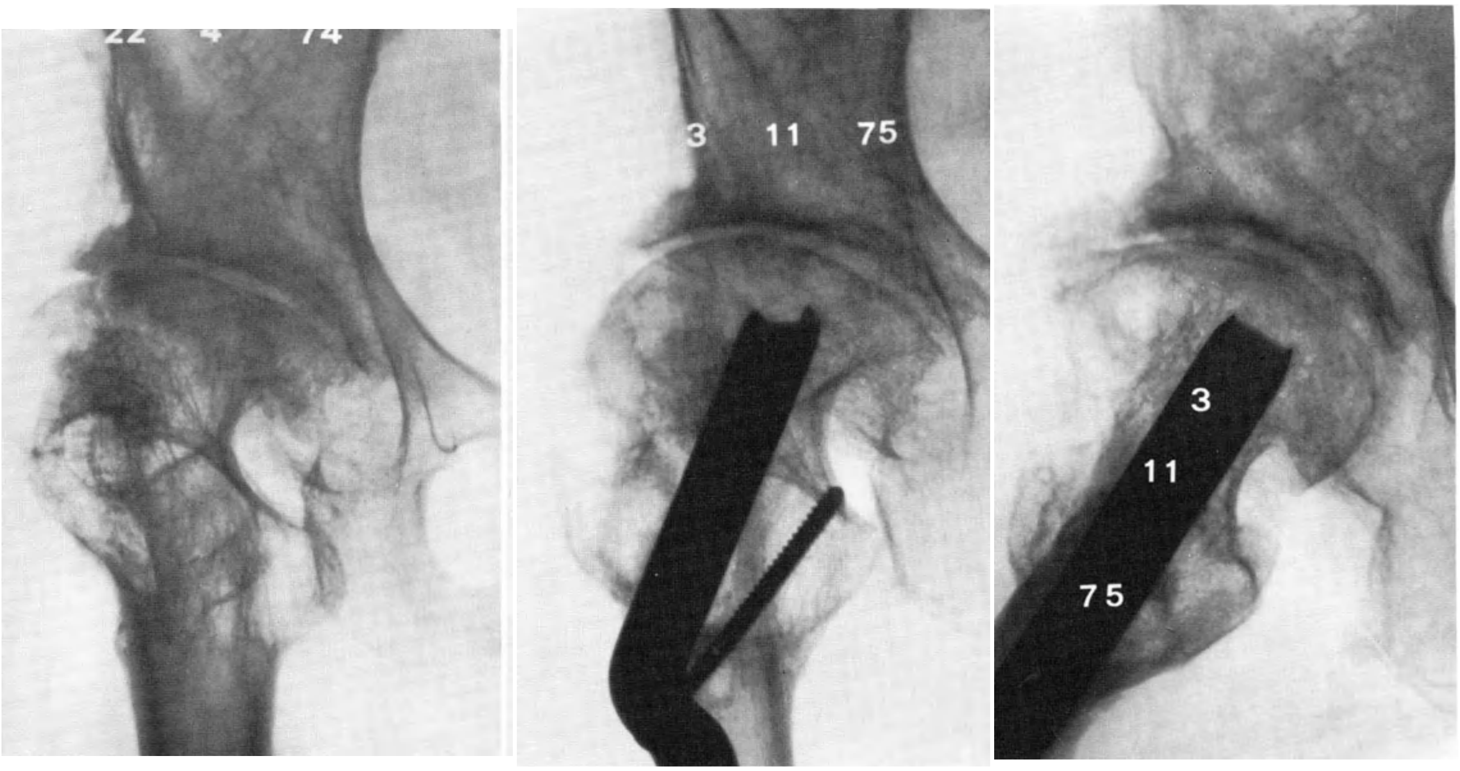


Fig. 77. R.G., age 57. *22—4—74* Secondary osteoarthritis of right hip. Valgus osteotomy had been carried out 25 years previously. *3—11—75* 1 year, 6 months after valgus osteotomy of 30°.

	before operation			after operation		
Fl./Ext.	30°	20°	0°	70°	0°	0°
Ab./Add.	0°	0°	0°	20°	0°	30°
Ext./Int.	30°	30°	0°	10°	0°	10°
	pain			no pain		
	2 cm shortening			no shortening		

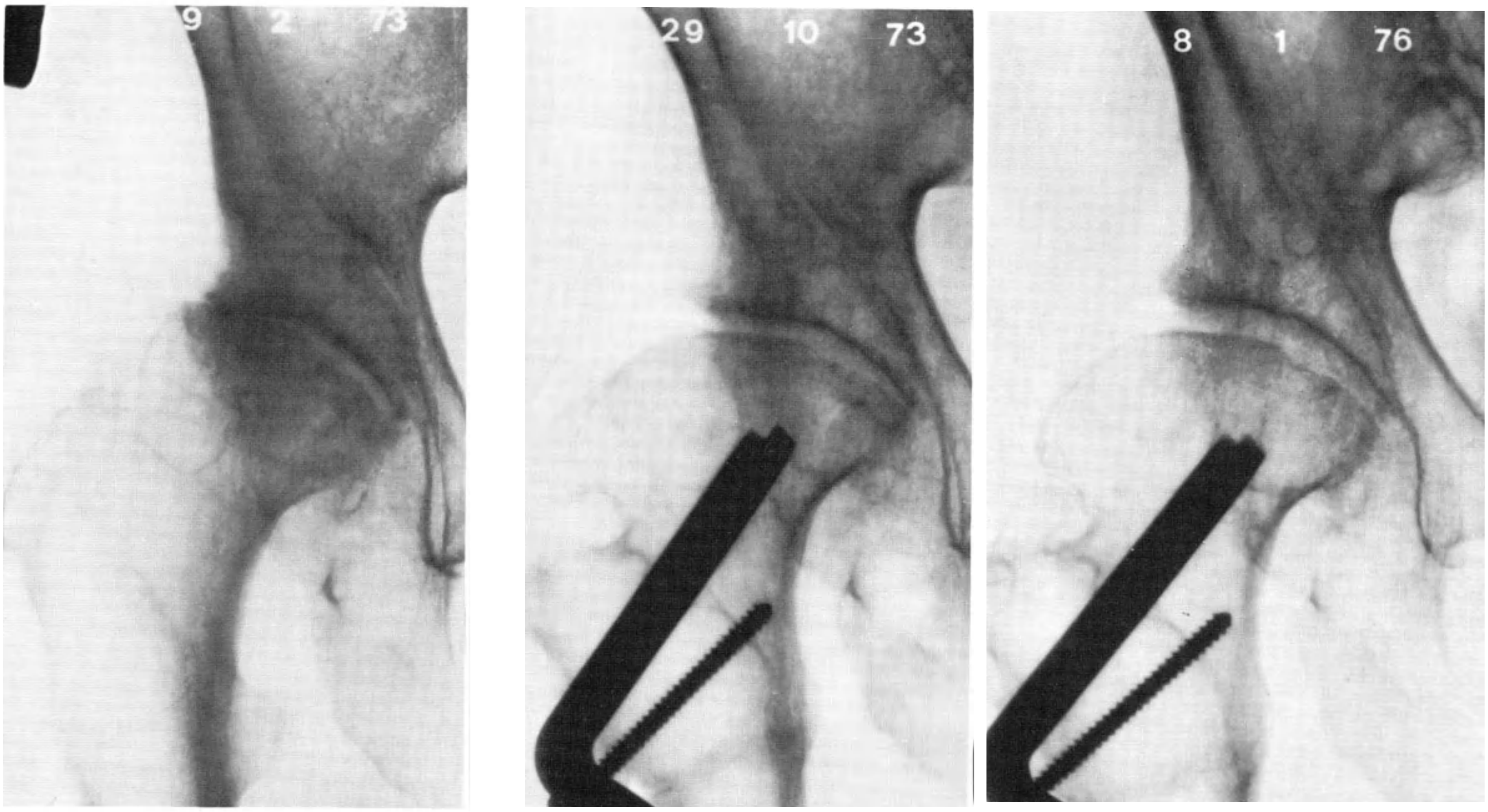


Fig. 78. R.B., age 41. *9–2–73* Secondary osteoarthritis of right hip. The fulcrum of movement is at superolateral corner of the joint. *29 – 10–73* 8 months after osteotomy of valgus 35° extension 20°. The joint space is large; fulcrum of movement is on the capital drop and on scanty tent osteophyte. *8–1–76* 3 years after operation. Disease has healed. The entire joint surface is bearing the body weight. The fulcrum of movement has disappeared and center of rotation is now center of new head CR_1

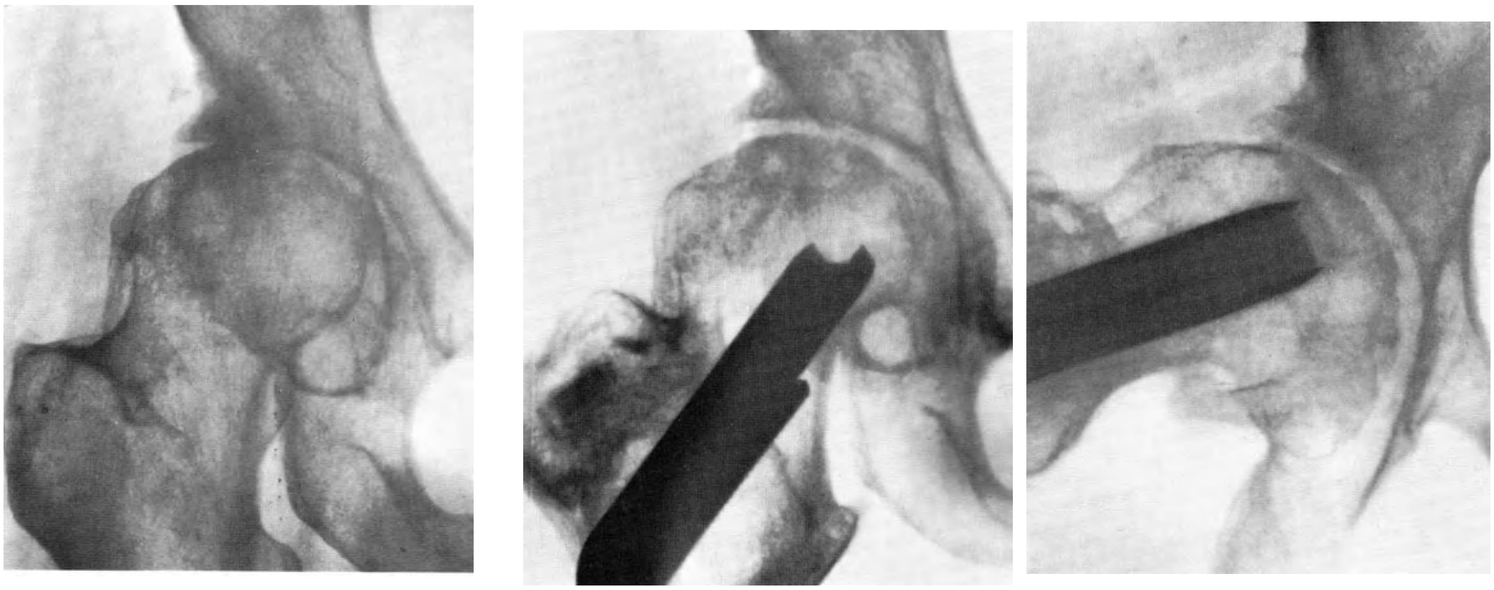


Fig. 79. G.S., age 49. *12–1–73* Primary osteoarthritis of right hip. *30–1–75* 4 years after osteotomy of valgus 30° extension 20°. Hip has healed because weight-bearing joint surface is larger than before, thanks to the hypertrophied capital drop and increased roof osteophyte

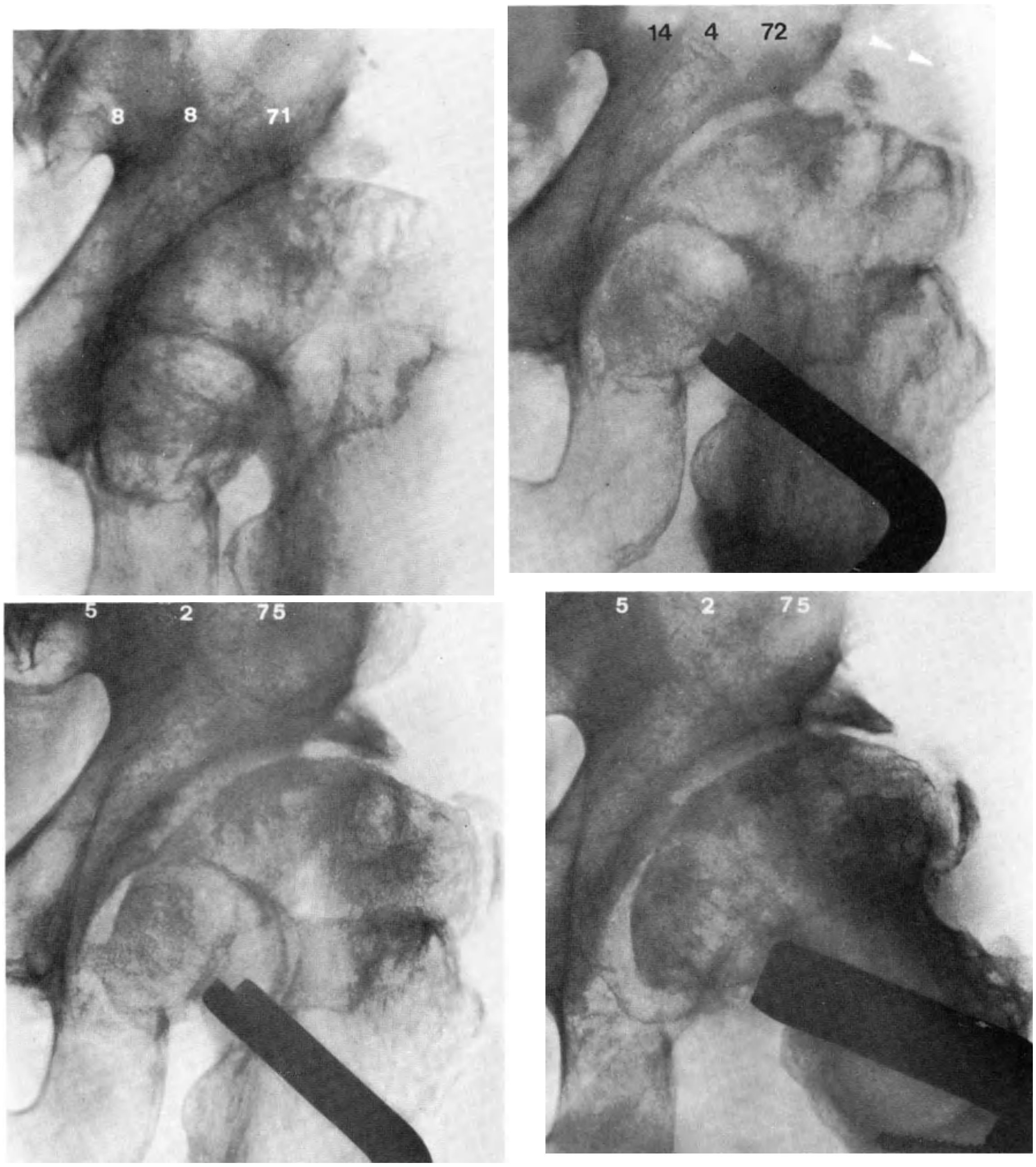


Fig. 80. G.A., age 57. *8–8–71* Severe osteoarthritis of left hip, secondary to subluxation. Force *S* is present. Roof osteophyte has appeared; capital drop and inferior cervical osteophyte have fused and widened the joint surface but not enough to prevent the disappearance of joint space. *14–4–72* 8 months after valgus osteotomy of 30°. Trabeculae of roof osteophyte are parallel to superior zone of capsule. The joint space appears. *5–2–75* 3 years, 6 months after operation. Roof osteophyte is well formed and makes joint space horizontal. This is thick, wide, and uniform. Force *S* has disappeared and force *Q* has reappeared. Joint has healed. Patient has full movement and is free from pain

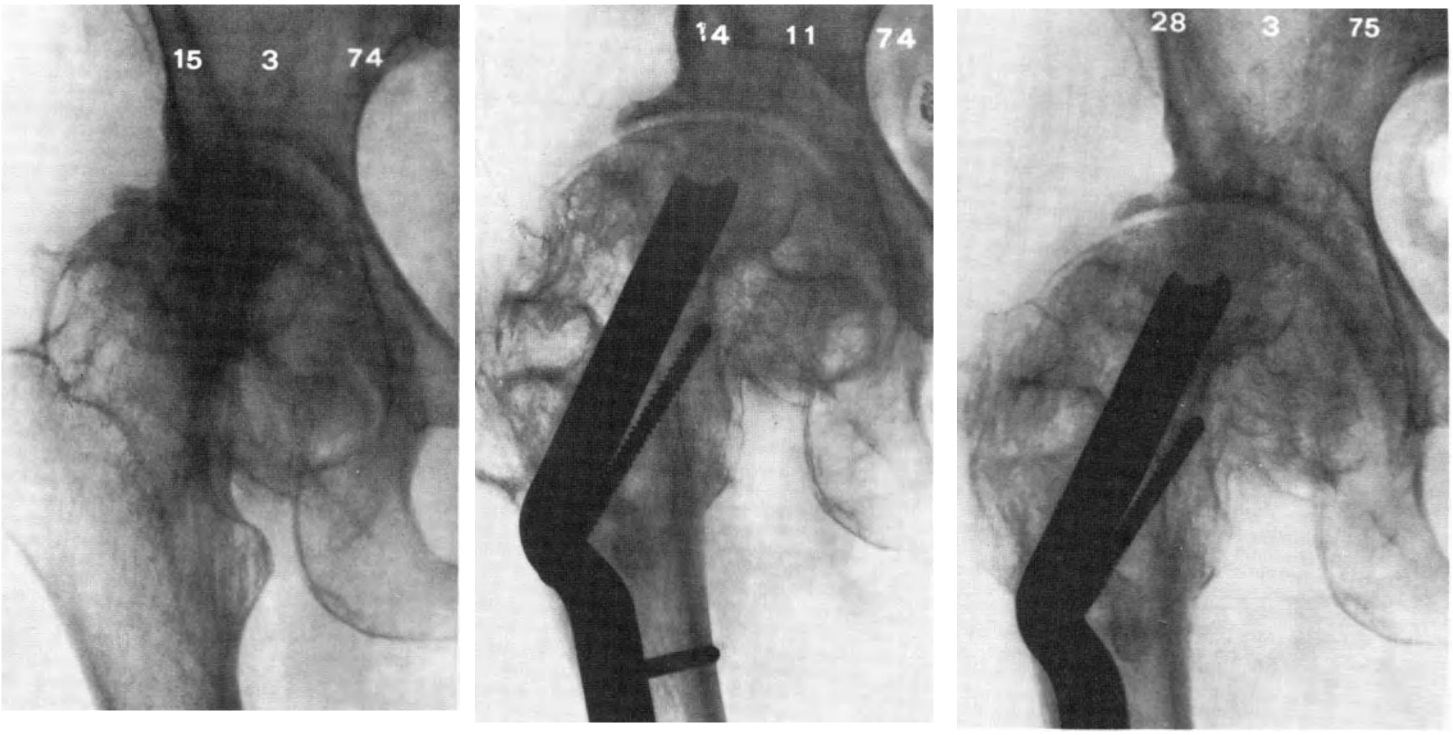


Fig. 81. T.I., age 75. *15–3–74* Severe primary osteoarthritis of right hip. *14–11–74* 8 months after valgus osteotomy of 35°. The joint space has reappeared. Roof osteophyte has become regular and well-shaped. Capital drop and inferior cervical osteophyte have fused and form a pseudo-femoral head. The opposite and converging directions of trabeculae of the two osteophytes is evident. *28–3–75* X-ray result after 12 months

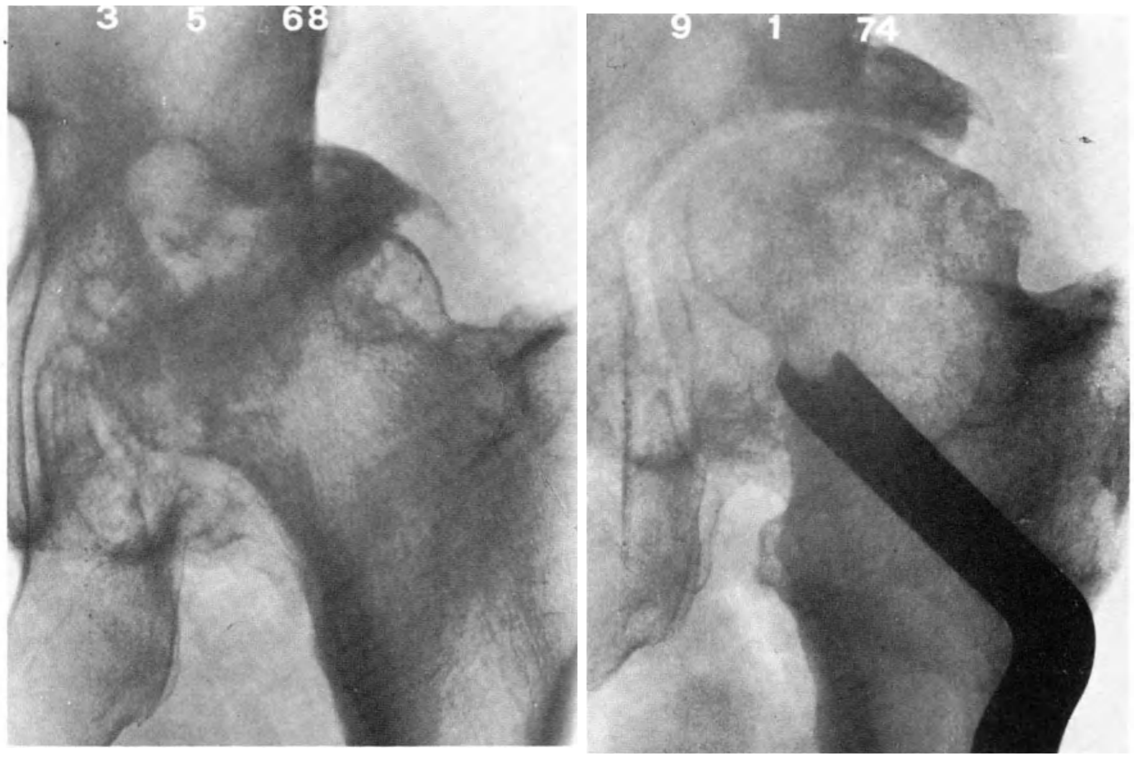


Fig. 82. P.C., age 56. Severe osteoarthritis healed after a valgus osteotomy. *3–5–68* Severe osteoarthritis. *9–1–74* 5 years, 8 months after valgus osteotomy of 30°. Disease has healed. Reconstruction of the joint happened because the head developed a larger diameter, due to fusion of capital drop and inferior cervical osteophyte. Contact areas between this new head and both stout tent osteophyte and roof osteophyte are large. The tension in ligamentum teres and in its synovial membrane have hypertrophized capital drop and tent osteophyte already present before operation. The roof osteophyte, already present, has become stouter because of tension in superior zone of joint capsule and in its synovial membrane after the operation

