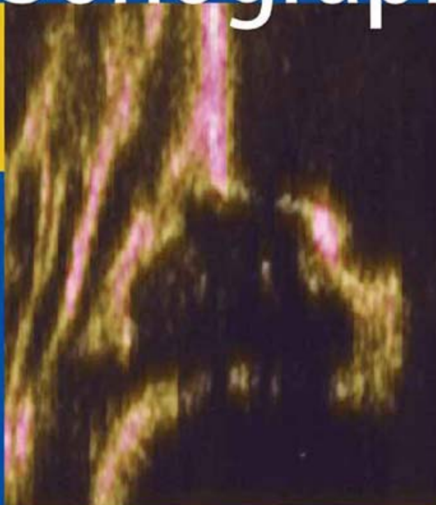
R. Graf

Hip Sonography



Diagnosis and Management of Infant Hip Dysplasia

Second Edition

Springer

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Diagnosis and Management of Infant Hip Dysplasia

With the collaboration of S. Scott, K. Lercher,
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Springer

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Library of Congress Control Number: 2006921371
ISBN 10 3-540-30957-8 Springer Berlin Heidelberg New York
ISBN 13 978-3-540-30957-4 Springer Berlin Heidelberg New York

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Editor: Dr. Ute Heilmann, Heidelberg
Desk editor: Dörthe Mennecke-Bühler, Heidelberg
Cover design: Frido Steinen-Broo eStudio Calmar, Spain
Production & Typesetting: LE-TeX Jelonek, Schmidt & Vöckler GbR, Leipzig
Printed on acid-free paper SPIN 11603481 21/3100/YL – 5 4 3 2 1 0

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Acknowledgement

The authors wish to thank Mrs. Christine Puff for her hard work and extraordinary enthusiasm whilst typing this manuscript.

Foreword

This book is a distillation of the knowledge and experience Prof. Reinhard Graf has acquired in 25 years of research and teaching. It cannot replace a practical training course in hip ultrasound, but it is invaluable as an accompaniment to the course and as a reference manual for all trained practitioners in hip ultrasound.

If the examination technique is followed, then diagnostic sonograms will be obtained quickly and easily. If the interpretation and measurement techniques are followed, they will result in an accurate diagnosis that is fundamental to ensuring appropriate treatment.

I first met Prof. Graf over 20 years ago after I had struggled unsuccessfully, for several months, to produce a reproducible, diagnostic hip ultrasound examination.

Within hours of commencing a training course with Prof. Graf in the hospital at Stolzalpe, Austria, the scales fell from my eyes and I started to understand what I was looking at.

I persuaded Prof. Graf to come to England to run a course here. He has now come for 17 consecutive years and the Dorchester course has trained over 700 orthopaedic surgeons, paediatricians, physiotherapists, radiologists and sonographers in the UK in the practice of hip ultrasound.

Professor Graf has conducted innumerable training courses worldwide including in Australia, Chile, India and Japan. In addition, as a result of his work, several countries, including Austria, Germany and Switzerland, have introduced National Screening of Neonatal Hips by Ultrasound.

His research continues. I have seen Prof. Graf modify the classification of the hip ultrasound appearances and the ultrasound examination technique over the years, reflecting his increasing knowledge both of the pathophysiology of developmental hip dysplasia and how errors in scan technique can lead to misdiagnosis.

The triumph of hip ultrasound, when performed to the high standard achievable today, is the detection of those hips with clinically silent dysplasias that subsequently develop a dislocation, or persistent dysplasia, if not treated (Graf type IIc). These account for the great majority of the previously so-called clinically missed congenital dislocations.

Those of you who have had the good fortune to be taught by Prof. Graf know of the skill, energy and enthusiasm that he brings to his teaching. It has been a very great privilege to work with him over all these years and to see the developments in hip ultrasound that, if properly applied, can lead to the abolition of late presenting hip dislocations.

Our aim should be that every baby born should have the benefit of an accurate hip ultrasound examination, performed to today‘s standard, with appropriate treatment when necessary to prevent the crippling deformities that result from missing the diagnosis in the newborn.

Dr. Sally Scott, FRCR
Dorchester, UK
2006

Introduction

Where Is the Problem?