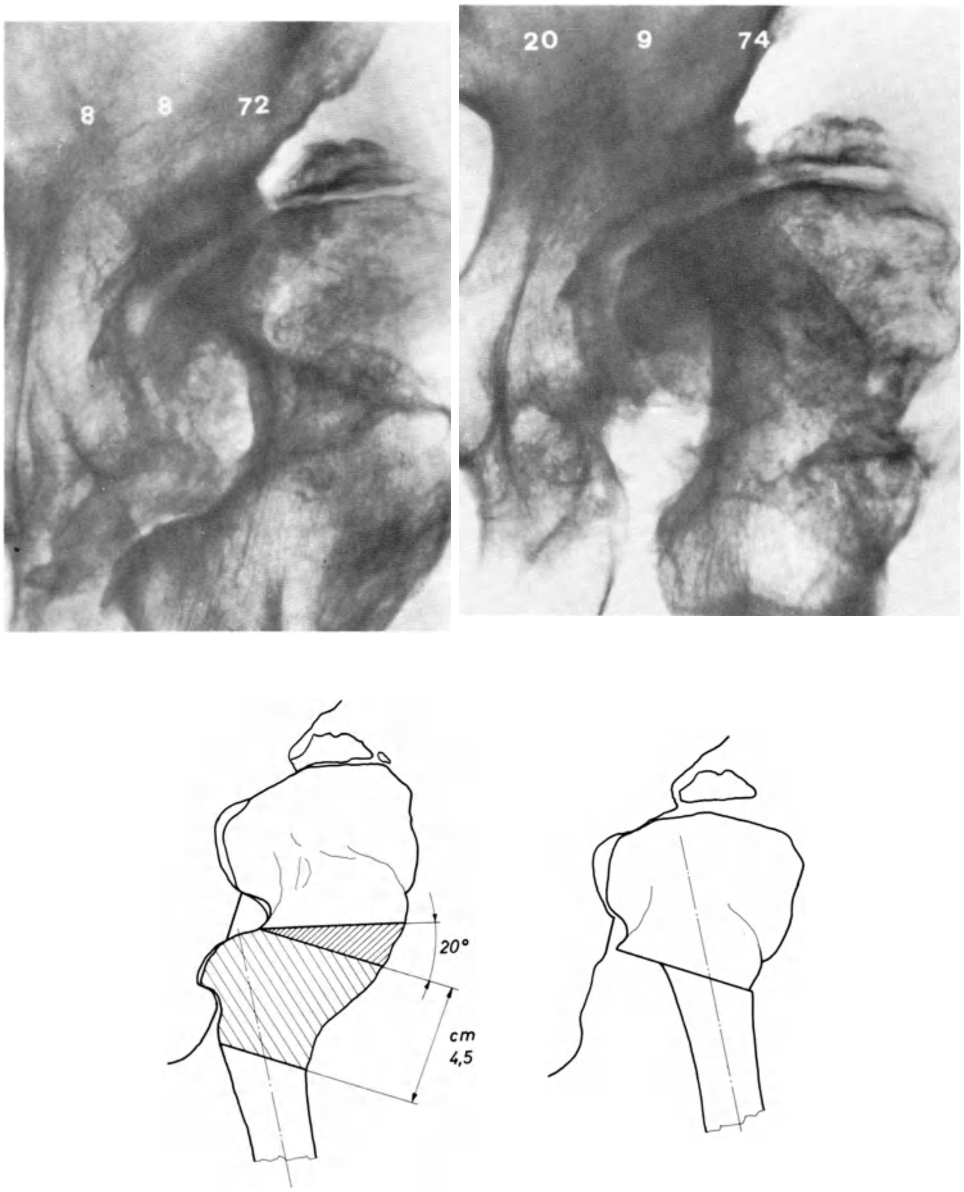


Fig. 83. F.A., age 63. *8—8—72* Osteoarthritis of left hip, secondary to C.D.H. Patient at 3 years of age had poliomyelitis in right limb, which is now 5 cm shorter than the left one. Left femur underwent a Schanz-osteotomy 20 years ago. The movements:

Fl./Ext.	20°	20°	0°
Ab./Add.	30°	30°	0°
Ext./Int.	40°	40°	0°
Lengthening		5 cm	
Pain			

20—9—74 2 years after osteotomy of valgus 20° extension 20°, shortening 5 cm. The joint space is regular. The spur of previous osteotomy and floor osteophyte have been removed. The new roof osteophyte is fusing with the old one, which has suffered a fatigue fracture. Patient walks painlessly. The joint has a nearly full movement

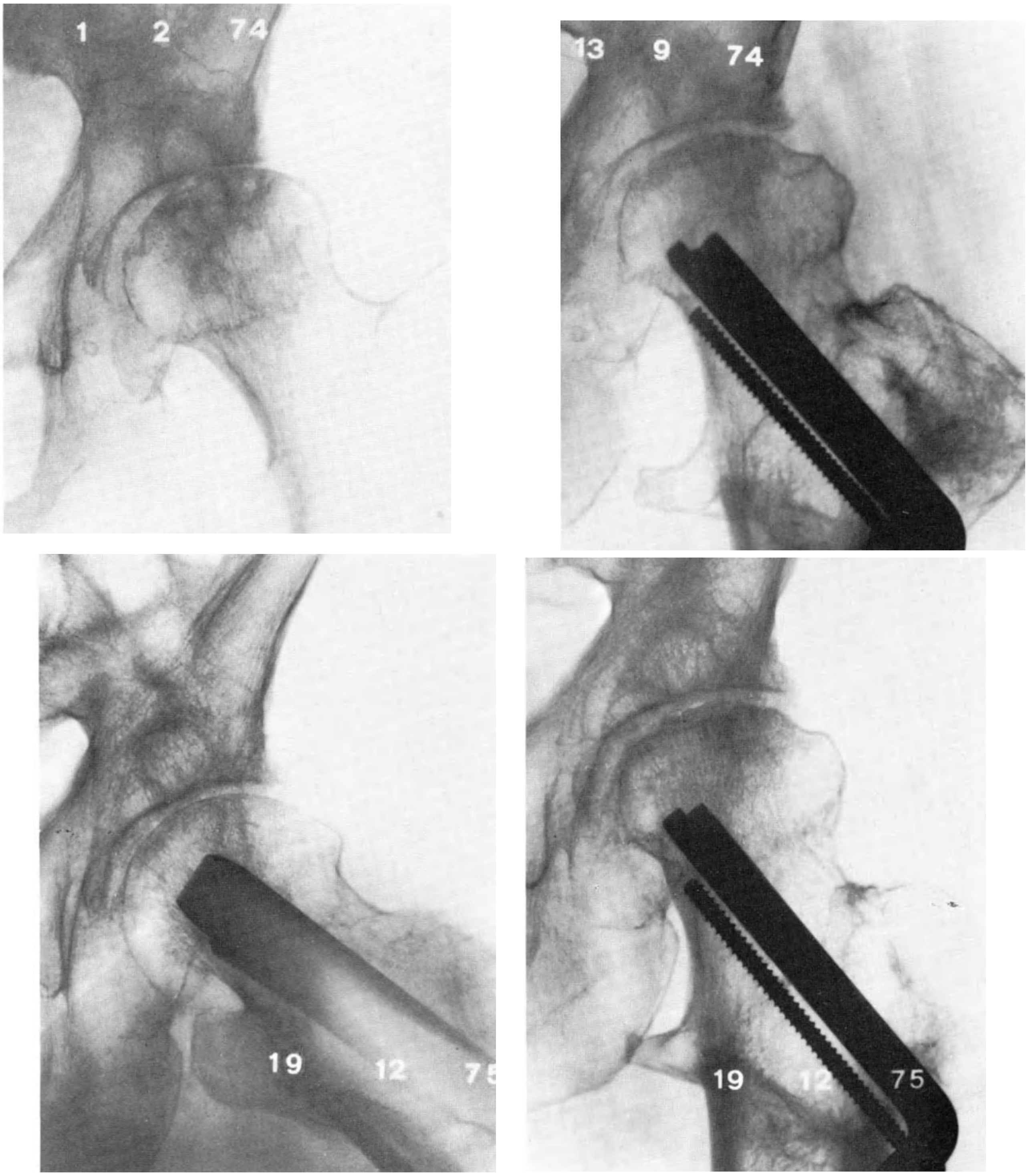


Fig. 84. A.G., age 53. *1–2–74* Primary osteoarthritis of left hip. *13–9–74* 7 months after valgus osteotomy of 30°. *19–12–75* 1 year, 10 months after operation. Femoral head is becoming spherical. The joint space, although not yet normal, has appeared. The joint function is normal and painless

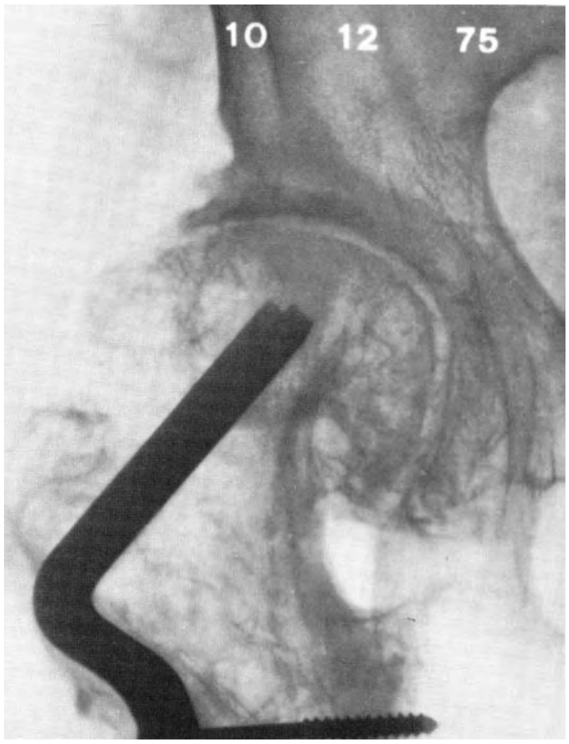
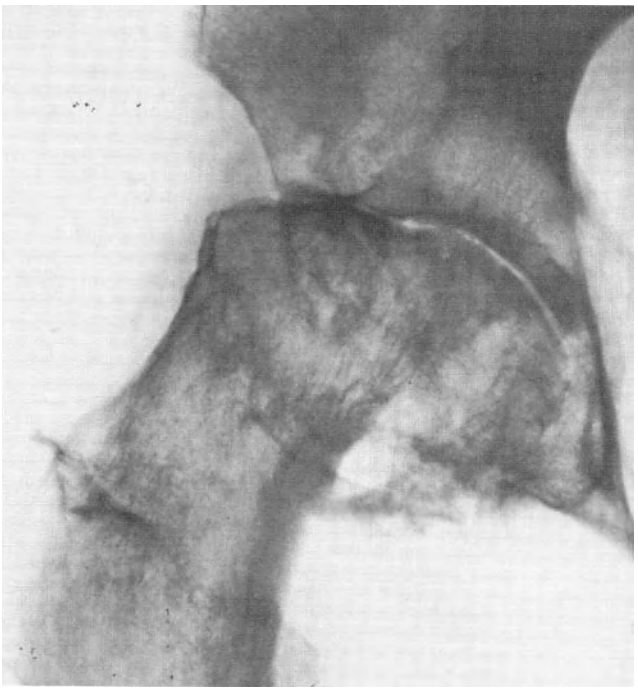


Fig. 85. P.T., age 67. *20–10–69* Primary osteoarthritis of right hip. The joint surface is oblique and force *S* is present. Hip is painful with 40° of flexion; no abduction; 15° of fixed adduction; 4 cm of shortening (real and apparent); pain. *10–12–75* 6 years after valgus osteotomy of 35°. Horizontal direction of joint surface is clearly evident, thanks to a sturdy roof osteophyte. Force *Q* is present. The joint space is regular. Active flexion is 80°; abduction 30°; adduction 40° the external and internal rotation 30°; the real shortening is 1 cm; no pain. Patient is free from pain, walks freely, and climbs mountains



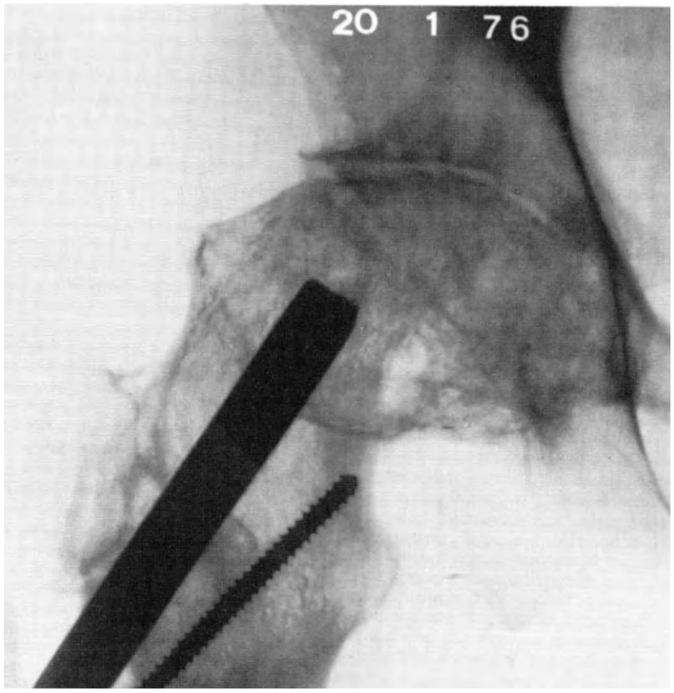


Fig. 86. D.I., age 39. *20–8–74* Secondary osteoarthritis of right hip. Femoral head is nearly out of the socket and has been replaced by new bone formation. This formation is the consequence of the fusion of the capital drop and elephant's trunk osteophyte. Clinically:

Fl./Ext.	60°	40°	0°
Ab./Add.	0°	10°	30°
Ex./Intr.	30°	30°	0°
Shortening		1.5 cm	
Pain			

20–1–76 16 months after osteotomy of valgus 35°-extension 25°. Patient walks without a stick, painlessly. Clinically:

Fl./Ext.	80°	0°	0°
Ab./Add.	20°	0°	30°
Ex./Intr.	20°	0°	20°
No shortening			
No pain			

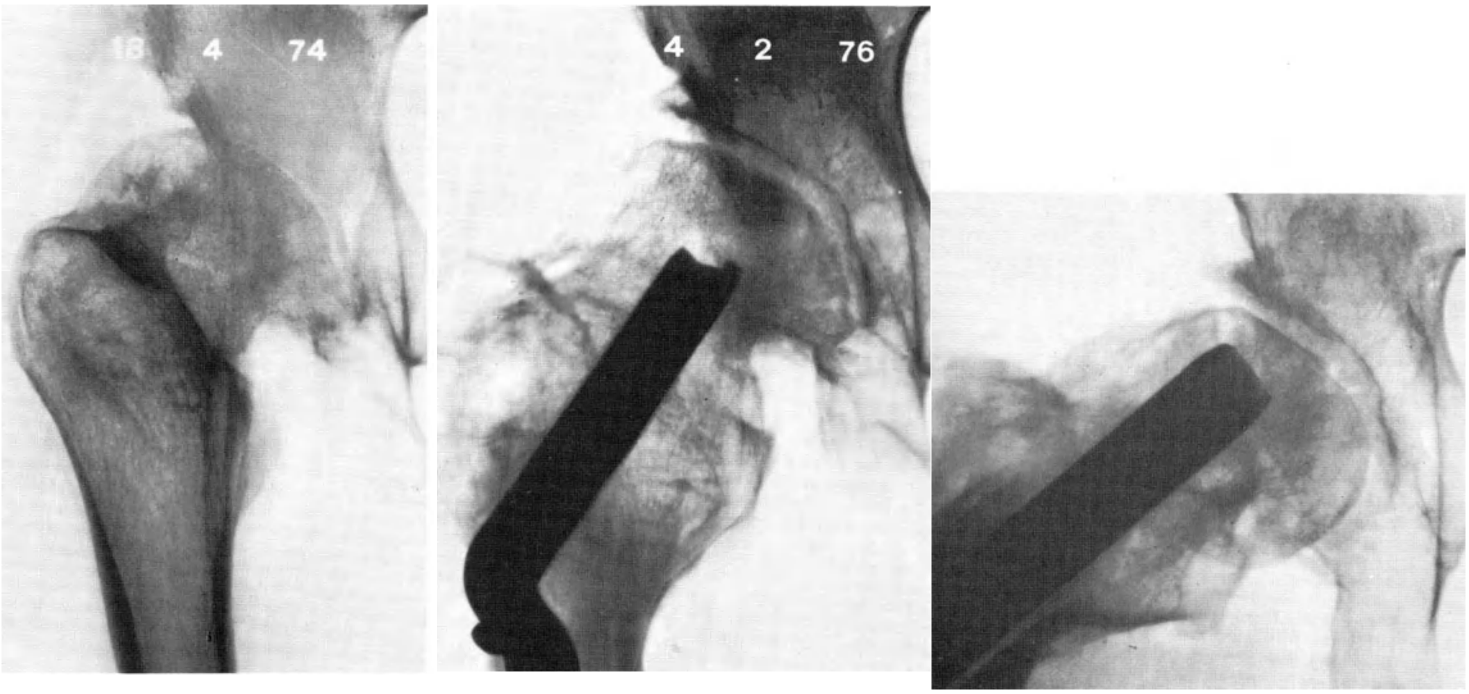


Fig. 87. O.A., age 47. *18–4–74* Secondary osteoarthritis of right hip. *4–2–76* 22 months after osteotomy of valgus 30° extension 20°. Clinically:

Fl./Ext.	90°	0°	0°
Ab./Add.	30°	0°	20°
Ex./Intr.	10°	0°	10°
No shortening			
No pain			

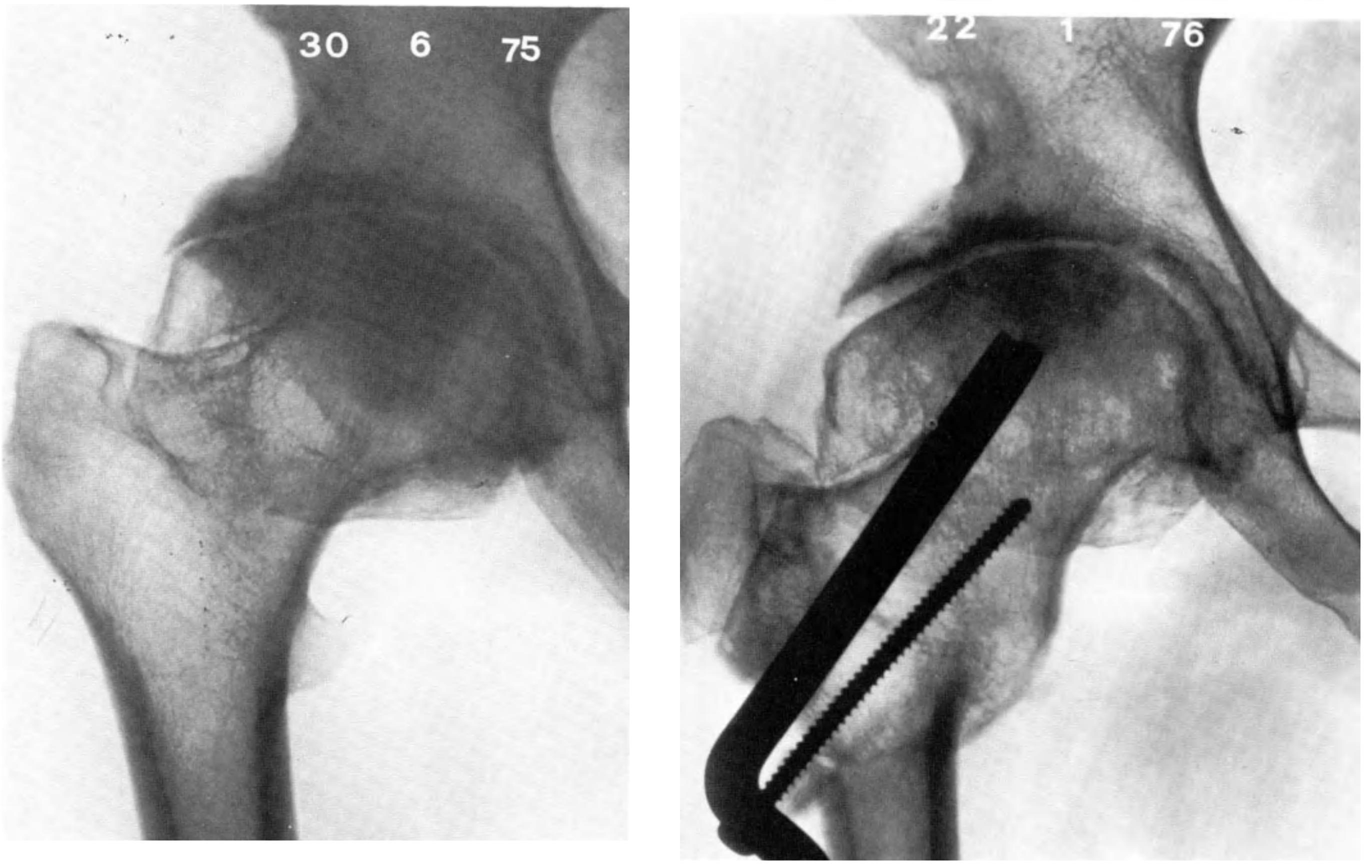


Fig. 88. G.R.M., age 39. *30–6–75* Primary osteoarthritis of right hip. Mega-head due to hypertrophic superior cervical osteophyte. The attempt by nature to achieve a large weight-bearing joint surface is clearly visible. *22–1–76* Widening of the joint surface has been obtained in a short period of time by osteotomy of valgus 35° extension 20°

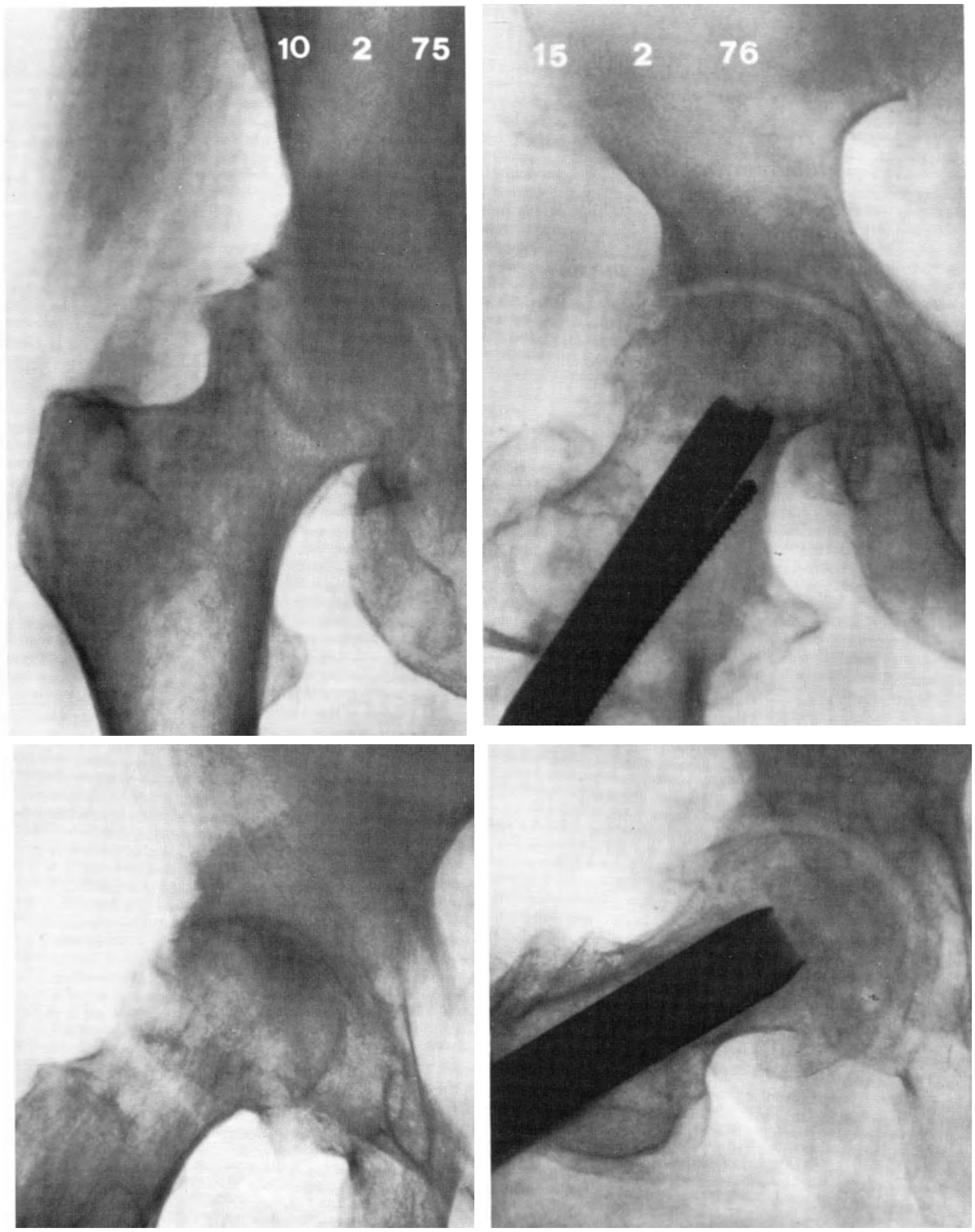
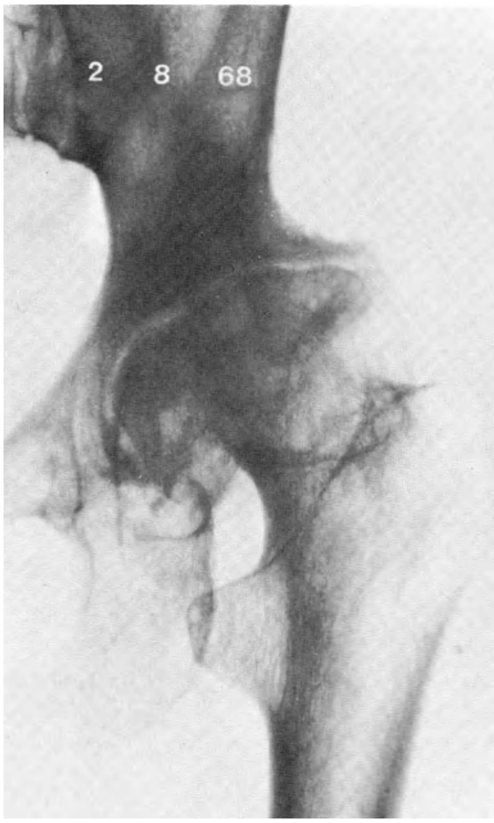


Fig. 89. M.B., age 52. *10–2–75* Primary osteoarthritis of right hip. *15–2–76* X-ray result 1 year after osteotomy of valgus 30° extension 20°. Patient walks without a stick and without limping. Clinically:

Fl./Ext.	80°	0°	0°
Ab./Add.	30°	0°	30°
Ex./Intr.	20°	0°	10°



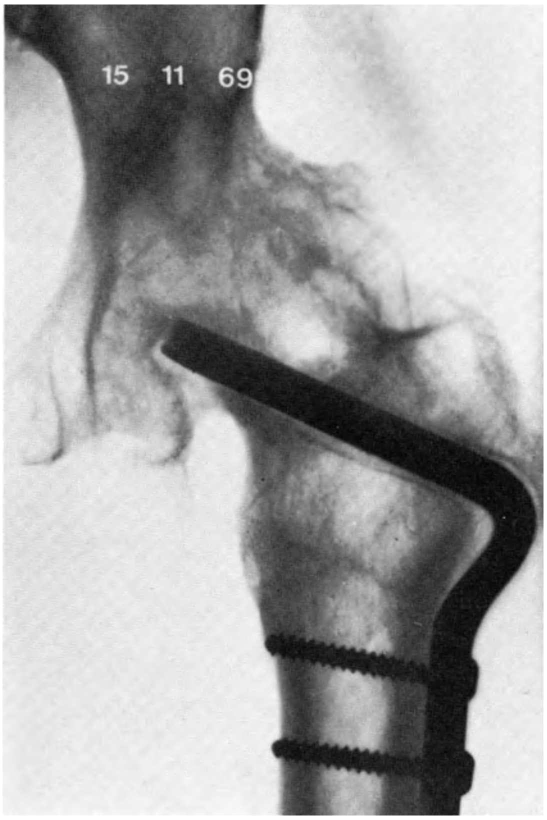


Fig. 90. C.I., age 45. *2–8–68* Secondary osteoarthritis of left hip. Clinically:

15–11–69 Bone fusion in the correct position after valgus osteotomy of 20°. Failure of the osteotomy is probably due to a near absence of movement before operation. Hip is, however, painless and patient is satisfied

Fl./Ext.	30°	30°	0°
Ab./Add.	0°	0°	10°
Ex./Intr.	30°	30°	0°
Limping			
Pain			

II. Varus Osteotomy

1. Indication for Varus Osteotomy

According to PAUWELS (1963, 1965a, b, 1973), the varus osteotomy indicated when it is necessary:

a) To prevent an osteoarthritis of the hip, by correcting a valgus femoral neck, in cases of coxa valga subluxans

b) To heal a developed osteoarthritis of the hip.

But, according to our experience (based on about 250 cases), the varus osteotomy is seldom indicated for a developed osteoarthritis of the hip.

2. Effect of Varus Osteotomy

In coxa valga subluxans the reason for a varus osteotomy is to center the femoral head into the acetabulum, i.e., to make the direction of the resultant force R more horizontal. This is achieved both by raising the greater trochanter cranialward (Fig. 91) and by the disappearance of the pain, which allows the center of gravity S_5 to move medially.

The new direction of the resultant force R causes, in some cases, the disappearance of the force S and the reappearance of the force Q (Fig. 92); in other cases it causes an increase in the force Q (Fig. 93).

This difference is due to the varying inclination of the weight-bearing joint surface.

In osteoarthritis of the hip, the varus osteotomy is indicated in two cases:

1. Before the appearance of the force S, i.e., when the osteophytes are not yet present.
2. In cases in which a round head with a valgus neck and a horizontal weight-bearing surface are present (Fig. 94).

These characteristics are not frequentely combined in a developed osteoarthritis.

When the femoral head is not spherical, a varus osteotomy reduces the weight-bearing joint surface and therefore increases the severity of the osteoarthritis.

It is important to note that even in this case the final result is sometimes not completely disappointing, because the plastic adaptability of bone and the progressively growing osteophytes widen the joint surface. Unfortunately that means, clinically, a longer and more painful period of healing (Fig. 95).

It is thought that the positive effect of a varus osteotomy in an osteoarthritis is due to the increase of the weight-bearing joint surface, to the lengthening of the muscular lever arm, and to the relaxation of the abductors, gluteus medius, and gluteus minimus.

This relaxation causes the temporary appearance of "Trendelenburg's gait." This provokes an inclination of the pelvis toward the opposite side every time the operated hip is leaned on in a monopodal support (stance phase) (Figs. 98 and 99).

Trendelenburg's gait is not permanent; later on it disappears as the gluteus medius and minimus readjust.

In the author's view point, the temporary relaxation of the gluteus medius and minimus, during the first period of 6 months or more after the operation, makes the resultant force R of the abductors much more horizontal.

This is because the piriformis is not relaxed by the raising of the greater trochanter and it exerts a powerful force to compensate for the decreased action of the gluteus medius and minimus. Therefore the resultant force R and the counter-resultant force R_1 also become more horizontal. Force Q is increased, pushing the head into the acetabulum, even if the weight-bearing joint surface is not horizontal.

The inclination of the weight-bearing joint surface is not, in this first period, of primary importance (Fig. 99).

During the second period, however, when the gluteus medius and minimus have readjusted in length and tone (and Trendelenburg's gait has therefore disappeared), the resultant force of the abductors becomes more vertical again and force R and force R_1 also become more vertical.

Force Q is thus reduced and force P increased.

Now the inclination of the weight-bearing joint surface becomes important. If it is horizontal, forces P and Q will have a normal magnitude and the joint will function normally (Fig. 93); if it is oblique, force Q will be correspondingly reduced and force P again increased, causing the patient pain (Fig. 92).

Force P will now wear away the acetabular surface and the femoral head, increasing the obliquity of the weight-bearing joint surface. Finally force Q will disappear (point of reversal) and force S will reappear pushing the head out of the acetabulum (Fig. 97).

In fact, when the patient feels pain, he shifts his center of gravity toward the painful limb and accelerates this whole process, making force S appear earlier.

Proof that a varus osteotomy has been correctly indicated is given, at a variable period of time after the operation, by:

1. Reappearance of the joint space
2. No reappearance or no increase of the roof, superior cervical, capital drop, tent osteophyte
3. Good and painless joint function.

3. Technique of Varus Osteotomy

A varus osteotomy always shortens the femur.

The figures (Figs. 106–109) indicate the exact amount of shortening, in cases where no bone wedge or a bone wedge of full- or halfthickness is removed.

When a bone wedge must be removed, it is advisable to cut it from the distal fragment, otherwise the ADAM's arch becomes weakened (Fig. 103).

It is always useful to divide the tendon of the ileopsoas, to reduce the permanent pressure on the joint.

The femoral shaft must be shifted inward for two reasons:

1. To prevent a varus in the knee
2. To prevent too high a bending stress and strain in the neck of the femur.

The "AO 90° angled plate" is, in the author's opinion, advisable. If a 90° angled plate is utilized and a varus of 20° is necessary, the chisel preparing the blade channel must be introduced into the neck of the femur at an angle of 70° to the axis of the shaft. Usually, on the frontal plane, the angle between the chisel and axis of the shaft of the femur must be 90° minus the value of the wedge to be removed.

Therefore: to obtain a varus of 10°:
$90° - 10° = 80°$

to obtain a varus of 20°:
$90° - 20° = 70°$

to obtain a varus of 30°:
$90° - 30° = 60°$

and so on (Fig. 104).

The varus osteotomy in some cases must be combined with an extension or flexion or derotation osteotomy.

The degree of varus osteotomy must be such as to restore normal biomechanics in the hip.

If normal biomechanics is not achieved (Figs. 95 and 97) the force *S*, in spite of varus osteotomy, reappears and incessantly pushes the head out of the socket, as the hypertrophic osteophytes testify later.

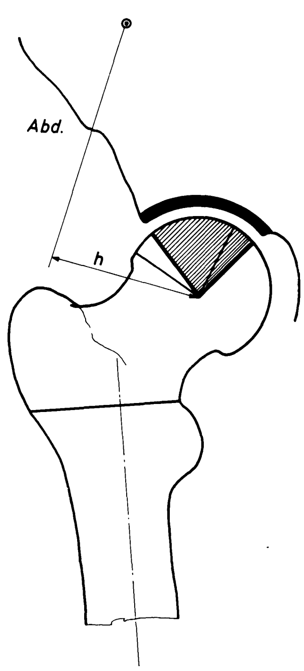
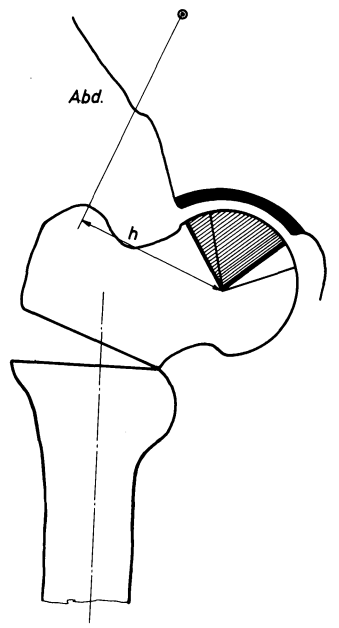


Fig. 91. Effects of a varus osteotomy.
The varus osteotomy achieves three results: 1. a) Relaxation of the gluteus medius and minimus due to raising greater trochanter. b) Relaxation of the hamstrings due to their being shortened. 2. Increase in length of the muscular lever arm. 3. Centering of femoral head into the acetabulum, by making direction of the resultant force *R* more horizontal.



Centering of the femoral head does not obtain an inreased covering of head by acetabulum. In fact, with varus osteotomy, a part of the lateral quadrants of the head becomes covered, but a corresponding part of medial quadrants becomes uncovered

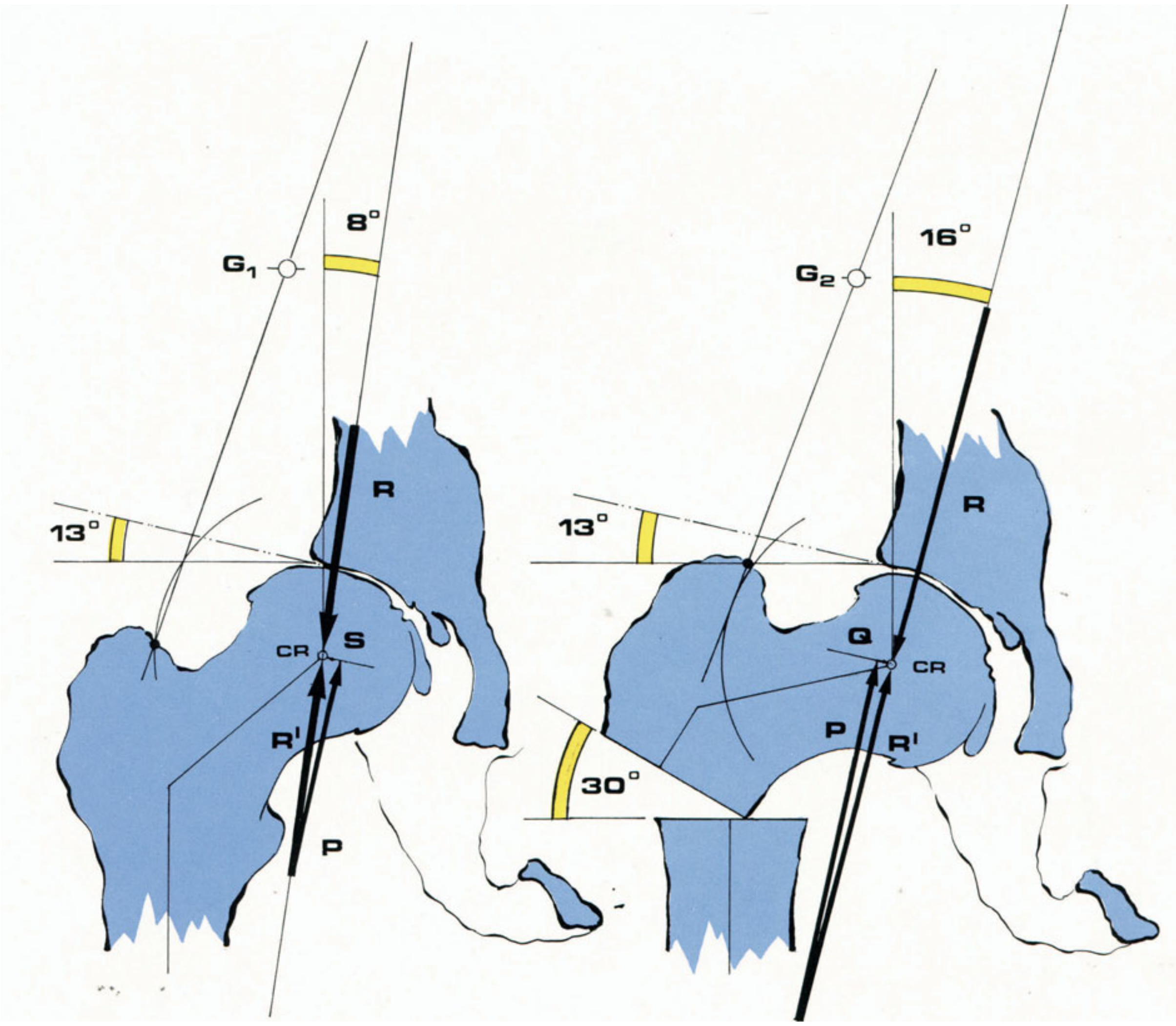


Fig. 92. Change from force S to force Q by varus osteotomy.

In this figure we see a case of osteoarthritis of the hip in which varus osteotomy of 30° has been performed causing a raising of greater trochanter and an increase in weight-bearing joint surface. For this last reason the patient no longer has any pain and does not displace center of gravity of his body toward hip. Resultant force R has inclination of 16°, counter-resultant force R_1 has same inclination and its component forces are now P and Q. This means that by varus osteotomy force S has been removed and force Q has been generated. In spite of this procedure we have not yet obtained a normal biomechanical situation, because the acetabular roof is still slanting and force Q is small and force P is very high. This force P compresses and gradually flattens femoral head and acetabulum, progressively increasing the obliquity of weight-bearing joint surface. For this reason force Q slowly disappears and force S appears, pushing head out of socket and building up osteophytes. In short, in case like this, in the author's viewpoint, the varus osteotomy is not indicated. (See Fig. 97)

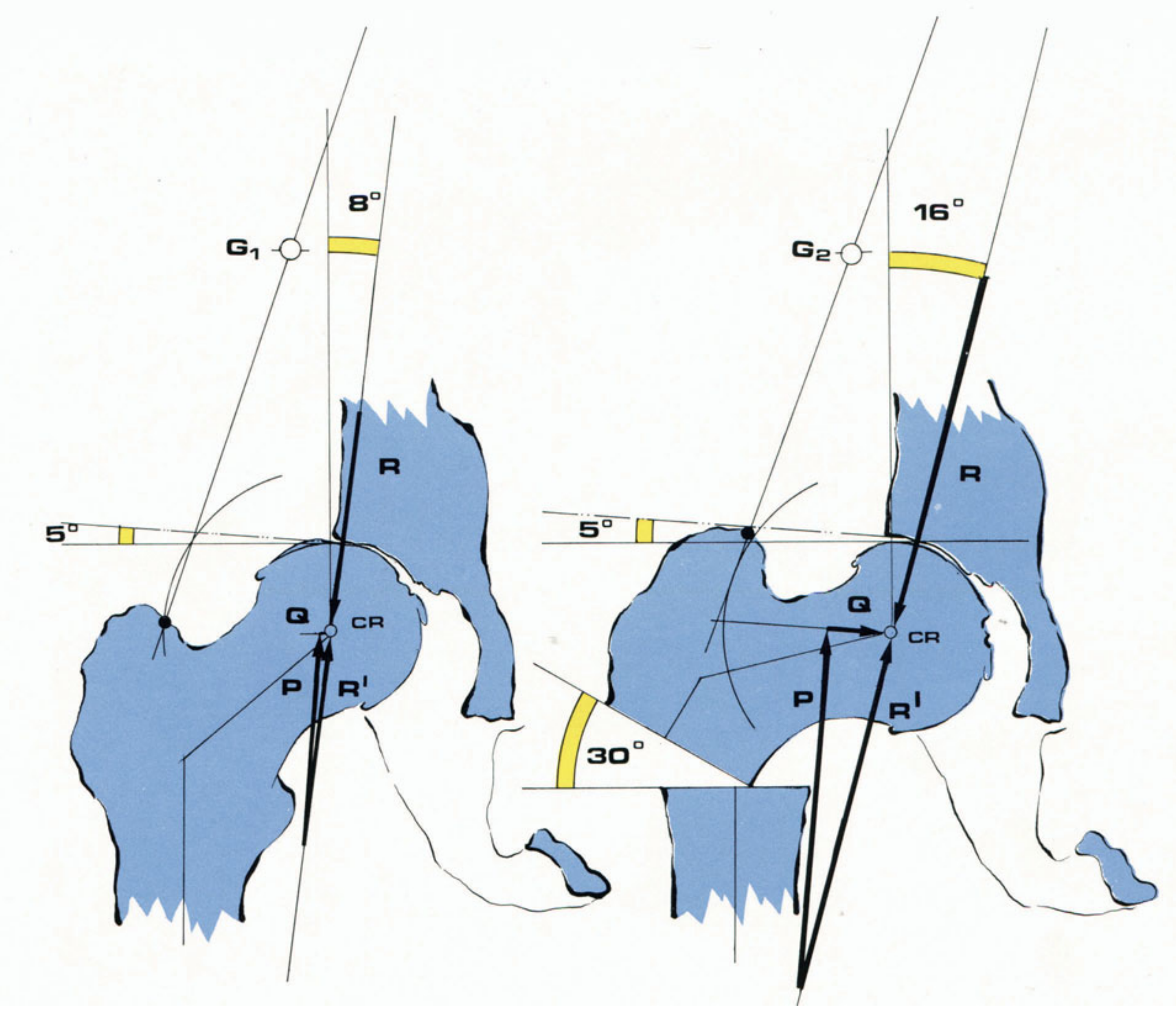


Fig. 93. Change from small to large force Q by varus osteotomy. Figure shows that the anatomical situation is closely similar to preceding one, except for obliquity of the roof which is now 5°. The component forces of counter-resultant force R_1 are a high P and a low Q. After operation of 30° of varus, the biomechanical state of the hip is normal. The magnitude of force Q is increased because force R is more oblique. This is due to raising of greater trochanter and to the fact that the patient no longer displaces his center of gravity toward the hip, which is now not painful. This is a suitable case for varus osteotomy