Orthopaedic surgeons, paediatricians and radiologists all deal with the problem of dislocation and dysplasia of the infant hip. If dysplasia and displacement of the infant hip are described together under the heading "Disorders of Hip Maturation" then together they constitute the commonest disease of the musculoskeletal system. These disorders have implications not only for the child itself and its entire family, but they are of enormous consequence for public health. It is currently thought that 9%–10% of all hip replacements carried out are necessary because of a hip maturation disorder. Hence the importance of early detection. Generally, authors agree that early detection of dysplasia or displacement is fundamental for adequate treatment. However, opinion differs widely as to what requires treatment. Should only displaced or dislocated hips be treated or should a dysplastic bony acetabulum without any displacement be treated? How many resolve spontaneously without treatment? Should "unstable" hip joints be treated? There is no consensus about how "instability" should be defined. Does instability require treatment only if the femoral head can be dislocated out of the socket or if, under pressure, the femoral head shifts within the socket?

Hip ultrasonography with its ability not only to visualise the unossified parts of the newborn hip but also to show movement of the femoral head within the socket has brought about an enormous improvement in infant hip diagnosis. Hip ultrasound is practicable, reproducible, and able to be taught and learnt.

It is easy to be impressed by observing with ultrasound the movements of the femoral head in the acetabulum. However, these observations are purely subjective and can lead to misdiagnosis. The cartilaginous and bony parts of the hip joint must be objectively measured and quantified in relation to the age of the baby, otherwise sonography ends in catastrophe.

How to Solve the Problem

Making a correct diagnosis is important, not for personal gain but only as a basis for treatment. The value of hip ultrasound is its ability and accuracy at showing exactly the anatomical pathology in the hip, thereby enabling treatment to be tailored to the exact pathology. The ultrasound appearances of the infant hip change rapidly in the first few weeks of life. Using the ultrasound appearances together with the baby's age, a classification has been developed with the purpose of ensuring that appropriate "stage-dependent" treatment is used. For example, a child with a dislocated hip requires different treatment from one with a dysplastic but undisplaced hip. A shallow bony acetabulum may be normal physiological immaturity at birth or dysplasia in an older infant. The normal development of the hip joint is most rapid during the first few months of life, thus an early diagnosis with appropriate effective treatment is essential for a good outcome.

Even though the Graf technique of hip sonography, developed in the late 1970s, has led to general screening of all infant hips in Austria, Germany and in Switzerland, it is still criticized by most Anglo-American countries, because of its perceived complexity. "Perceived complexity" because it no longer uses the original clinical and x-ray classification of normal, dysplastic, subluxated and dislocated, but classifies according to the exact anatomical pathology that must be identified and treated appropriately. According to the motto: “The better the diagnosis (= typing), the more selective and effective the treatment.”

Instability must also be classified: which movements of the femoral head in the acetabulum are according to the age and are normal and which movements are pathological? The experience of the examiner is not important: the measurements which are reproducible and independent of the examiner make the decision!

Motto: Better ultrasound today than a limp tomorrow!

How to Use This Manual

This manual differs from other publications:

- It shows what is actually possible with hip ultrasound.
- It presents the current knowledge in an abbreviated form.
- It presents a summary of the German literature on hip sonography for non-German-speaking colleagues.
- Relevant literature is cited at the end of this book.
- It presents the standard achievable today and should help the user to avoid errors.
- It is based on the author’s experience of more than 20 years teaching clinicians the theory and practice of hip ultrasound.
- This manual cannot replace practical training with an authorized teacher in hip sonography, only support it.

Contents

1 Technique

Contents

1.1 Equipment

For hip ultrasound, no special ultrasound machines are needed. However, the following points are essential:

- Only ultrasound machines with ports for linear array transducers should be used. Sector probes should not be used for hip sonography due to the geometric distortion produced by refraction and defraction of the divergent ultrasound beam which can result in misdiagnosis (see Chap. 12).
- For hip sonography, a long but relatively light 5- or 7.5-MHz linear array probe is needed. Higher-frequency (7.5 MHz) probes have better resolution but poorer penetration. Newborns up to the 4th week of life must be examined with a linear transducer with a minimum frequency of 7.5 MHz, otherwise the small anatomical structures cannot be pointed out precisely enough.
- The pre- and post-processing adjustment varies depending on the type of machine used and is best discussed with the company's representative.
- The ability to electronically rotate the image through 90° on the monitor so that it can be viewed in the "standard projection" (see Sect. 1.3) or the use of a second monitor that can be turned on its side would be ideal.
- A hard-copy facility is essential. A thermal imager with its instantly available images is ideal, although film images may also be needed as they are more durable.
- Some ultrasound machines have software for the measurement lines and give the sonographic type automatically. However, the software for the measurement lines is sometimes incorrect! To accurately measure the sonograms by hand they must not be too small. The magnification factor should be 1:1.7 or more, so that it is possible also to measure by hand.