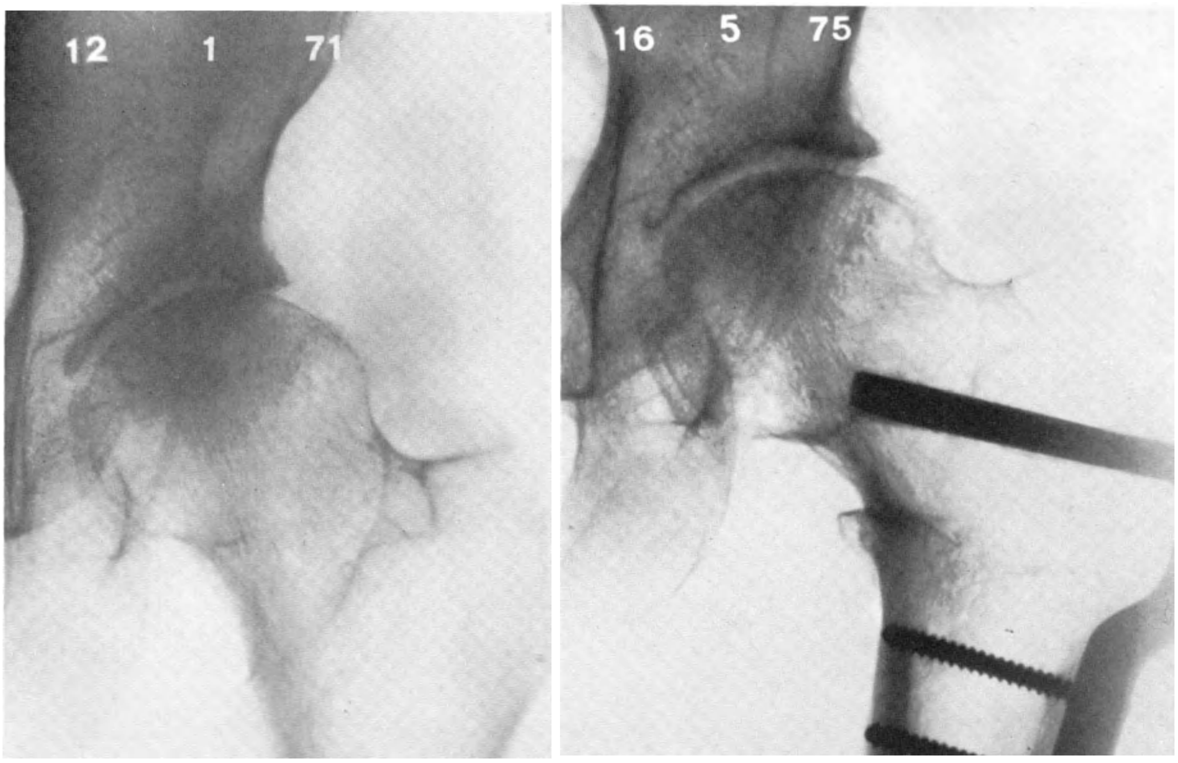
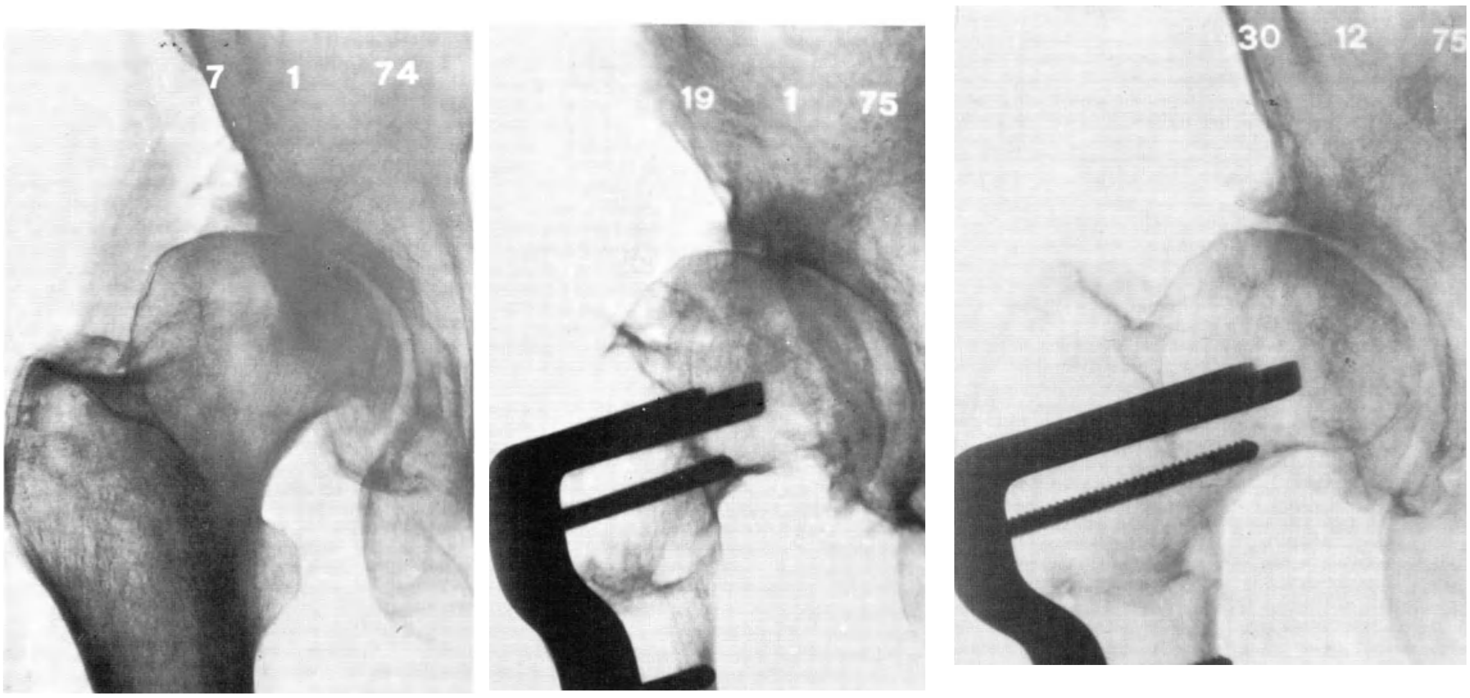


Fig. 94. R.D., age 41. *12—1—71* Primary osteoarthritis of left hip. Femoral head is spherical. The weight-bearing surface is horizontal. Force *S* has not yet appeared; little osteophyte of the socket (tent osteophyte) and osteophytes of head are due to increased force *P*, as zones of increased bone density demonstrate. *16—5—75* 4 years, 4 months after varus osteotomy of 20°. Because of increased force *Q* and decreased force *P* the disease has healed



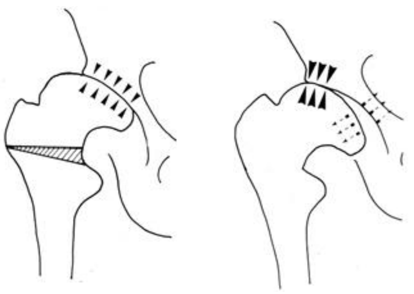


Fig. 95. Legend see opposite page

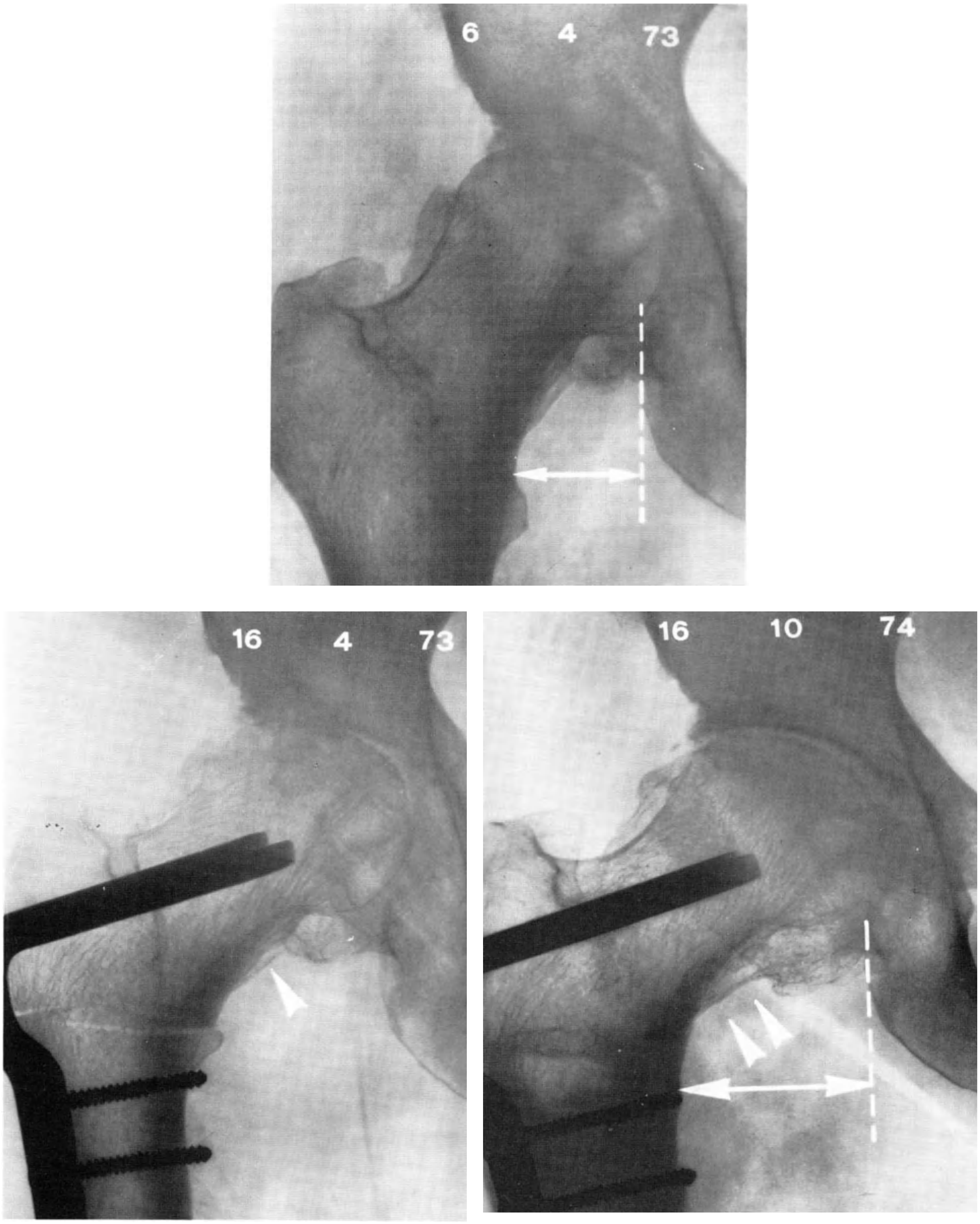


Fig. 96. R.R., age 51. *6–4–73* Primary osteoarthritis of right hip. *16–4–73* 10 days after varus osteotomy of 20°. *16–10–74* 1 year, 6 months after operation. Because ADAM's arch is further away from lower margin of acetabulum, inferior capsule and synovial membrane covering inferior part of neck of femur, are much more stretched than before the operation. The inferior cervical osteophyte, already present before the operation, has therefore increased

◁ **Fig. 95.** C.M., age 49. *7–1–74* Right osteoarthritis secondary to coxa valga subluxans. Because head had seemed spherical, varus osteotomy of 20° was performed. *19–1–75* 1 year after operation. Joint shows no improvement. This operation has clearly been a mistake, because head was not as spherical as it had appeared and therefore the joint space, after operation, is not uniform. Pressure is concentrated only on superior quadrants of head and on superolateral part of acetabulum. Direction of weight-bearing joint surface is more oblique, upward and outward, than before. Force *S* has therefore been increased. *30–12–75* 2 years after operation. In spite of previous mistake, the joint is healing, thanks to the plastic adaptability of the bone and progressive growth of osteophytes. These osteophytes are the result of persisting force *S*.

This example shows how deceiving X-ray may sometimes be. We should note that the presence of a capital drop would have suggested valgus osteotomy, which would have achieved a complete healing of the joint in a shorter period of time

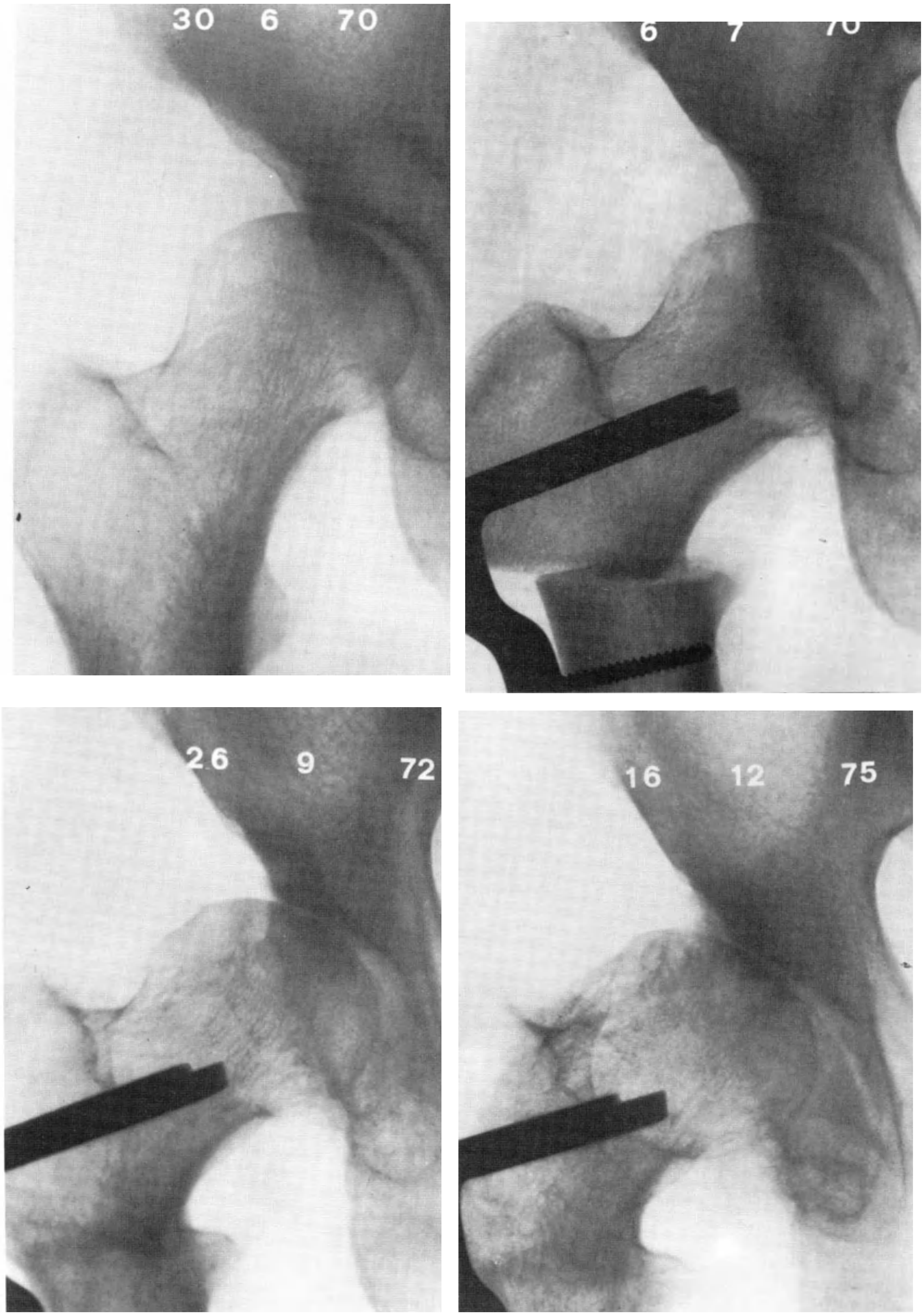


Fig. 97. S.E., age 32. *30–6–70* Secondary osteoarthritis of right hip, operated on with varus osteotomy of 20°.
When angle of varus osteotomy is insufficient, the head persists in slipping out of the socket, because force *S* is still present. It is instructive to note progressive increase (due to force *S*) in capital drop already present on *30–6–70* and in inferior cervical osteophyte. Roof osteophyte has also appeared (*16–12–75*)

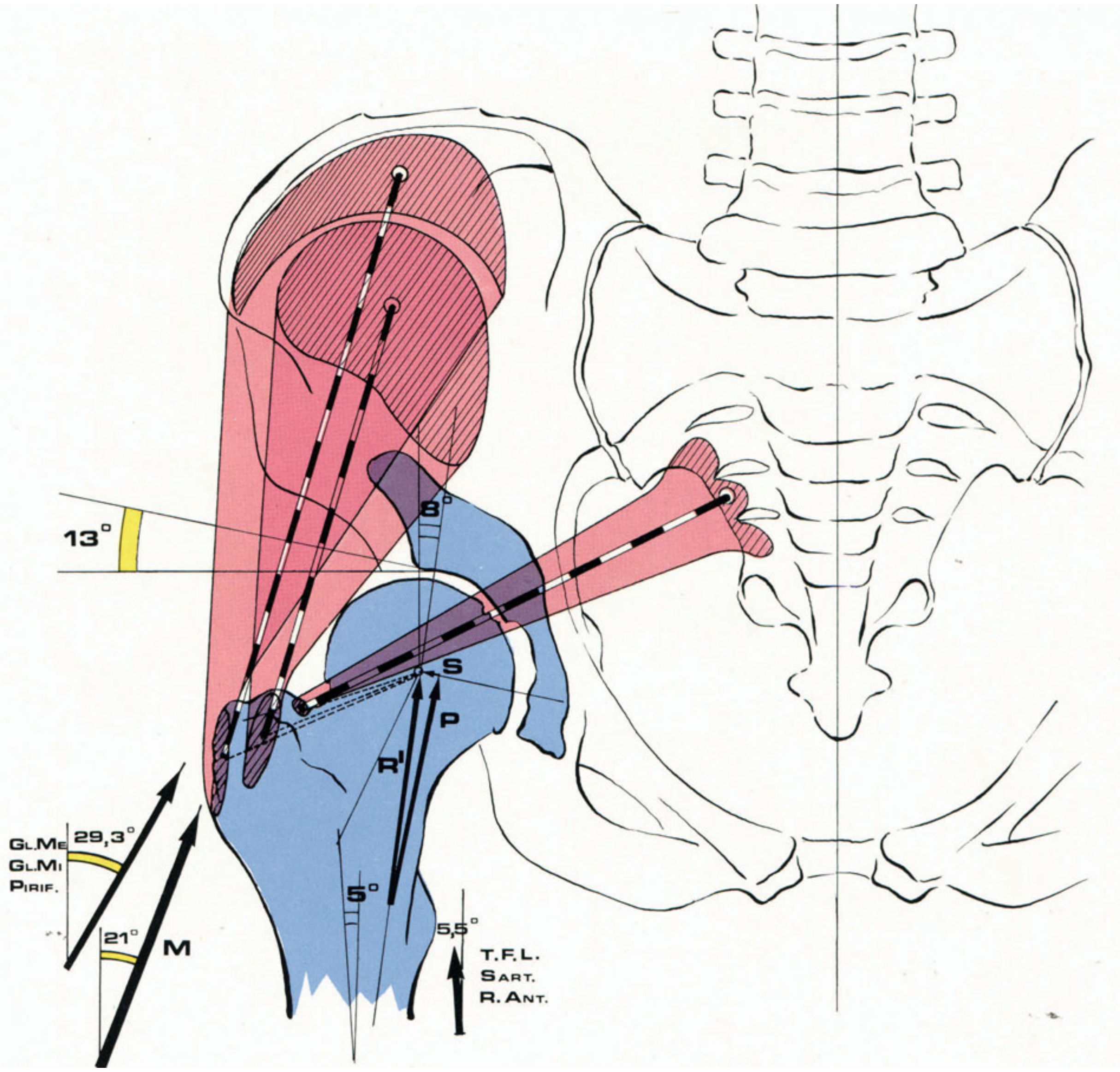


Fig. 98. The direction of resultant muscular force *M* of abductors in a normal hip has been deduced by FISCHER (1889). He considers two groups of abductors: 1. Gluteus medius, gluteus minimus and piriformis. 2. Tensor fasciae latae, sartorius, rectus femoris
In the 16th position of the stance phase resultant muscular force of first group of muscles has a cranioposteromedial direction inclined at 29.3° to the vertical; resultant muscular force of second group of muscles has a craniolateral direction of 5.5°; resultant muscular force of two groups has cranioposteromedial direction of 21°. Figure shows gluteus medius and minimus and piriformis and component forces *P* and *Q* of counter-resultant force R_1, when the shaft-neck angle of femur is 150° and inclination of weight-bearing joint surface is 13°. Because of pain the patient has displaced center of gravity of his body toward painful hip during the stance phase. Resultant force *R* therefore has an inclination of 8° (instead of 16° as in a normal hip), counter-resultant force R_1 has same inclination and acts in opposite direction. Force *S* pushes femur head, which in this case is spherical, out of acetabulum. It seems ideal case for varus osteotomy

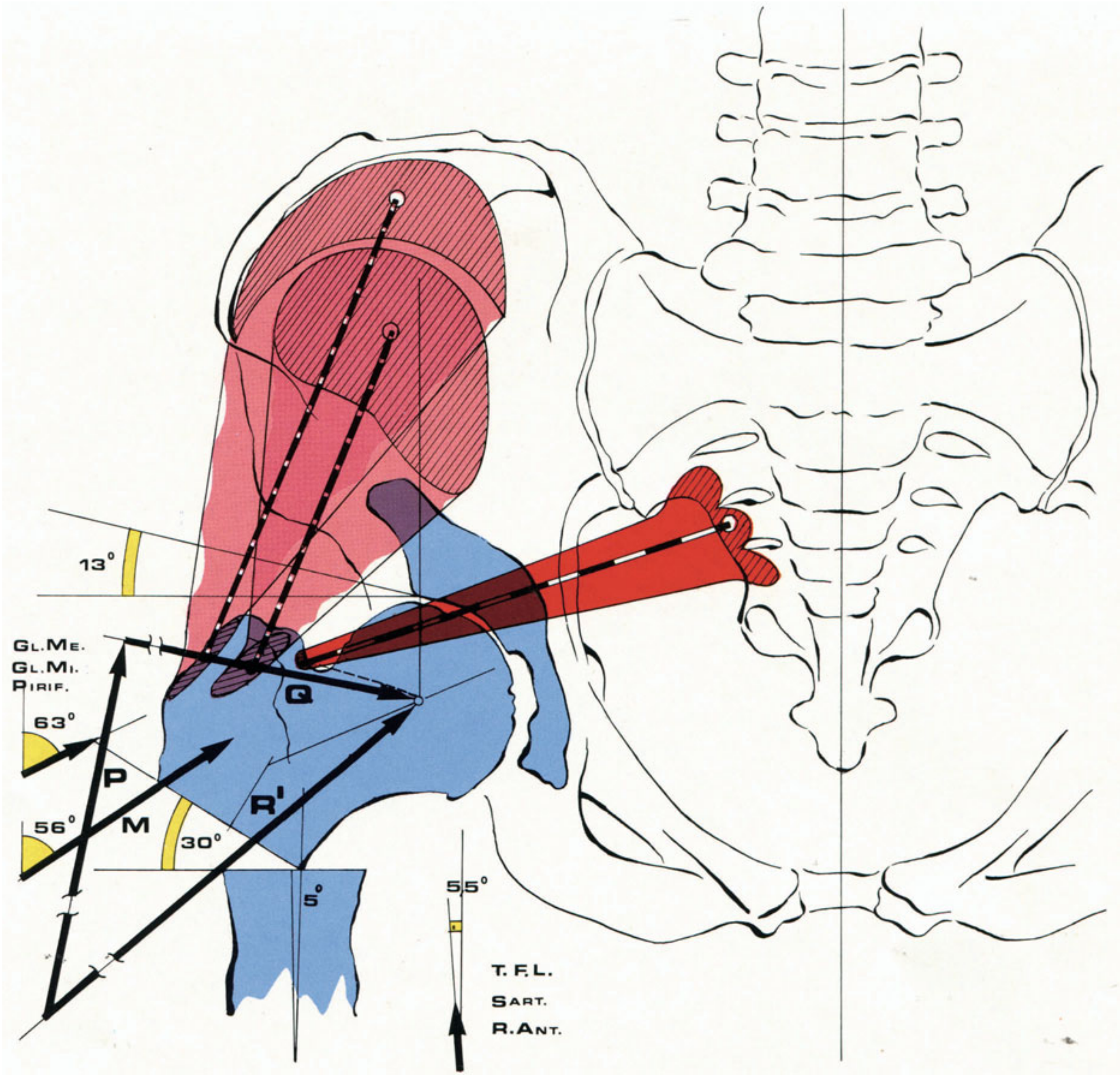


Fig. 99. Figure shows biomechanical situation of abductor muscles after a varus osteotomy. We can distinguish two periods after the operation: the *first* one, when gluteus medius and gluteus minimus are relaxed because of raising of greater trochanter; the *second* one, when these two muscles have readjusted their length and their tone. During the *first* period the only abductor muscle to be barely affected by the raising of greater trochanter and by the shortening of femur, is piriformis, whose fibres are horizontal. This moderately strong muscle, during stance phase, must exert a powerful action to compensate for decreased action of gluteus medius and minimus. Resultant force of these three muscles is therefore more horizontal than normally. For this reason resultant force R and counter-resultant force R_1 also become more horizontal. Component force Q becomes increased and pushes femoral head into acetabulum, compensating to some extent for inclination of acetabular roof. During the *second* period, when length and tone of gluteus medius and minimus have been readjusted, resultant muscular force becomes more vertical and therefore resultant force R and counter-resultant force R_1 become more vertical. For this reason its component force Q is reduced. Force P is high and in the long run wears away head and acetabulum, making weight-bearing joint surface even more oblique. Thus force Q progressively decreases to zero (point of reversal), after which force S appears. This force pushes femoral head out of acetabulum. In the second period the efficacy of the operation is entirely dependent on inclination of acetabular roof (Figs. 92 and 93)

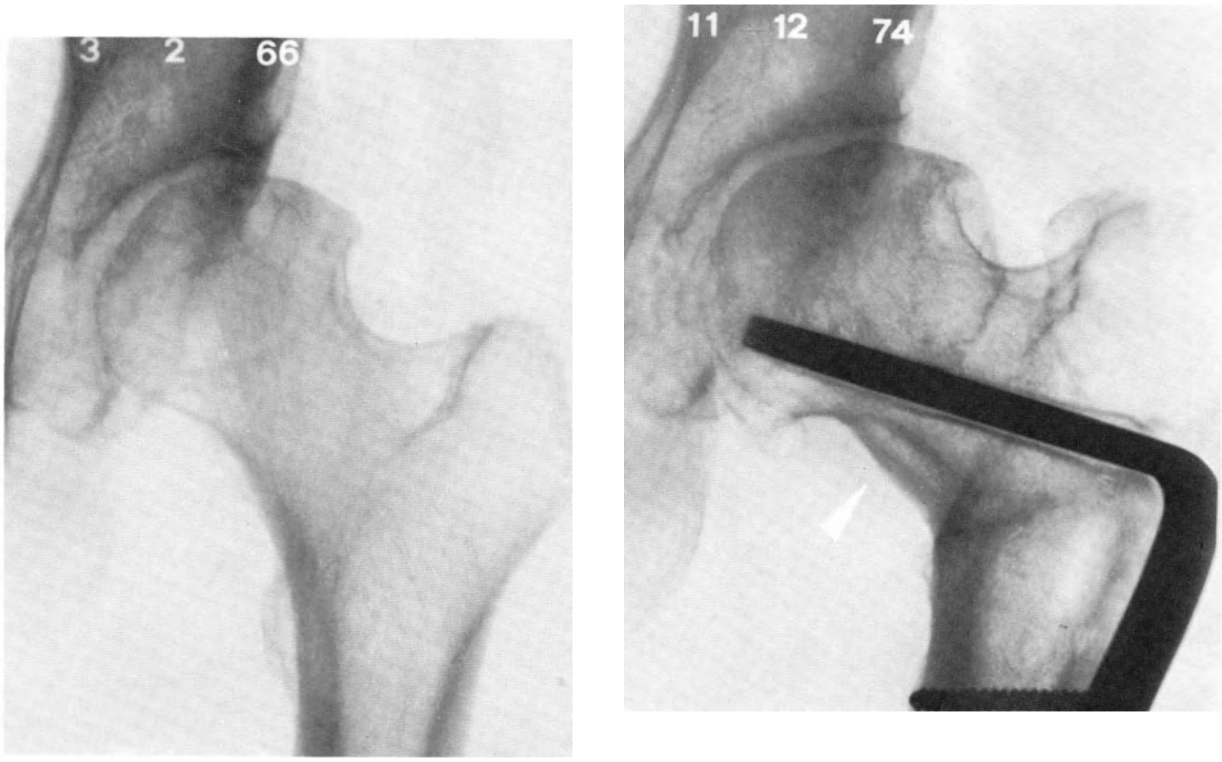


Fig. 100. G.G., age 49. *3–2–66* Secondary osteoarthritis in coxa valga. *11–12–74* 8 years, 10 months after varus osteotomy of 25°. Result is satisfactory because force Q has been increased, as the weight-bearing joint surface was horizontal before operation

Fig. 101. B.M., age 32. *14–9–71* Secondary osteoarthritis of right hip. *20–1–76* 4 years, 4 months after varus osteotomy of 20°. Hip joint has healed because before operation femoral head was spherical and weight-bearing joint surface was horizontal

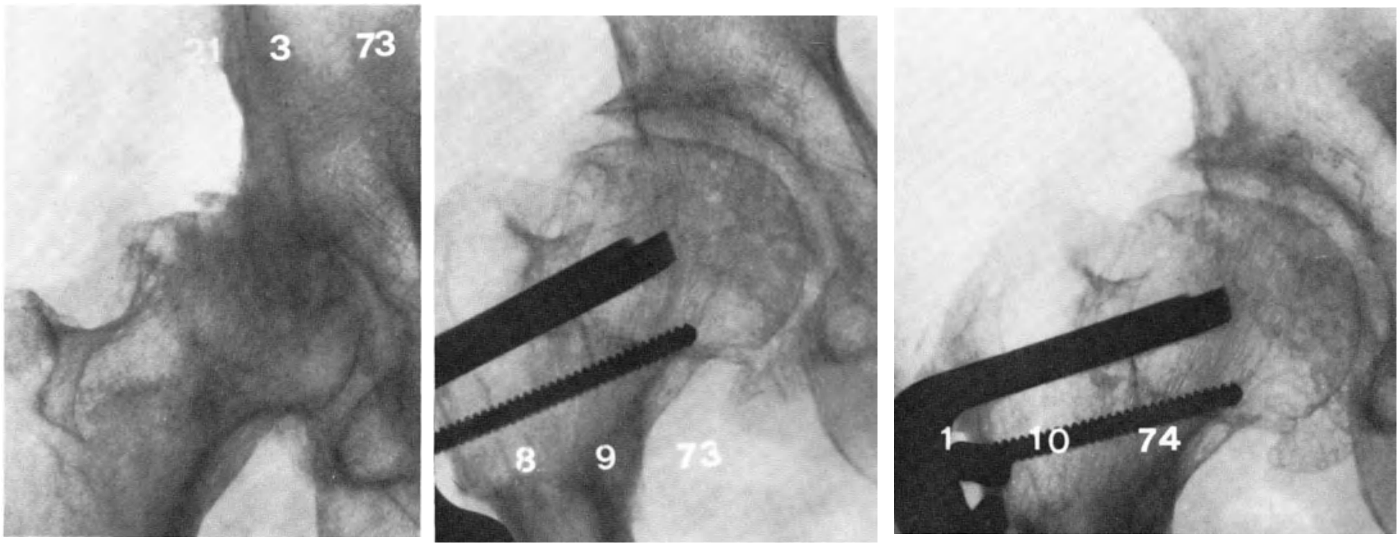


Fig. 102. L.A., age 57. *21—3—73* Primary osteoarthritis of right hip. Force *S* has caused femoral head to glide upward and outward. Osteophytes are clearly visible: (a) on the head: superior cervical osteophyte, inferior cervical osteophyte, coming probably from Amantini's plica and capital drop; (b) on the acetabulum: roof osteophyte. *8—9—73* 6 months after varus osteotomy of 20°. The joint space and bone structure are becoming normal. *1—10—74* 19 months after operation. The joint space is normal, head spherical; zones of increased bone density have disappeared.
Result is satisfactory. Probably a slight shifting of head has occurred, as hypertrophied roof osteophyte may testify

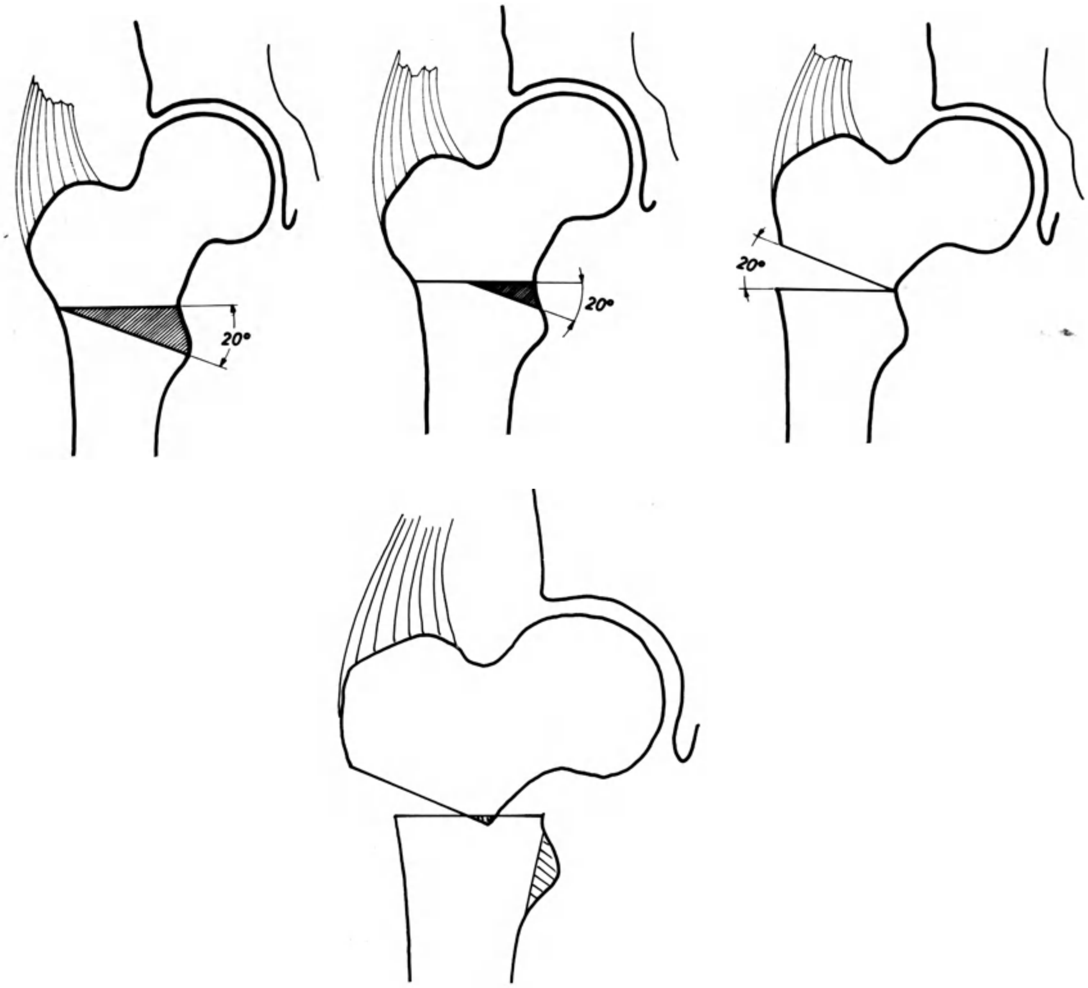


Fig. 103. A varus osteotomy can be obtained by: 1. Removing a full-thickness bone wedge. 2. Removing a half-thickness bone wedge. 3. Dividing transversly the intertrochanteric region of femur and, without removing any bone wedge, shifting superior fragment upward.
When a bone wedge must be removed, it is advisable to cut it from the distal fragment, otherwise ADAM's arch becomes weakened. It is always useful to divide the tendon of the ileopsoas to reduce constant pressure on joint. The femoral shaft must be shifted inwards for two reasons: 1. to prevent a varus in the knee; 2. to prevent too high a bending stress in neck of femur

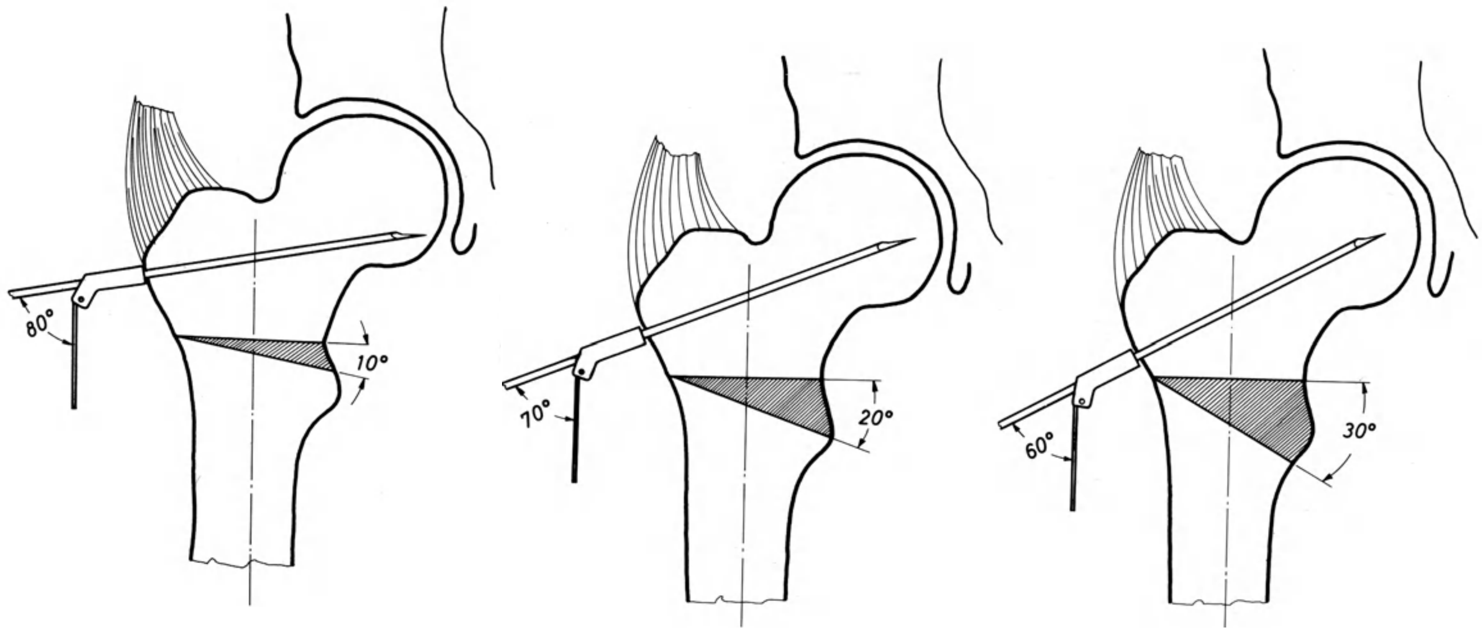


Fig. 104. This figure shows how to insert the chisel to prepare the blade channel for varus osteotomy.
The angle formed by chisel and shaft of femur, using a 90° angle plate, must be 90° less the value of the angle of bone wedge to remove.

To obtain 10° of varus the angle must be 90°−10°=80°
To obtain 20° the angle must be 90°−20°=70°
To obtain 30° the angle must be 90°−30°=60°

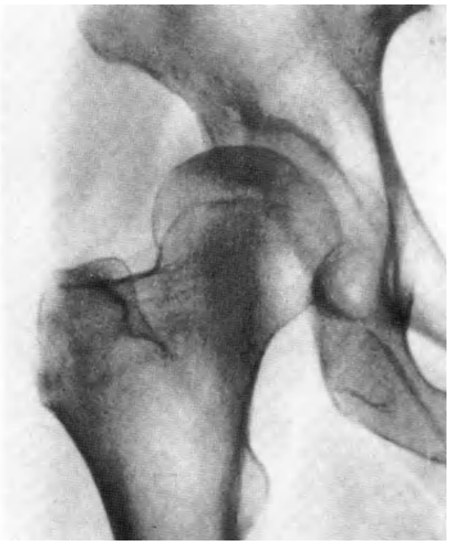
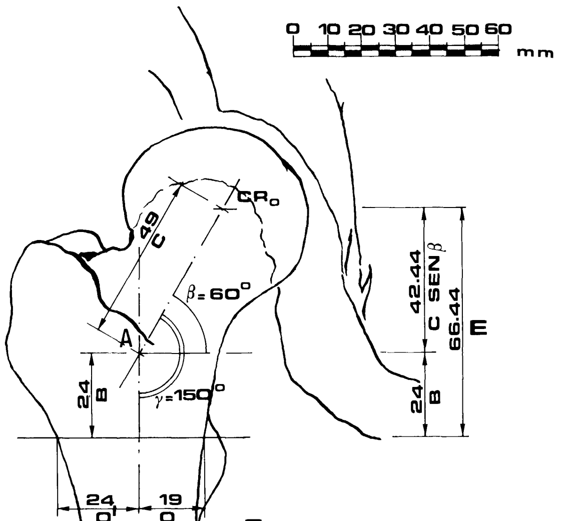


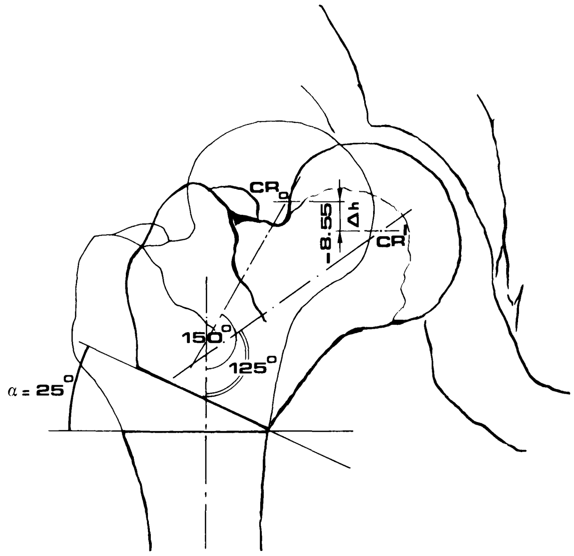
Fig. 105. Mathematical formulae are available to calculate length of the femur after a varus osteotomy. The outline of the proximal part of femur, taken from an anteroposterior X-ray, is drawn on tracing paper. Center of rotation of the original femoral head *CR* is determined. We are considering femoral head previous to the process of osteoarthritis. In fact, looking attentively at the anteroposterior X-ray, the outline of original head looms out. Axis of the shaft and axis of the neck are marked, which at their point of intersection *A* form an angle γ, which is called CCD angle. The length of neck is called *C*. This is the distance between points *A* and *CR*. Angle γ less 90° is called β. Angle of varus we have previously calculated with our tracing paper is called α. About 2.5 cm below point *A* horizontal cut of the osteotomy is traced. *E* is vertical distance between *CR* and the through horizontal cut of the osteotomy. O'' is width of metaphysis at level of horizontal cut. Usually, axis of shaft cuts this width into two different parts: O' and O. Figure 105 helps us to fix key-points of our hip and to use formulae according to the type of varus osteotomy. From formulae we can calculate $E\alpha$, that is, the new vertical distance between *CR* and the plane through horizontal cut of the osteotomy. The previous distance *E* is compared to $E\alpha$ and the difference in height Δ is combined. X-ray is taken at 1 m of distance focus/film and at 20 cm of distance femur/film. With these distances the magnification rate is 1.125:1. Final result Δh must be divided by 1.125. (See also figures on page 116)



$E = B + C \text{ SEN } \beta$

$E = 24 + 49 \text{ SEN } 60° = 66.44$

NO WEDGE REMOVAL

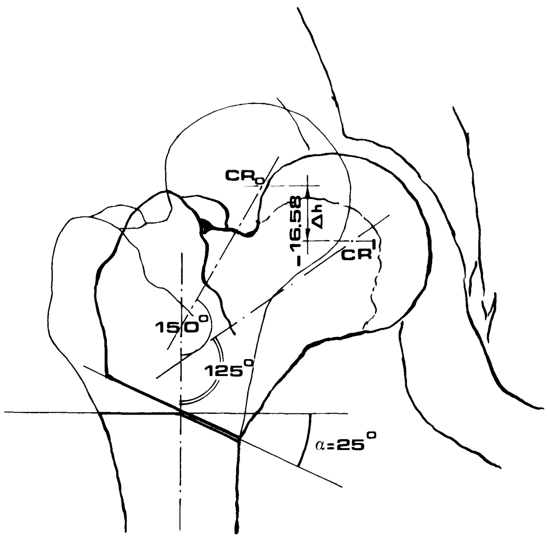


$E\alpha = B \text{ COS } \alpha + C \text{ SEN } (\beta - \alpha) + O \text{ SEN } \alpha$

$E\alpha = 24 \text{ COS } 25° + 49 \text{ SEN } (60° - 25°) + 19 \text{ SEN } 25 = 57.89$

$\Delta h = E\alpha - E$ $\quad \Delta h = 57.89 - 66.44 = -8.55$

PARTIAL WEDGE REMOVAL

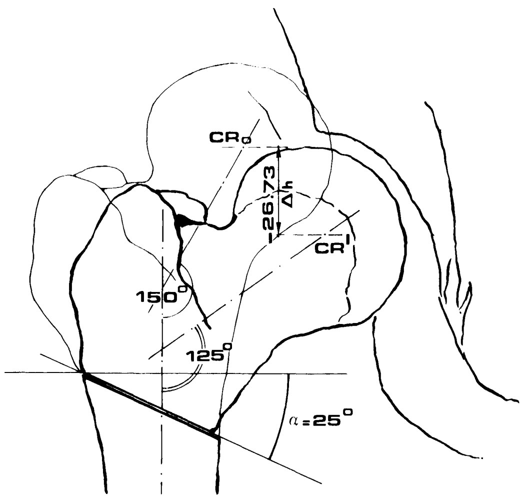


$E\alpha = B \text{ COS } \alpha + C \text{ SEN } (\beta - \alpha)$

$E\alpha = 24 \text{ COS } 25° + 49 \text{ SEN } (60° - 25°) = 49.86$

$\Delta h = 49.86 - 66.44 = -16.58$

COMPLETE WEDGE REMOVAL

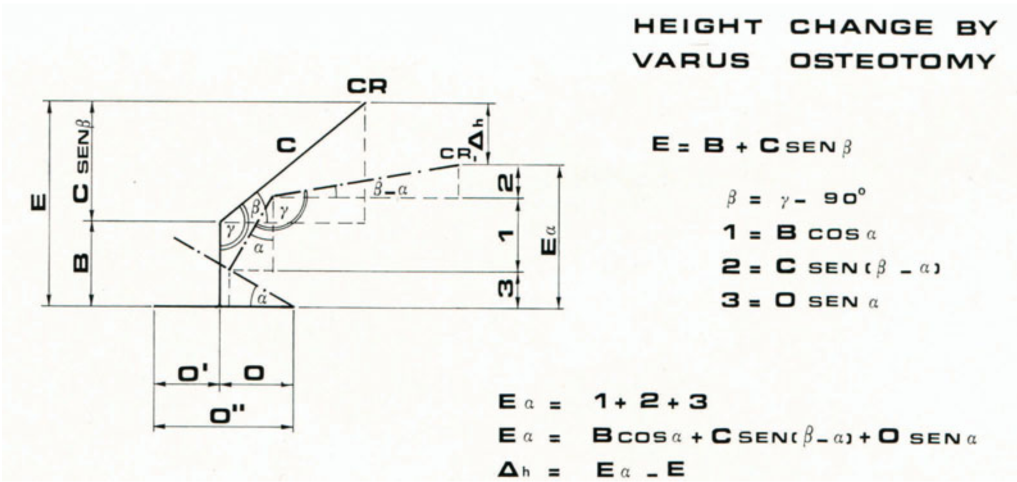


$E\alpha = B \text{ COS } \alpha + C \text{ SEN } (\beta - \alpha) - O' \text{ SEN } \alpha$

$E\alpha = 24 \text{ COS } 25° + 49 \text{ SEN } (60° - 25°) - 24 \text{ SEN } 25° = 39.71$