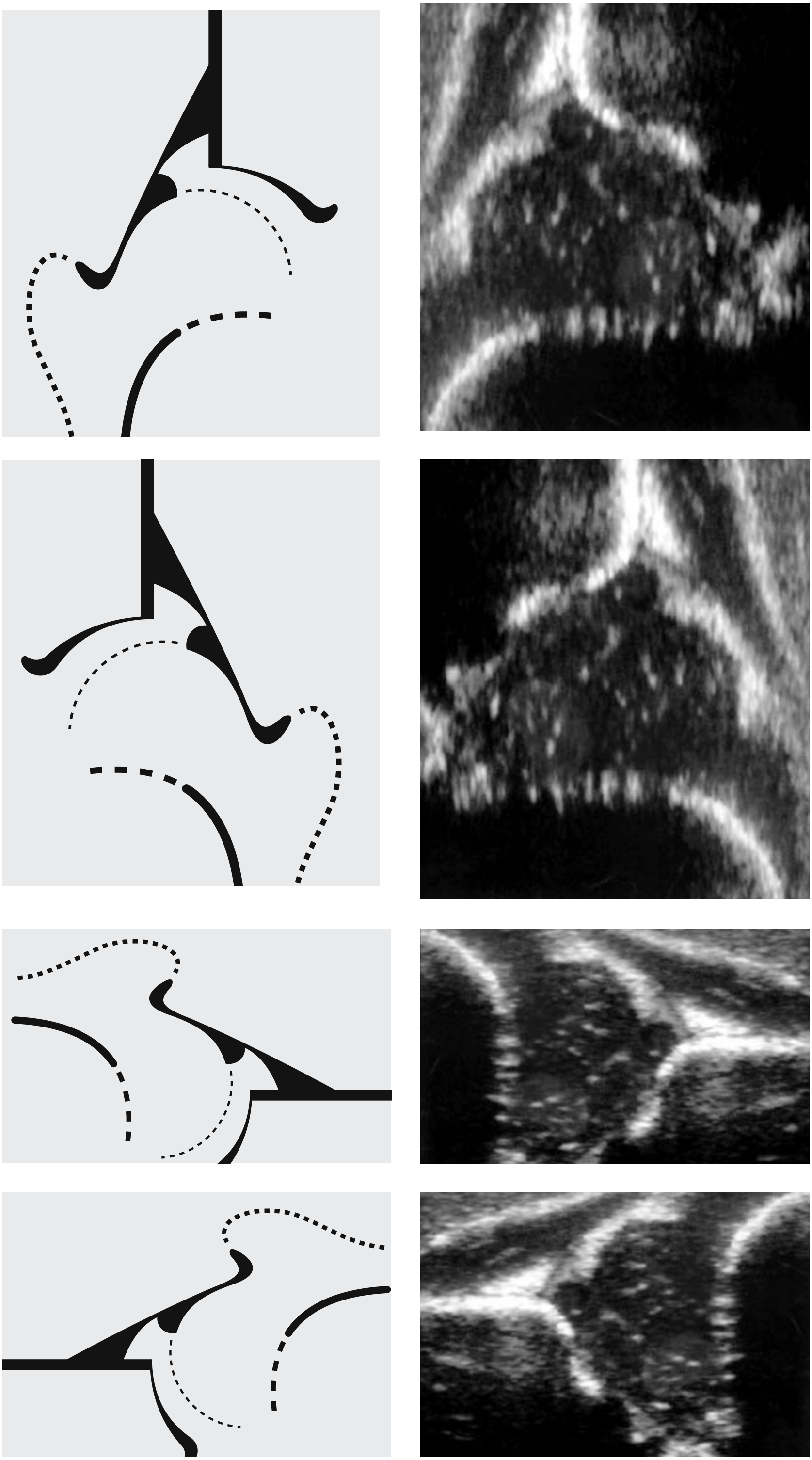
1.2 Additional Equipment for Hip Ultrasound

A cradle is essential so that the infant can be positioned in the standard way. A new probe-guiding system (Sect. 12.5) to avoid tilting effects is also essential. As the examination should be done standing rather than sitting, the table or trolley on which the cradle is placed should be of appropriate height with the cradle mounted on it.