$\Delta h = 39.71 - 66.44 = -26.73$

Fig. 105 (continued). Legend see page 115



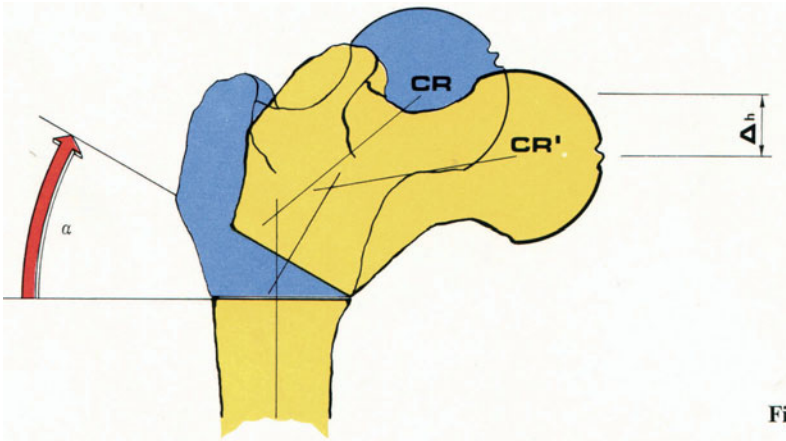
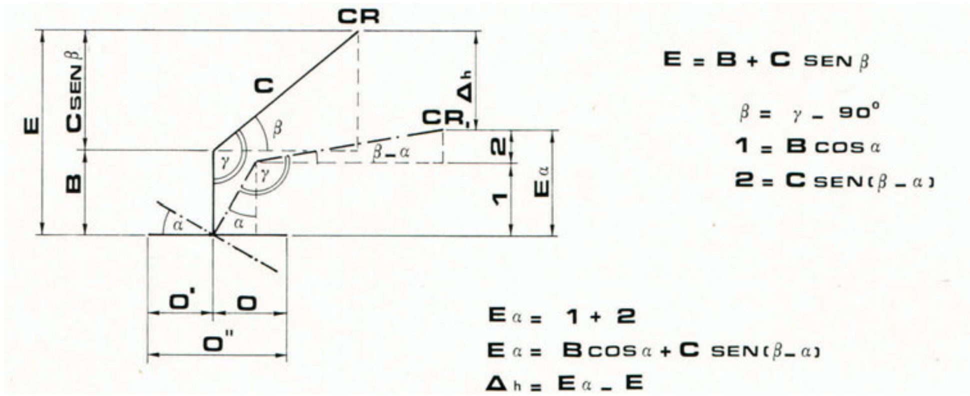


Fig. 106. For explanation see Fig. 108



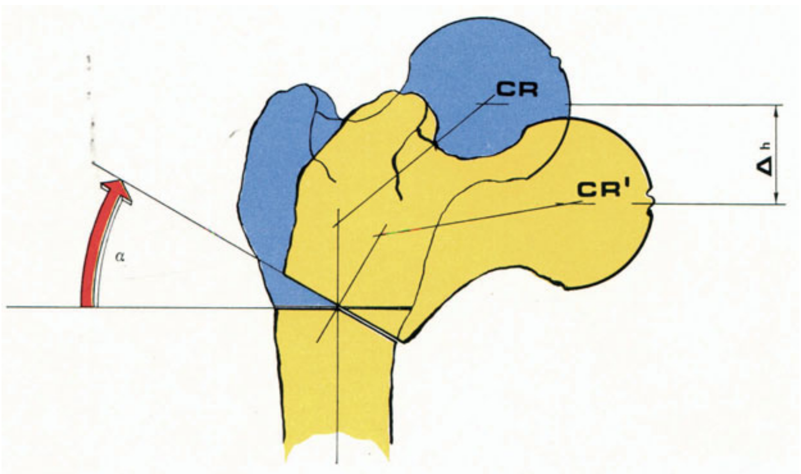


Fig. 107. For explanation see Fig. 108

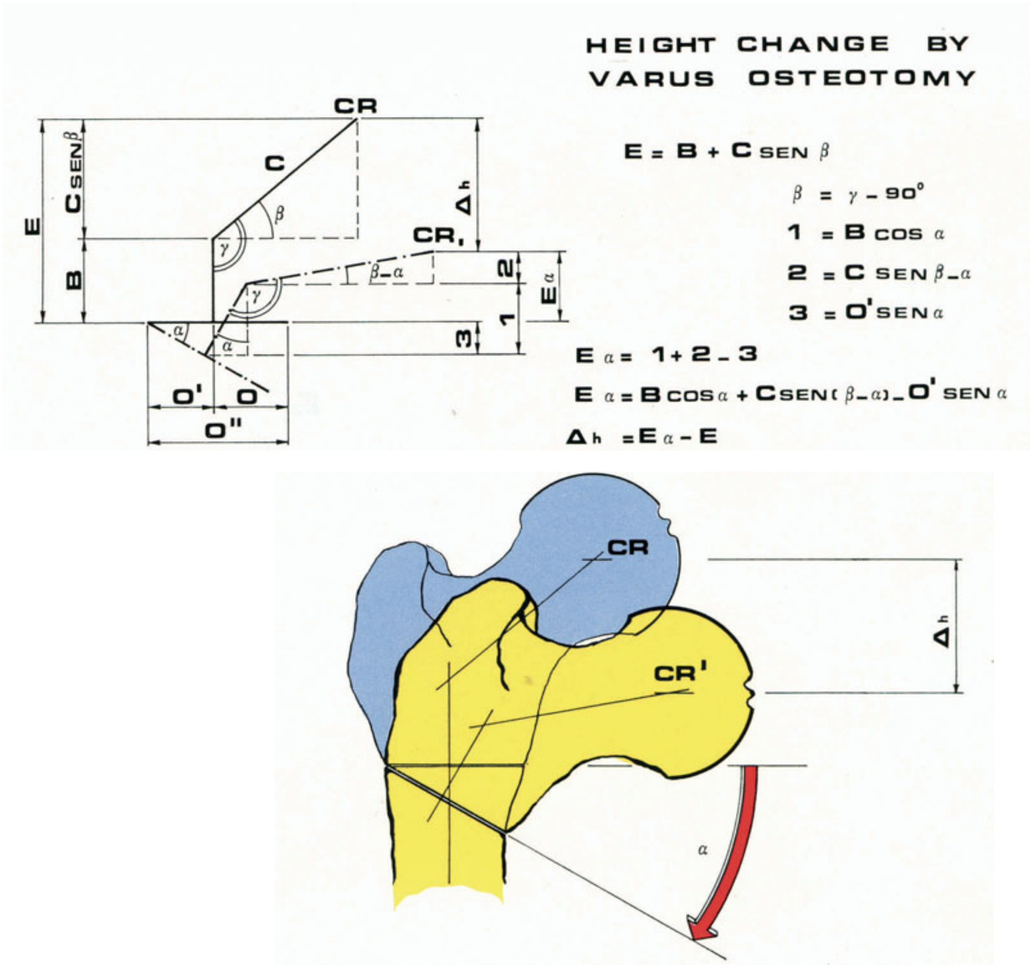
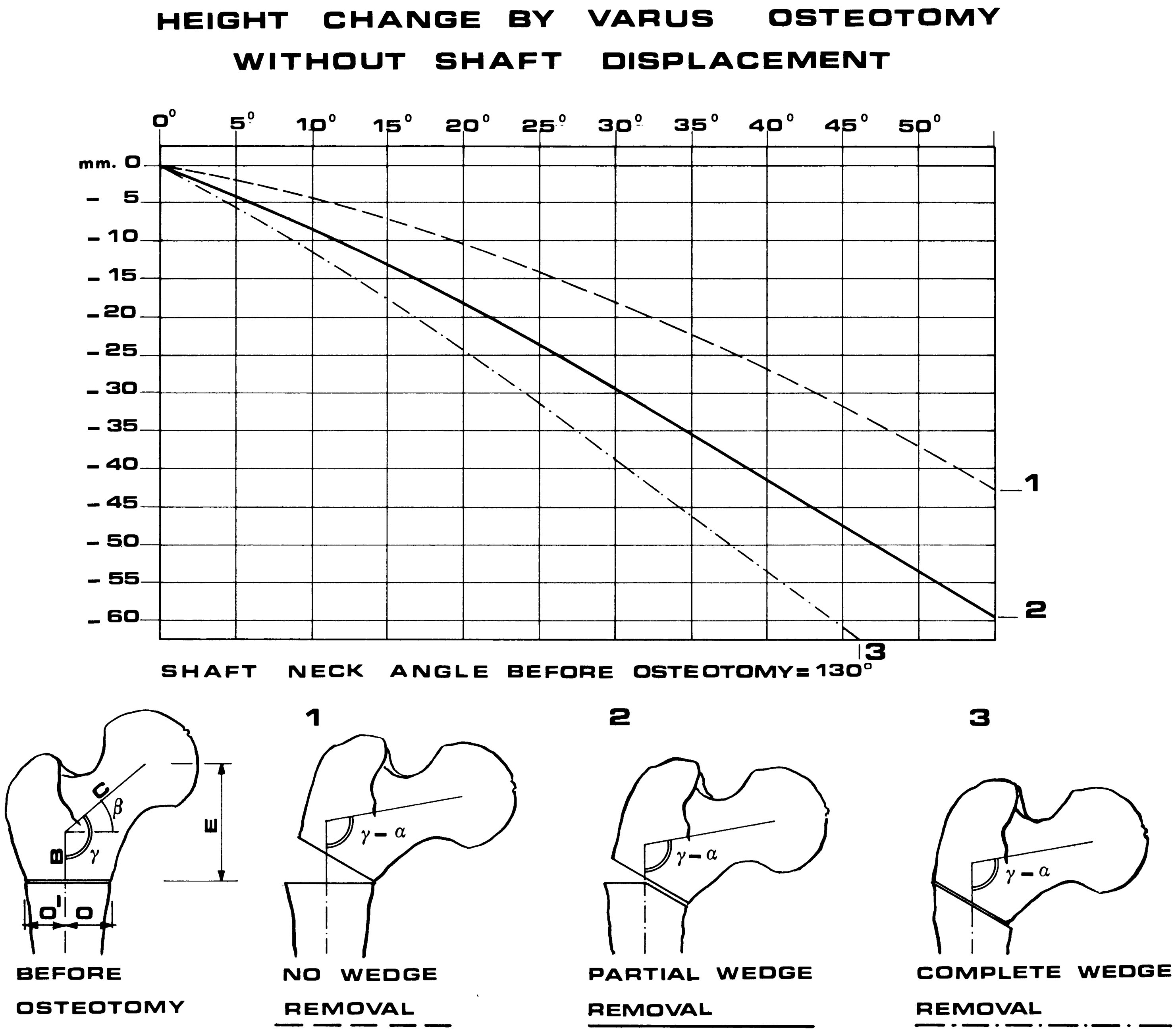


Fig. 108. Alterations in length of femur after varus osteotomy. Femur is always shortened by the operation. Amount of shortening depends on angle of varus and on amount of bone to be removed. Diagrams show how values of shortening are obtained



$$\Delta h = E\alpha - E$$

$$E\alpha = B \cos \alpha + C \operatorname{sen}(\beta - \alpha)$$

$$E\alpha = B \cos \alpha + C \operatorname{sen}(\beta - \alpha) + O' \operatorname{sen} \alpha$$

$$E\alpha = B \cos \alpha + C \operatorname{sen}(\beta - \alpha) - O \operatorname{sen} \alpha$$

Fig. 109. Figure shows actual shortening of femur according to type of varus osteotomy

F. How the Resultant Force R May be Reduced

The force R may be reduced:

a) by shifting the body's center of gravity S_5 toward the supporting limb
b) using one or two sticks.

a) in 16th position of the right stance phase the resultant force R has an inclination of 16° in the frontal plane. In a man weighing 66.98 kp its value is 200 kp when the force K (weight of the body less the weight of the supporting limb) is 54.5 kp.

If the center of gravity is shifted toward the supporting hip, the resultant force R is reduced. When the center of gravity is perpendicular to the center of the head of the femur, the force R has the same value as K, that is 54.5 kp. If the center of gravity is shifted further out, that is, lateral to the center of the head of the femur, the force acting on the femoral head increases because the adductors contract, in order to keep the pelvis level. We have, therefore, a new resultant force R, which is greater than the force K (Fig. 110).

From the tables (Figs. 111 – 112) we can see how the forces R, M, P, and Q change, according to the varying length of the lever arm of the weight of the body, as the center of gravity moves in the frontal plane.

It is evident that, as the body weight moves toward the oscillating limb with a lever more than 10.99 cm long, the forces R, M, P, and Q increase rapidly. When the resultant force R is parallel to force M (21.22°) and the lever arm of the body weight is greater than 43.20 cm, force R tends to infinity. However, when the body weight moves laterally to the head of the supporting femur, the forces R and *Add.* (adductors) increase only to a certain point. Once the perpendicular from the center of gravity falls laterally beyond the foot, the equilibrium of the body is lost.

The adductor forces are calculated on a model with the following characteristics:

1. Adductor lever arm = 8.2 cm.
2. Angle between the adductors and the vertical = 18°
3. Resultant force R has an inclination in the frontal plane of 1.5° – 3° – 4.5° – 6° (Figs. 112 and 113).

b) A stick is used by the patient to reduce pain. It does this by reducing the resultant force R and therefore the load on the head of the femur.

This is achieved by reducing the moment of the body weight $K \cdot b_2$ by the counter-moment of the pressure the patient applies on the stick $St \cdot b_3$, that is $(K \cdot b_2 - St \cdot b_3)$. This, in turn, results in an equal reduction in the moment of the muscle pull $(M \cdot b_1)$ on the other side of the center of rotation CR of the head of the femur, required to balance the now diminished moment of the body weight (Fig. 114).

Altogether this achieves a significant reduction in the resultant force R, whose magnitude can be calculated by applying either ABBATANI's theorem of sinuses or the theorem of CARNOT (see footnote). The use of a stick also stops the shift of the center of gravity toward the painful supporting limb.

As the pain worsens, the patient puts more pressure on the stick to reduce the resultant force R. This is effective only up to the point where the magnitude of the moment $K \cdot b_2 - St \cdot b_3$ is zero; now the resultant moment is zero and the real weight on the femoral head is K less St. There is no longer a resultant force R.

If more pressure is applied on the stick, the resultant moment will be lateral to the center of rotation of the head of the femur. To maintain balance, the adductors will contract and this will result in a new and increased resultant force R, causing pain.

To gain further relief from pressure the patient will be compelled to use two sticks (Fig. 115).

The Center of Gravity of the body of a patient with a stick has the same position as in a man with a normal hip and therefore the lever arm of the weight of the body has the same length (10.99 cm, according to O. FISCHER). Dividing the value of the moment $K \cdot b_2 - St \cdot b_3$ by 10.99 cm a new value of the weight of the body (K_1) is obtained. Dividing the value of the moment $(K \cdot b_2 - St \cdot b_3)$ by the length of the lever arm of the Abductors (4 cm, according to O. FISCHER), the value of the force of the Abductors necessary to keep the pelvis level is obtained. Knowing the values of the forces K_1 and M and applying the Theorem of Sinuses (Abbattani's Theorem):

$$a : \sin\alpha = b : \sin\beta = c : \sin\gamma$$

or the Theorem of Carnot:

$$c = \sqrt{a^2 + b^2 - 2ab \cdot \cos\gamma}$$

the value of the resultant force R may be deducted.

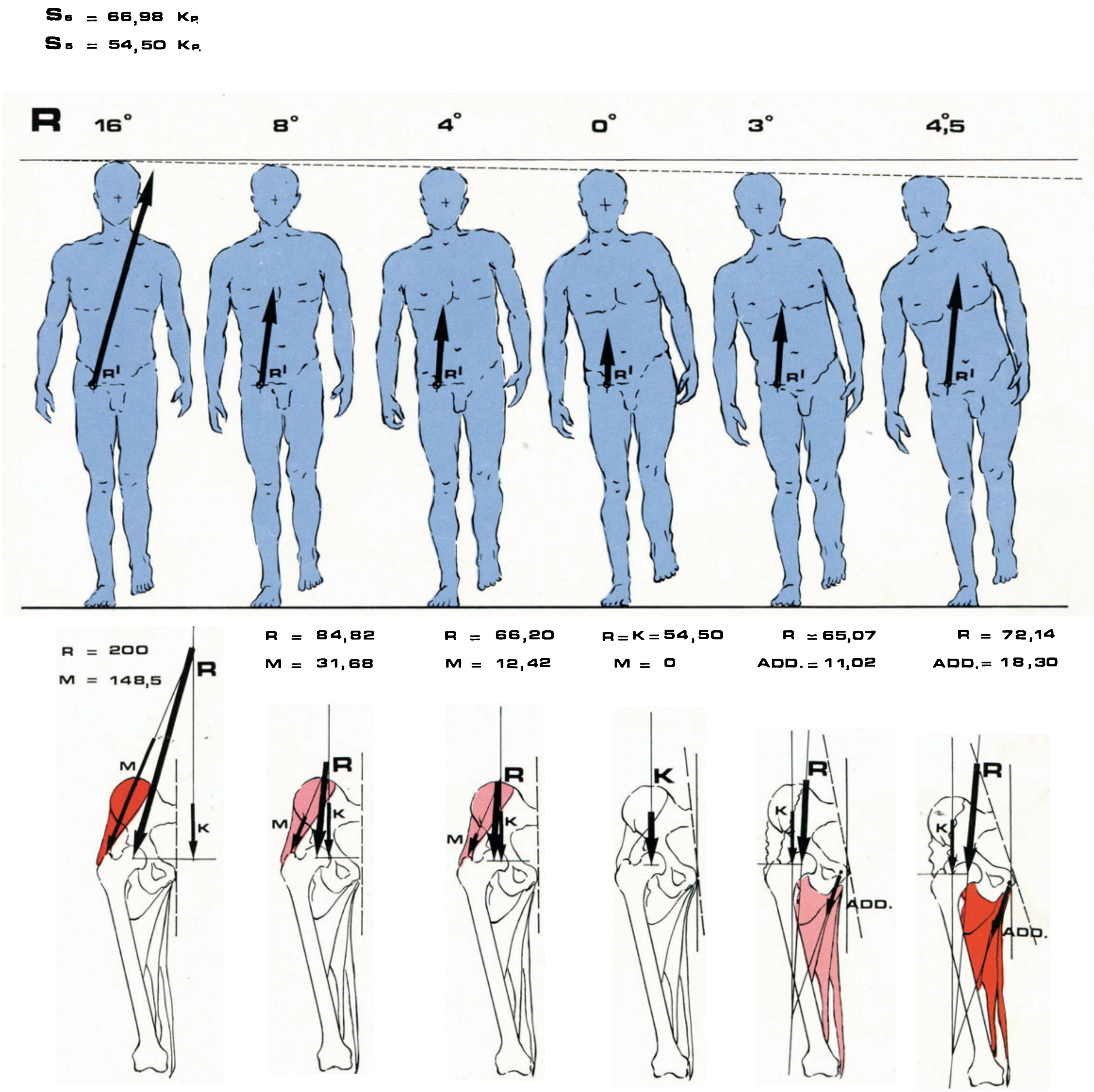


Fig. 110. For explanation see Fig. 111

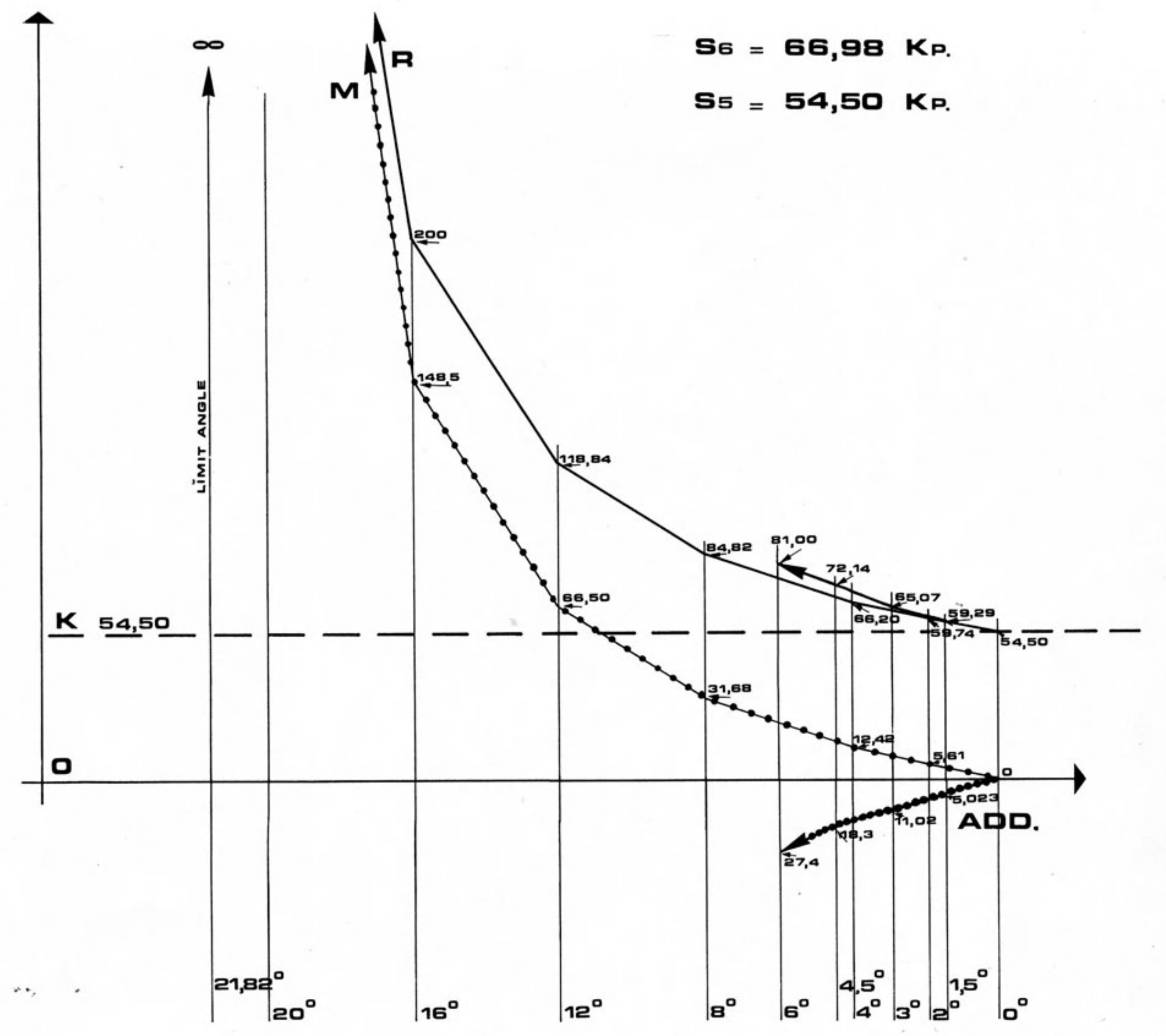


Fig. 111. Diagram shows magnitude of forces *M* (abductors), *Add* (adductors), and *R* (resultant), when body's center of gravity of healthy man of 66.98 kp of weight (S_6), standing on one limb, shifts in frontal plane. The weight to be considered is 54.50 kp (S_5). When resultant force *R* is inclined at 16° in frontal plane, the value of *R* is 200 kp, value of *M* is 148.5 kp. If body's center of gravity is shifted toward supporting limb, inclination of *R* in frontal plane progressively decreases from 16° to 0°. At the same time magnitudes of force *R* and *M* decrease. When body's center of gravity is perpendicular to center of head of femur, the load acting on head is 54.5 kp and value of force *M* is 0 (zero). If body's center of gravity is shifted further laterally to center of head, adductors contract to maintain pelvis level. A new resultant force *R* is formed and its value is higher than 54.5 kp. If body's center of gravity is shifted toward the oscillating limb, the inclination in frontal plane of resultant force *R* increases to a certain point, but not further. This is due to the fact that the magnitude of forces *R* and *M* becomes monstrous. (Between 16° and 20° value of force *R* is 641 kp and value of force *M* is of about same magnitude.) When inclination of *R* is equal to that of *M* (21.82°), magnitude of forces *R* and *M* tends to infinity. This situation is not possible because the equilibrium of the body is lost

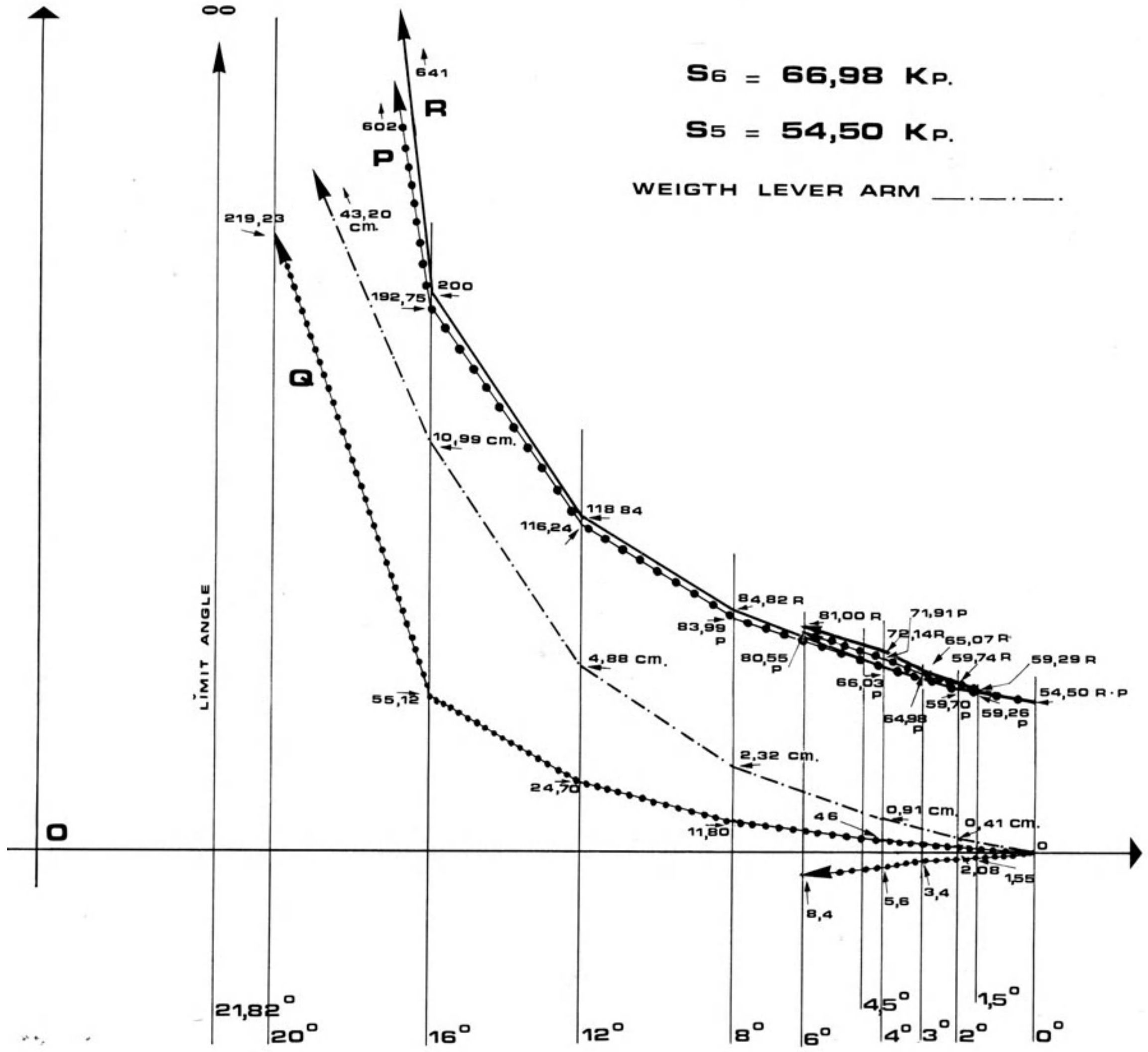


Fig. 112. Diagram shows values of forces *R*, *P*, and *Q* and length of weight lever arm, when body's center of gravity shifts in the frontal plane. It is interesting to note that, when patient shifts center of gravity of his body toward center of rotation of femoral head, craniomedial, laterocaudal inclination of resultant force *R* decreases as far as 0°. When patient shifts center of gravity of his body further laterally, inclination of resultant force *R* does not pass the vertical position, but increases from 0° to 6° again in craniomedial, laterocaudal direction. This is due to contraction of adductors. For this reason force *Q*, which progressively decreases as inclination of force *R* decreases from 16° to 0°, reappears when body's center of gravity is shifted further laterally beyond center of head of femur

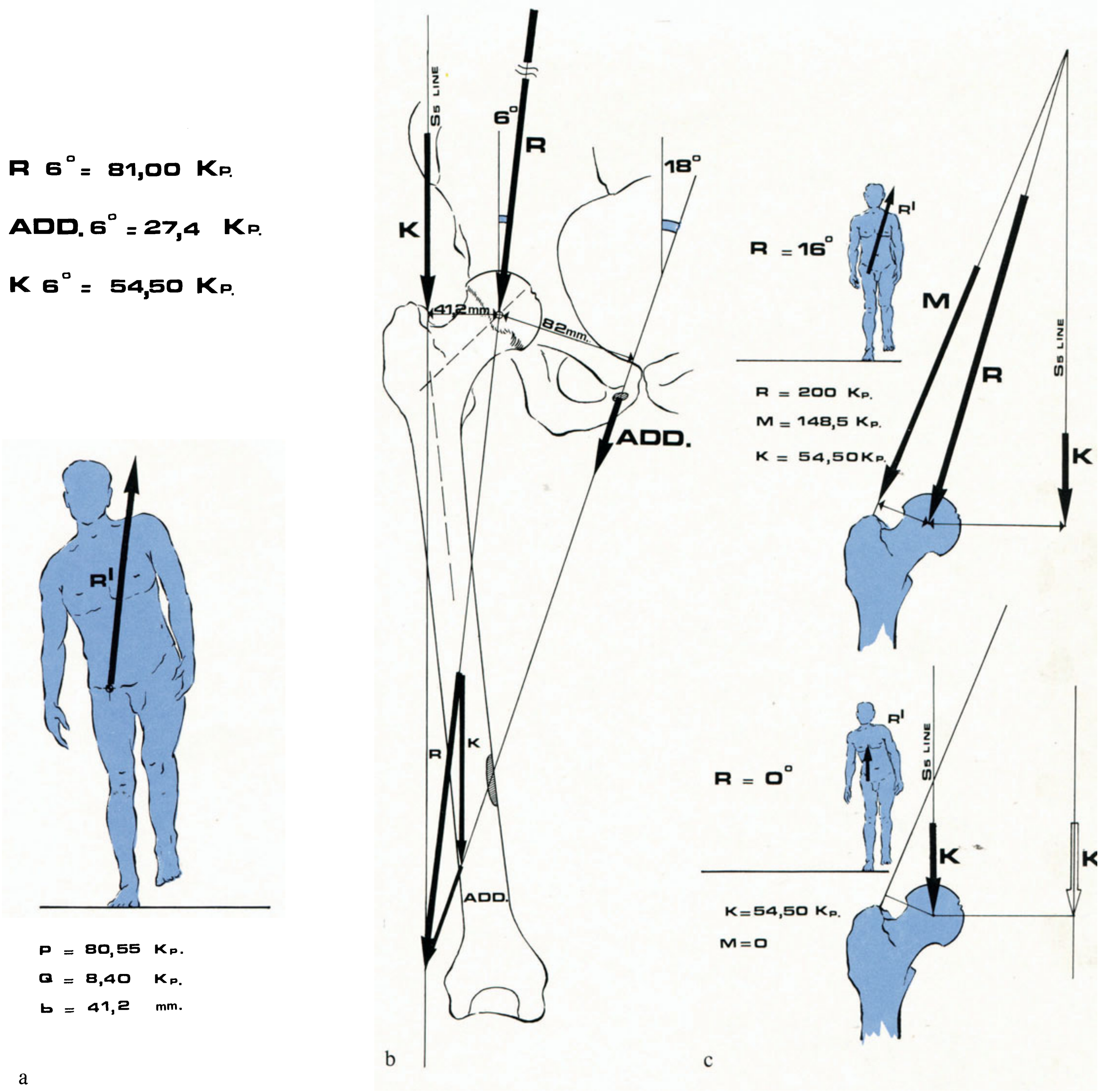


Fig. 113a–c. Diagram shows: (a) ($R=16°$) magnitude of forces *R*, *M*, and *K*, when body's center of gravity is located medially to center of rotation of femoral head and resultant force *R* in frontal plane has inclination of 16°. (b) ($R=0°$) magnitude of forces *K* and *M*, when body's center of gravity is above center of rotatin of femoral head and *R* has an inclination of 0°. (c) ($R=6°$) magnitude of forces *R*, *Add.*, *K*, *P*, and *Q*, when body's center of gravity is shifted laterally beyond center of rotation of femoral head, with weight lever arm *b* 41.2 mm long. The forces are calculated on model of 66.98 kp in weight. Force *K* is 54.5 kp. Length of lever arm of adductors is 82 mm. Lever arm of body's weight is 41.2 mm. Inclination of adductors is 18°

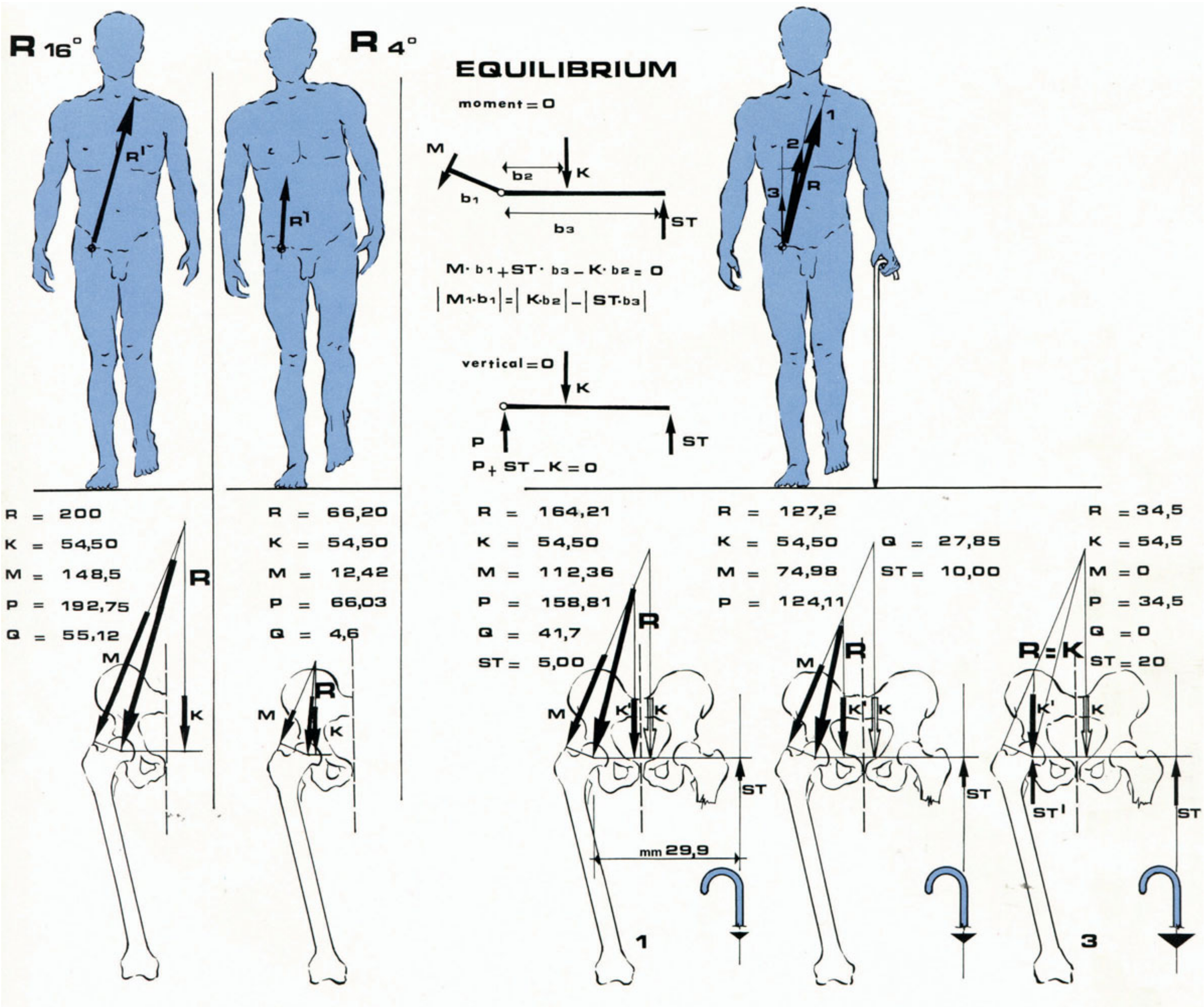


Fig. 114. Effect of stick. Effect of the stick is to reduce magnitude of the moment of weight of the body. In fact, from the moment: $K \cdot b_2$ must be deducted the moment $St \cdot b_3$ (St = pressure on stick). Result is moment of smaller magnitude, which is balanced by reduced muscular moment $M \cdot b_1$ and therefore force M is also reduced. By this the resultant force R is diminished. Diagrams show magnitude of forces R, K, M, P, and Q when pressure on the stick is 5 kp, 10 kp, and 20 kp. Maximum effect of the stick is achieved when moment $K \cdot b_2$ is equal to moment $St \cdot b_3$. In this case the length of lever arm of the body weight is zero and the real load on femoral head is the weight of body less the push of the stick St. In short, the ultimate result of the stick is reduction of the length of lever arm of the body weight (b_2). Reduction may be such to abolish completely lever arm; hence moment of body weight is zero ($K \cdot 0 = 0$)

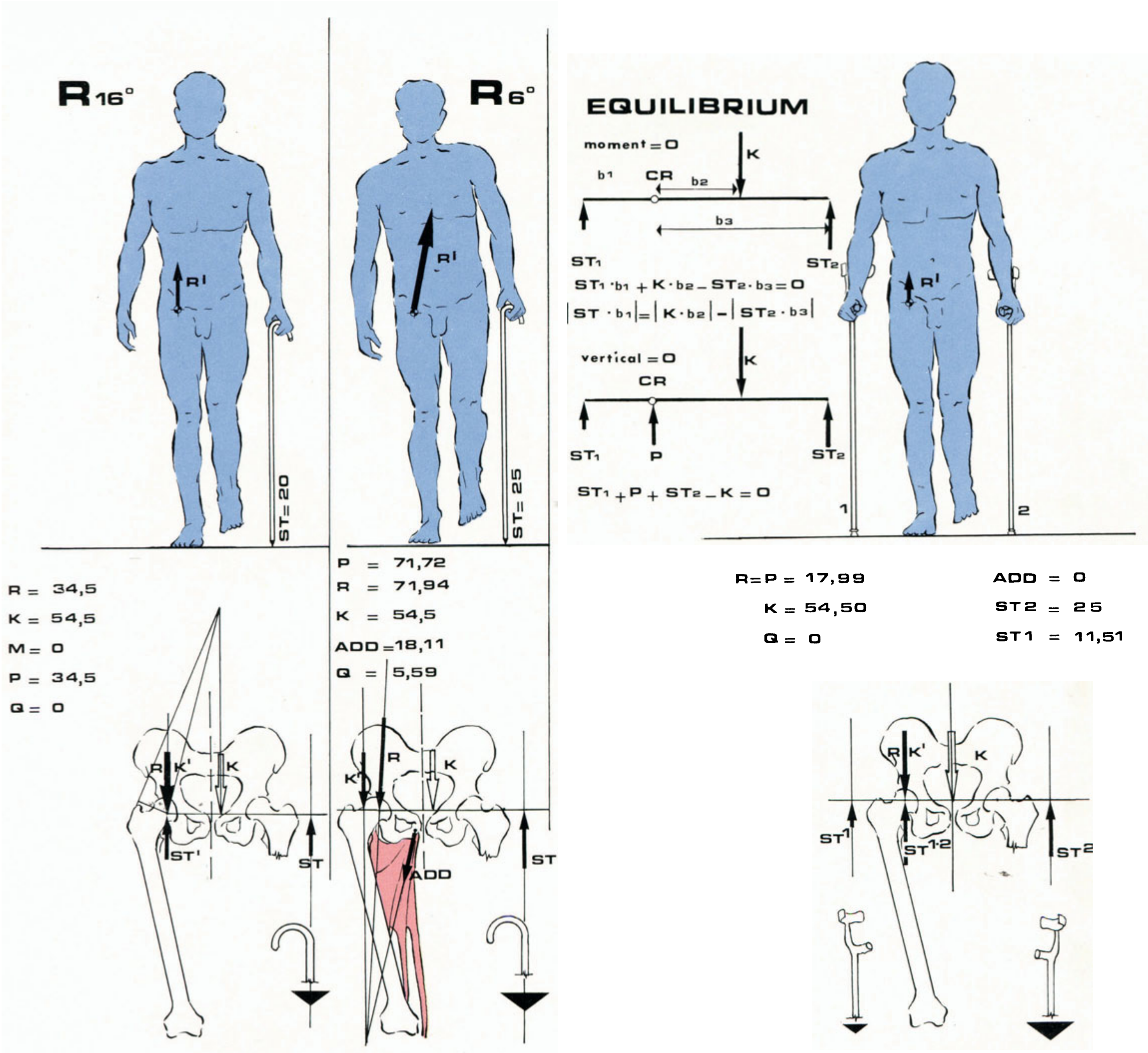


Fig. 115. $R_{16°}$ shows value of forces, when subject exerts pressure of 20 kp on stick (*St*). Magnitude of force R_1 is 34.5 kp. $R_{6°}$ shows value of forces, when subject exerts pressure of 25 kp on stick (*St*). Magnitude of force R_1 is 71.94 kp. Note contribution of adductors (*Add.* = 18.11 kp). Third diagram (equilibrium) shows reduction of force *R*, when subject uses two sticks. Force R_1 is reduced to 17.99 kp; that is $R_1 = K \cdot b_2 - [(St_2 \cdot b_3) + (St_1 \cdot b_1)]$. On the frontal plane the amount of pressures on sticks (St_1, St_2) and force P are equal to K. St_1 (11.51 kp) + St_2 (25 kp) + P (11.99 kp) = K (54.5 kp)

G. Summary

A conception of the pathogenesis of osteoarthritis of the hip and a consequent therapy, based on biomechanical principles, are described.

The trigger point of the pathogenesis is the obliquity of the anterocraniolateral part of the joint surface of the hip. This obliquity at first provokes:

1. Progressive disappearance of force *Q* and increase in force *P*
2. Appearance of force *S* and the progressive decrease in force *P*.

Force *S* is responsible for the osteophytes, because it makes the head of the femur glide laterally, cranially, and anteriorly. This gliding of the head stretches the ligamentum teres and its synovial membrane, the joint capsule and its synovial membrane, and the synovial membrane covering the neck of the femur. The taut structures undergo bone metaplasia and build up osteophytes.

The osteophytes are present in particular zones of the joint:

a) On the femur we can find: the superior and inferior cervical osteophyte and the capital drop (this last is due to the fusion of the fovea osteophyte and the inferior marginal osteophyte).
b) On the acetabulum we find: the roof osteophyte, the floor osteophyte, and the tent osteophyte.

3. A continual increase in force *S*, which becomes greater than force *P*.

At this moment a new osteophyte appears. This one has the shape of an elephant's trunk. This kind of osteophyte usually fuses with the capital drop and the two together build a mega-head (Fig. 116). This new enlarged head is an ideal anatomical solution that nature puts at our disposal to get (in a short period of time) by the valgus-extension osteotomy, the healing of osteoarthritis of the hip.

The valgus-extension osteotomy is indicated as a consequent therapy.

The biomechanical effect of valgus-extension osteotomy is to reduce the pressure on the head of the femur, to exploit the hydraulic mechanism, and to stretch even more the superior zone of the joint capsule, the ligamentum teres and their synovial membranes.

This stretching stimulates the formation of the roof osteophyte, of the superior cervical osteophyte, of the tent osteophyte, and of the capital drop. These osteophytes increase the weight-bearing joint surface. The unit weight on the articular surface is reduced and the diseased joint heals.

The roof osteophyte changes the slanting superolateral part of the joint surface into a horizontal one and therefore halts the glide of the femoral head. We can refer to it as a block (Fig. 117).

An operation of valgus-extension osteotomy is described.

The operation must result in an increase of the weight-bearing joint surface in order to reduce the unit weight and therefore the unit stress and allow cartilage and bone to heal.

The technique of the operation must achieve these aims:

1. To reduce the resultant force *R*
2. To stimulate the building up of the capital drop, the tent osteophyte, and the roof osteophyte
3. To reduce the pressure on the antero-superior part of the head of the femur
4. To avoid any lengthening of the femur
5. To exploit the hydraulic mechanism
6. To avoid a valgus in the knee.

In some instances the valgus osteotomy need not be combined with an extension osteotomy. These are the cases in which the pressure on the anterior part of the head of the femur is not evident from an axial-view X-ray.

With this technique we can obtain a real "physiological arthroplasty."

The personal experience of the author in over 1200 such operations proves that an oval-shaped head with a longer vertical diameter is not suitable for a valgus osteotomy, because after the operation we get a painful and restricted bearing surface on the sensitive superior part of the socket.

In these cases it is advisable to convince the patient to wait for 6 months or a year before undergoing the operation.

During this time the medial osteophytes grow and after the operation the healing is quicker and is not painful.

However, a flat head (with a longer horizontal diameter) gives a more favorable and quicker result, because the medial osteophytes (capital drop and tent osteophyte) allow the development of the shock-absorbing mecha-

nism and the immediate reduction of the resultant force *R* (Fig. 118).

When the acetabulum is highly oblique, the intertrochanteric valgus-extension osteotomy must be associated with the osteotomy of the pelvis (CHIARI, 1970).

It is obtained by this a horizontal weight-bearing surface and a non painful fulcrum located medially at the capital drop (Fig. 119).

The real contra-indications are a spherical head without osteophytes, a marked osteoporosis of the joint components, a completely stiff hip, or an extensive necrosis of the head. It is also contraindicated in patients with a short life expectancy or in the aged.

In these cases, as well as in cases of a very degenerate hip, a total hip replacement or, particularly for young patients, an arthrodesis is indicated.

The biomechanical effect of varus osteotomy, the effect of Trendelenburg's gait, the way to calculate the exact final length of the femur, the explanation of some unsatisfactory results after such an operation, the indications and the operative technique are described.

The effects on the head of the femur of shifting the body's center of gravity in the frontal plane and of using one and two sticks have also been discribed.