1.3 Image Projection

For ease of viewing and therefore interpretation, the standard projection used in hip ultrasound is to view the images as though they are the antero-posterior views of a right hip on an x-ray. (Researchers have shown that this is the projection most easily interpreted by the brain). The conventional ultrasound projection where the head is to the left of the screen is therefore reversed, ideally the image or monitor can then be rotated through 90° for ease of viewing. All hip joints will therefore be projected so that they look like x-ray antero-posterior views of the right hip (Fig. 1.1a–d).

Fig. 1.1a–d. Possible projections of the infant hip, using ultrasonography. **a** Recommended anatomical projection, **d** conventional ultrasound projection. Of all the possibilities, the anatomical projection is the most suitable. Projections **b** and **c** are not recommended, but projection **c** is still better than projection **d**



a

b

c

d

2 Anatomy and Ultrasound of the Normal Infant Hip Joint

Contents

2.1 Explanation of Terminology Used in Describing the Ultrasound Anatomy

Echo hole:
(“Sound hole”) anechoic or hypoechoic area caused by tissues with low echogenicity (reflectivity), e.g. hyaline cartilage

Echo shadow or acoustic shadow:
anechoic area caused by total reflection of the ultrasound beam, e.g. bone

2.2 Ultrasound Characteristics of the Different Tissues in the Region of the Hip Joint

Bone: Seen as a bright echo with an acoustic shadow behind it. This is because bone is highly reflective and blocks the through transmission of the ultrasound beam, preventing structures deep to the bone being seen by ultrasound.

Relevant structures in the region of the hip joint are where the bone meets cartilage:

- The ilium immediately above the acetabulum.
- The lower limb of the os ilium in the floor of the acetabular fossa.
- Femoral head ossific nucleus (when present)
- The bony ischium.

Collagenous Connective Tissue and Fibrocartilaginous Structures: These are highly echogenic but echolucent allowing through transmission of the ultrasound beam so that structures deep to them can be seen.

These are:

- The joint capsule and the synovial (capsular) fold.
- The perichondrium of the cartilaginous acetabular roof and of the greater trochanter.
- The acetabular labrum.
- The ligamentum teres and the fovea in the femoral head.
- The intermuscular septa and the tendons of the reflex head of the rectus femoris muscle.
- The transverse acetabular ligament.

Ossification Within Hyaline Cartilage: Developing blood vessels and the condensation of cells that precede ossification give bright echoes but are sonolucent. These occur within the femoral head and at the chondro-osseous junction in the acetabular roof. These must be differentiated from the echoes that can occur in the hyaline cartilage roof of decentred hip joints when fibrocartilaginous degeneration caused by pathological pressure and shearing occurs.

Fat and Fibrous Connective Tissue: Usually give few or weak echoes, sometimes fat may be anechoic. In the infant hip fatty tissue may be seen as a hypoechoic zone in the acetabular fossa between the lower limb of the os ilium and the ligamentum teres or between the insertion of the joint capsule and the reflex head of the rectus-femoris muscle.

Hyaline Cartilage: Is hypoechoic or anechoic (depending on machine settings). The sinusoidal vessels may be seen as faint serpiginous echoes.

Hyaline cartilage is found in:

- The femoral head, proximal femoral neck and greater trochanter of the femur.
- The cartilaginous portion of the acetabular roof.
- The lunate surface of the acetabulum.
- The triradiate cartilage.

2.3 The Proximal Femur in Hip Ultrasound

At birth the femoral head, greater trochanter and “hat-shaped” proximal portion of the femoral