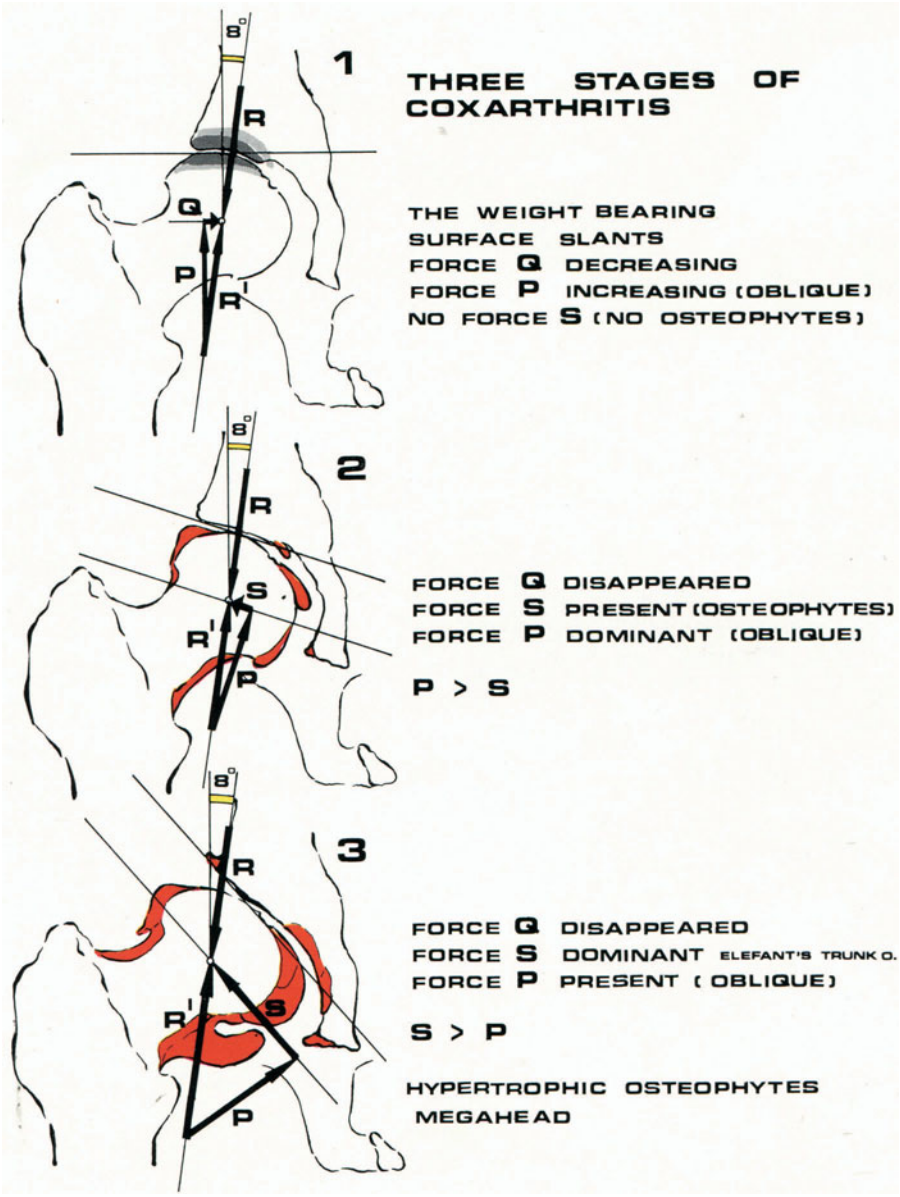


Fig. 116. Biomechanical forces and shapes of femoral head in three different stages of osteoarthritis

Fig. 118. By doing a valgus-extension osteotomy the capital drop of the femoral head comes into contact with the tent osteophyte of the acetabulum. The contact area acts as a non painful fulcrum for the head and holds the joint surfaces apart. The space obtained becomes ▷ filled with synovial fluid, which acts as a buffer like device

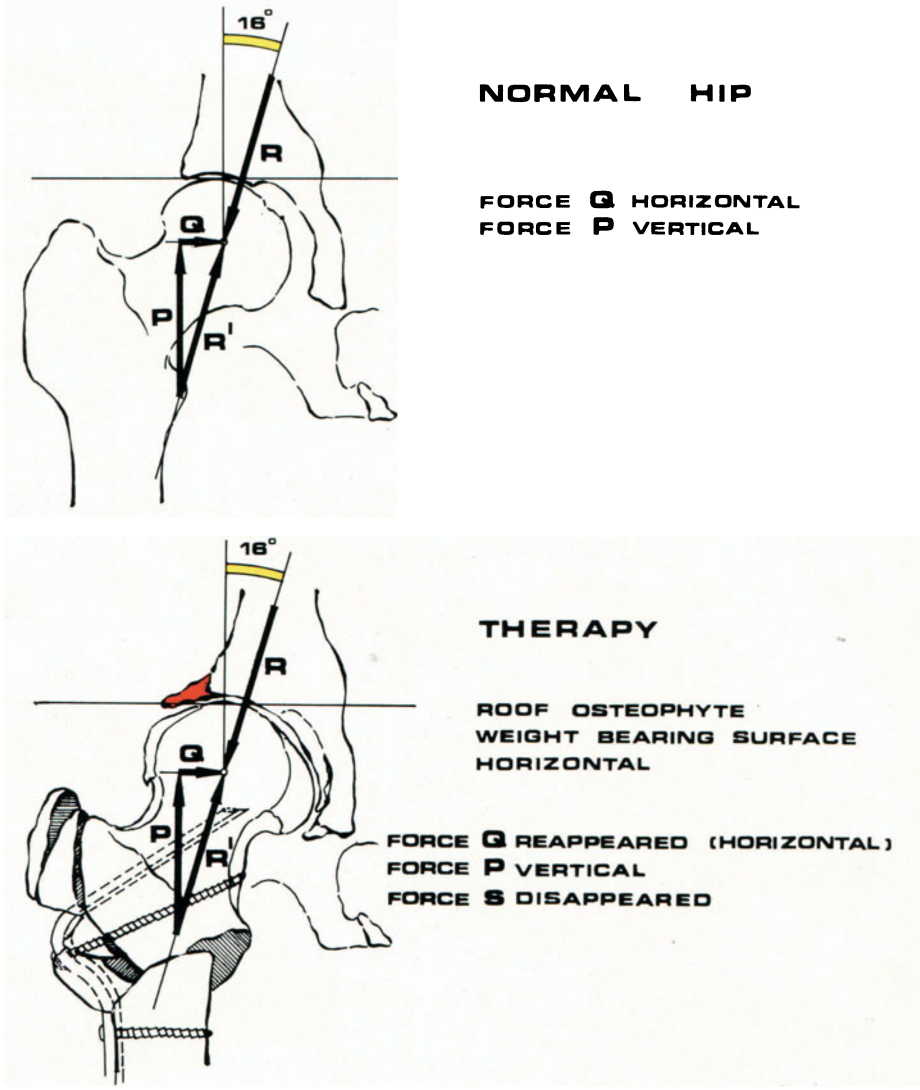


Fig. 117. Effect of valgus-extension osteotomy on biomechanical forces

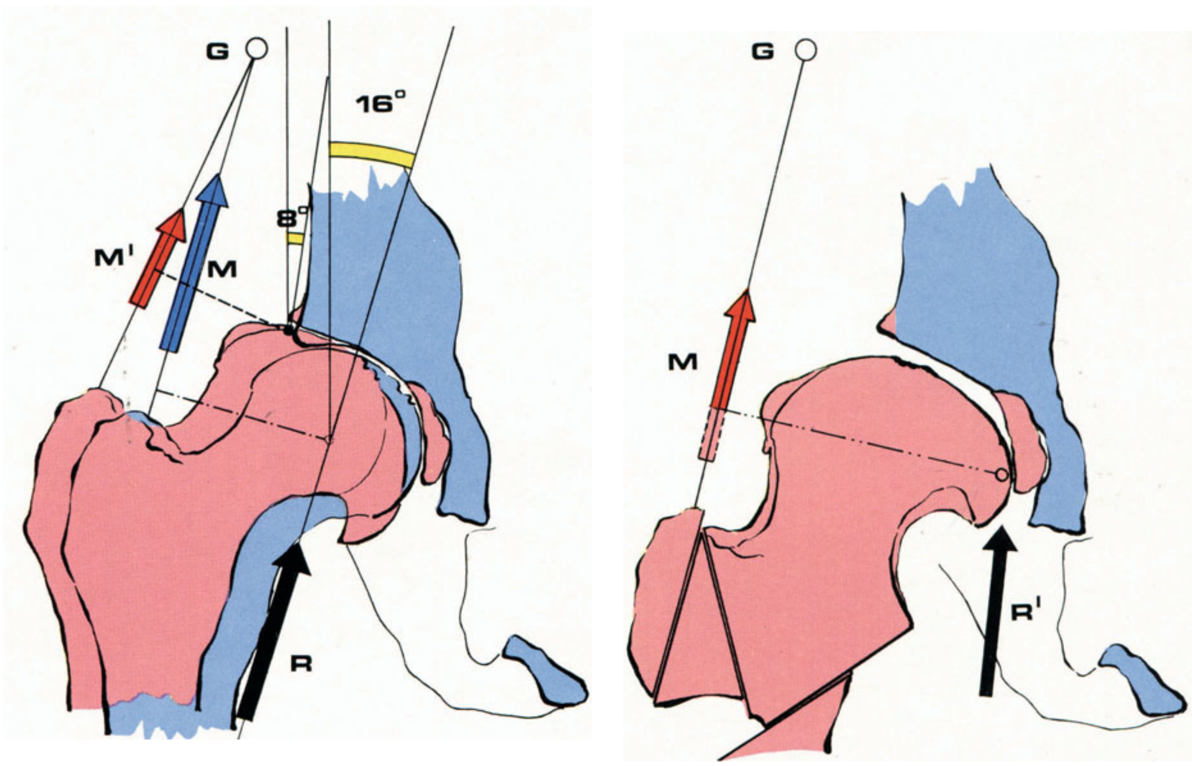


Fig. 118

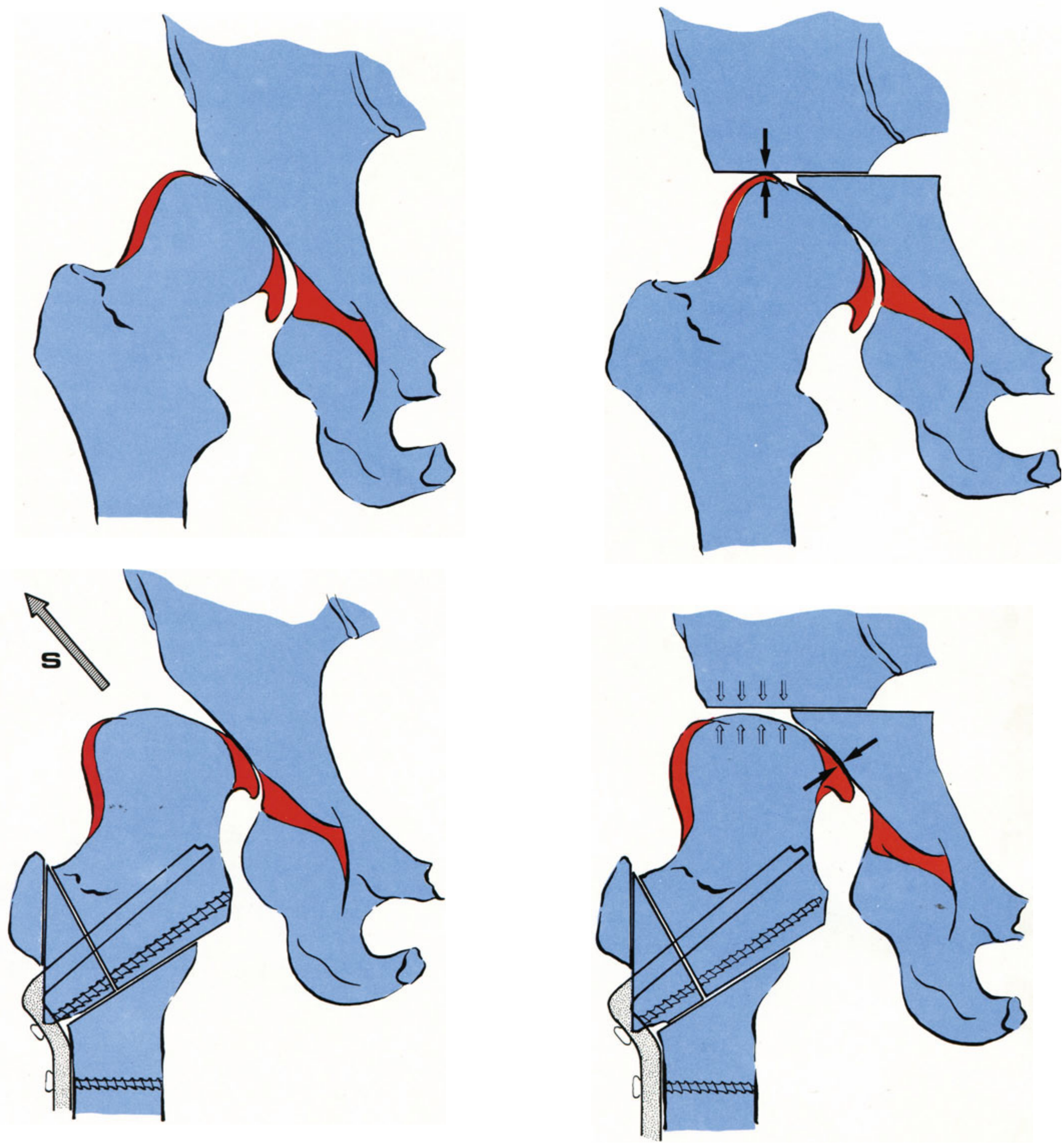


Fig. 119. When the acetabulum is very oblique a valgus-extension osteotomy may be associated with pelvic osteotomy (CHIARI, 1970).
By this is obtained a horizontal weight bearing joint surface and a non painful medial fulcrum made up by capital drop and tent osteophyte

References

Adam, A., Spence, A.J.: Intertrochanteric osteotomy for osteoarthritis of the hip. J. Bone Jt Surg. B **40**, 219–226 (1958).

Allgöwer, M.: Funktionelle Anpassung des Knochens auf physiologische und unphysiologische Beanspruchung. Langenbecks Arch. Klin.-Chir. **399**, 384–391 (1967).

Amantini, C.: Di Una Men Nota Ripiegatura Sinoviale dell'Articolazione Dell'Anca (Piega pettineo foveale). Annali dell'Università Libera di Perugia, Anno IV, 1888–1889, 1°, 47–76.

Armstrong, J.R.: Lumbar disc lesions. Edinburgh-London: E. & S. Livingstone LTD 1952.

Aufranc, O.E.: Constructive surgery of the hip. Saint Louis: The C.V. Mosby Company 1962.

Batra, H.C., Charnley, J.: Existence and incidence of osteoid in osteoarthritic femoral heads. J. Bone Jt Surg. B **51**, 366–371 (1969).

Bombelli, R.: Displasia cotiloidea ed artrosi deformante dell'anca – Revisione statistica su 441 casi di anche artrosiche. Archivio Putti **VIII**, 192–198 (1957).

Braune, W., Fischer, O.: Über den Schwerpunkt des menschlichen Körpers mit Rücksicht auf die Ausrüstung des Deutschen Infanteristen. Leipzig: Hirzel 1889.

Byers, P.D.: The effect of high femoral osteotomy on osteoarthritis of the hip – an anatomical study of six hip joints. J. Bone Jt Surg. B **56**, 279–290 (1974).

Casuccio, C.: La deambulazione nella sacro ileite. Chir. Organi Mov. **23**, 263 (1938).

Charnley, J.: Compression arthrodesis, including central dislocation as a principle in hip surgery. Edinburgh: Livingstone 1953.

Chiari, K.: Pelvic osteotomy for hip-subluxation. J. Bone Jt. Surg. B**52**, 174 (1970).

Chiarugi, G.: Anatomia dell'Uomo, Vol. 1. Milano: Soc. Ed. Libraria 1940.

Collins, D.H.: The pathology of articular and spinal diseases. London: Ed. Arnold & Co. 1949.

Croskey, M.I., Dawson, P.M., Luessen, A.C., Hahron, I.E., Wright, H.E.: The height of the centre of gravity in man. Amer. J. Physiol. **61**, 171–185 (1922).

Dee, R., Tait, G.B.W., Wyke, B.: Reflex function of the Legamentum capitis femoris in the hip joint. J. Bone Jt Surg. B **51**, 178 (1969).

Ferguson, A.B.: High intertrochanteric osteotomy for osteo-arthritis of the hip. J. Bone Jt Surg. A **46**, 1159–1175 (1964).

Ferguson, A.B.: The pathological changes in degenerative arthritis of the hip and treatment by rotational osteotomy. J. Bone Jt Surg. A **46**, 1337–1352 (1964).

Fick, R.: Handbuch der Anatomie und Mechanik der Gelenke. II. Allgemeine Gelenk- und Muskelmechanik. Jena 1910.

Fischer, O.: Über den Schwerpunkt des menschlichen Körpers. Leipzig: Hirzel 1889.

Fischer, O.: Der Gang des Menschen. Leipzig: Teubner 1899.

Fischer, O.: Der Gang des Menschen. II. Teil: Die Bewegung des Gesamtschwerpunktes und die äußeren Kräfte. Abhandl. Math.-Phys. Cl. d.K. Sächs. Ges. Wiss. **25**, 1–163 (1899).

Fränkel, J.: Kinematographische Untersuchung des normalen Ganges und einiger Gangstörungen. Z. orthop. Chir. **20**, 617 (1908).

Gardner, E.: The innervation of the hip joint. Anat. Rec. **101**, 353–371 (1948).

Gardner, E.: Nerve supply of joints. Instructional course lectures – The American Academy of Orthopaedic Surgeons. Ann. Arbor, Vol. IX, pp. 155–161 (1952).

Harrison, M.H.M., Schajowicz, F., Trueta, J.: Osteoarthritis of the hip. A study of the nature and evolution of the disease. J. Bone Jt Surg. B **35**, 598–626 (1953).

Hosokawa, O.: Istological study on the type and distribution of the sensory nerve endings in human hip joint capsule and ligament. J. Jap. orthop. Ass. **38**, 887–901 (1964).

Jeffery, A.K.: Osteogenesis in the osteoarthritic femoral head. J. Bone Jt Surg. B **55**, 262–272 (1973).

Jeffery, A.K.: Osteophytes and the osteoarthritic femoral head. J. Bone Jt Surg. B **57**, 314–324 (1975).

Kapandji, I.A.: Physiologie Articulaire. II. Paris: Libraire Maloine S.A. 1968.

Kellgren, J.H., Samuel, E.P.: The sensitivity and innervation of the articular capsule. J. Bone Jt Surg. B **32**, 84–92 (1950).

Knot, H.: Osteo-Arthritis of the hip joint. J. Bone Jt Surg. A **46**, 1326–1336 (1964).

Kummer, B.: Die Beanspruchung der Gelenke, dargestellt am Beispiel des menschlichen Hüftgelenks. Verh. Dtsch. Ges. Orthop., 55. Kongreß, Kassel, 1968, S. 301–311. Stuttgart: Enke 1969.

Kummer, B.: Die Beanspruchung des menschlichen Hüftgelenks. Allgemeine Problematik. Z. Anat. **127**, 227–285 (1968).

Landells, J.W.: The bone cysts of osteoarthritis. J. Bone Jt Surg. B **35**, 643–649 (1953).

Lanz, T., Wachsmuth, W.: Praktische Anatomie, Bd. 1. Berlin: Springer 1938.

Lloyd Roberts, G.C.: The role of capsular changes in osteoarthritis of the hip joint. J. Bone Jt Surg. B **35**, 627–642 (1953).

Mankin, H.J., Lippiello, L.: Biochemical and metabolic abnormalities in articular cartilage from osteo-arthritic human hips. J. Bone Jt Surg. A **52**, 424–434 (1970).

Mc Murray, T.P.: Osteoarthritis of the hip joint. Brit. J. Surg. **22**, 716–727 (1935).

Mc Murray, T.P.: Osteoarthritis of the hip joint. J. Bone Jt Surg. **21**, 1–11 (1939).

Morscher, E.: Intertrochantere Osteotomie bei Coxarthrose. Bern-Stuttgart-Wien: Huber 1971.

Müller, M.E.: Die hüftnahen Femurosteotomien. Stuttgart: Thieme 1957.

Müller, M.E.: Die hüftnahen Femurosteotomien, 2. Aufl. Stuttgart: Thieme 1970.

Müller, M.E., Allgöwer, M., Willenegger, H.: Manual der Osteosynthese – AO Technik. Berlin-Heidelberg-New York: Springer 1969.

Müller, R.: Die schicksalsmäßige Entwicklung der nicht chirurgisch behandelten Coxarthrose. Bern: Schenker 1968.

Murray, Pat, M., Drought, A.B., Kory Ross, C.: Walking patterns of normal men. J. Bone Jt Surg. A **46**, 335–360 (1964).

Ondrouch, A.S.: Cyst formation in osteoarthritis. J. Bone Jt Surg. B **45**, 755–760 (1963).

Osborne, G.V., Fahrni, W.H.: Oblique displacement osteotomy for osteoarthritis of the hip joint. J. Bone Jt Surg. B **32**, 148–160 (1950).

PAUWELS, F.: Neue Richtlinien für die operative Behandlung der Coxarthrose. Verh. Dtsch. Orthop. Ges., 48. Kongreß, S. 332–366. Stuttgart: Enke 1961.

PAUWELS, F.: The importance of biomechanics in orthopedics. Postgraduate Course – IXème Congres de la Societé Internationale de Chirurgie Orthopedique et de Traumatologie. Wien (Hofburg) 1.–7.IX. 1963. Tom II.

PAUWELS, F.: Funktionelle Anpassung des Knochens durch Längenwachstum. Verh. Dtsch. Orthop. Ges., 45. Kongreß, Köln 1957, S. 400–427. Berlin-Heidelberg-New York: Springer 1965.

PAUWELS, F.: Gesammelte Abhandlungen zur funktionellen Anatomie des Bewegungsapparates. Berlin-Heidelberg-New York: Springer 1965b.

PAUWELS, F.: Atlas zur Biomechanik der gesunden und kranken Hüfte. Berlin-Heidelberg-New York: Springer 1973.

PETERSON, H.A., WINKELMANN, R.K., COVENTRY, M.B.: Nerve endings in the hip joint of the cat – their morfology-distribution and density. J. Bone Jt Surg. A **54**, 333 (1972).

POLI, A.: Semeiologia clinica della claudicazione. Relaz. XXVIII Congresso S.I.O.T., 22.10.1937.

SAUNDERS, J.B., DE, C.M., INMAN, V.T., EBERHART, H.D.: The major determinants in normal and pathological gait. J. Bone Jt Surg. A **35**, 543–558 (1953).

SCHENK, R., WILLENEGGER, H.: Zur Biomechanik der Frakturheilung. Acta anat. (Basel) **53** (1963).

SCHENK, R., WILLENEGGER, H.: Morphological findings in primary fracture healing. Symp. Biol. Hung. **7**, 75–86 (1967).

SCHNEIDER, R.: Mehrjahresresultate eines Kollektivs von 100 intertrochanteren Osteotomien bei Coxarthrose. Hel. chir. Acta **33**, Fasc. 1/2, 185–205 (1966).

SCHWARTZ, B.P., HEALTH, A.L., MORGAN, D.W., TOWNS, R.C.: A quantitative analysis of recorded variables in the walking pattern of normal adults. J. Bone Jt Surg. A **46**, 324–334 (1964).

SOLOMON, L.: Drug-induced arthropathy and necrosis of the femoral head. J. Bone Jt Surg. B **55**, 246–261 (1973).

SPALTEHOLZ, W.: Atlante Manuale Anatomia Umana, Vol. 1. Milano: Editore Vallardi 1941.

STORCK, H.: Coxa valga, ein Beitrag zur Frage der den Knochen formenden Kräfte. Arch. orthop. Unfall-Chir. **32** (1932).

STRUTHERS, J.: Demonstration of the use of the round ligament of the hip joint. Edinb. med. J. **IV** (1858).

TESTUT, L.: Anatomia Umana. Un. Tipog. Edit. Torinese, 1923, Libro I, p. 196–200.

TRUETA, J., HARRISON, M.H.M.: The normal vascular anatomy of the femur head in adult man. J. Bone Jt Surg. B **35**, 442–461 (1953).

WARDLE, E.N.: Displacement osteotomy of the upper end of the femur. J. Bone Jt Surg. B **37**, 568–575 (1955).

WEBER, W., WEBER, E.: Mechanik der menschlichen Gehwerkzeuge. Berlin: Springer 1895.

WELLS, C.: Hip disease in Ancient Man. J. Bone Jt. Surg. B **51**, 576 (1969).

WIBERG, G.: Studies on dysplastic acetabula and congenital subluxation of the hip joint. Acta chir. scand. **83**, Suppl. 58 (1939).

WYKE, B.: Neurology of the hip joint. J. Bone Jt Surg. B **51**, 576 (1969).

Subject Index