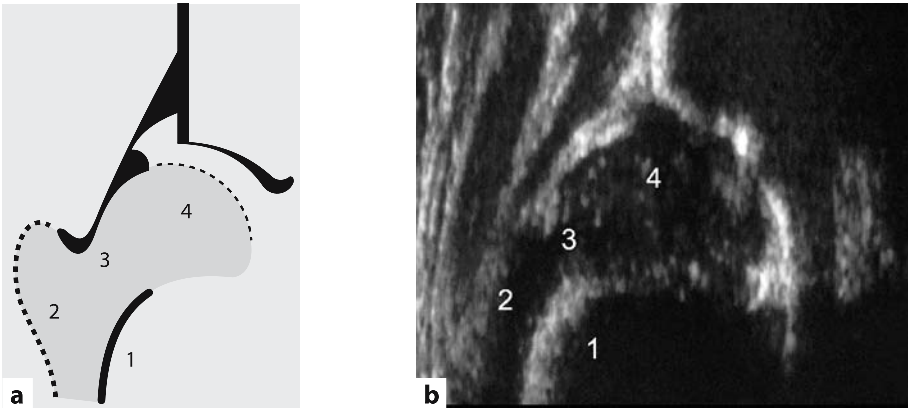


Fig. 2.1a, b. Anatomical interpretation of the sonographic image of an infant proximal femur: *1,* Bony part of the femoral neck (sound shadow). The strong echo at the chondro-osseous junction separates the bony part from the cartilaginous part of the femoral neck. *2,* Greater trochanter. *3*, Cartilaginous part of the femoral neck (hyaline cartilage). *4*, Cartilaginous femoral head (hyaline cartilage)

neck are of hyaline cartilage. These are separated from the bone shaft by the chondro-osseous border (epiphyseal plate Fig. 2.1). The chondro-osseous junction is very echogenic due to the histological structure of cell columns in the epiphyseal plate and then the total reflection of the sound beam by the bony structures of the femur. The echo of the chondro-osseous junction is an important landmark to be used to identify the femoral neck and as a basis for the identification of all the other anatomical structures. In order to achieve the best standard of hip ultrasound, we now know that, ideally, the chondro-osseous junction should be seen on every sonogram. Not only as the landmark for anatomical identification, but also because its appearance alters if the transducer is tilted. Tilting the transducer distorts the image and can lead to serious misdiagnosis (see Chap. 12).

The shape of the chondro-osseous junction changes with growth. The shape of the echoes also depends on the rotation, abduction and or adduction of the femur.

There are three basic shapes (Fig. 2.2a–c).

- Curved: In newborns.
- Palisaded: Parallel vertical echogenic strips medially, because of rather poor reflections from the medial part of the chondro-osseous junction.
- Medial part but not seen: Hidden by the acoustic shadow from the ossified lateral portion.

2.4 Femoral Head

Being hyaline cartilage, the femoral head is hypoechoic or anechoic. The small serpiginous echoes of the sinusoids in the hyaline cartilage may be seen (Fig. 2.3). Some ultrasound settings will show the thin, completely anechoic cell-free outer rim of the femoral head.

The femoral head is not completely round but is slightly oval or “nut shaped”. Geometrically, the infant hip is a “nut” or oval joint with

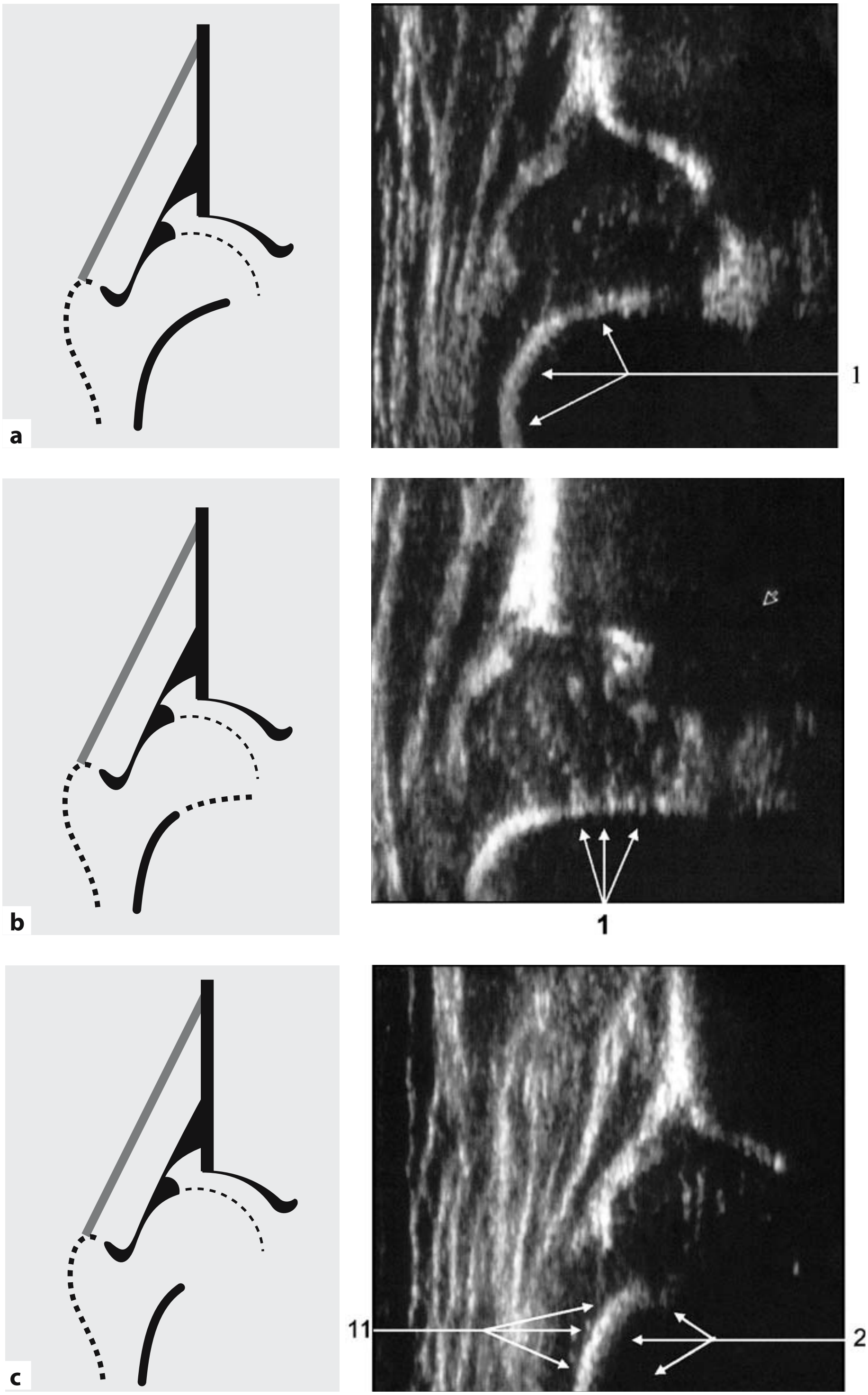

a
1
b
1
c
11
2

Fig. 2.2a–c. Age-related changes in the shape of the chondro-osseous junction of the femoral neck. **a** Early in life: curved shape. **b** Palisades: echostrips in the medial part of the chondro-osseous junction. *Arrows* mark the palisades. **c** Advanced maturation: Reversed V shape, with the medial part of the chondro-osseous junction being invisible, hidden in the sound shadow of the lateral, bony part. *1*, Chondro-osseous border; *2*, acoustic shadow of the bony part of the femur

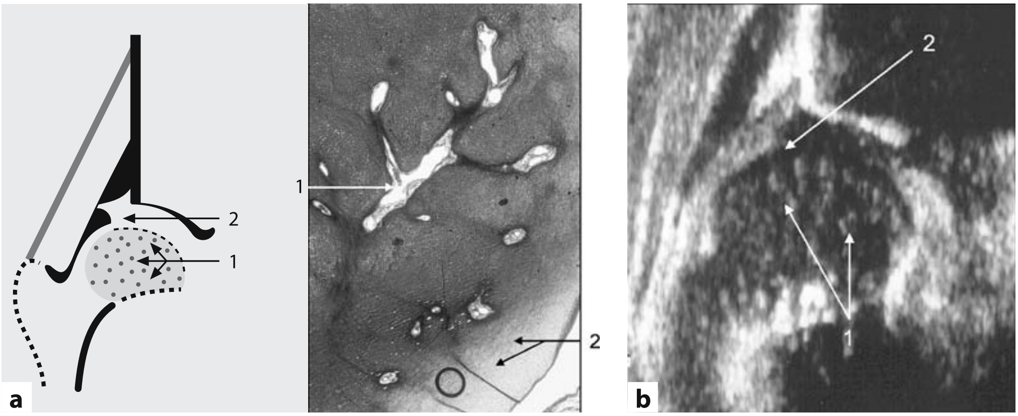


Fig. 2.3. a Non-ossified femoral head: The sinusoids within the hyaline cartilage of the femoral head give worm-like echoes (*1*). The surface of the femoral head, zona annularis (*2*) has no sinusoids and appears as an echo-free ring. **b** Sonographic image of infant hip demonstrating worm-like echoes within the unossified femoral head (*1*) and the echo-free ring-like zone, zona annularis (*2*)

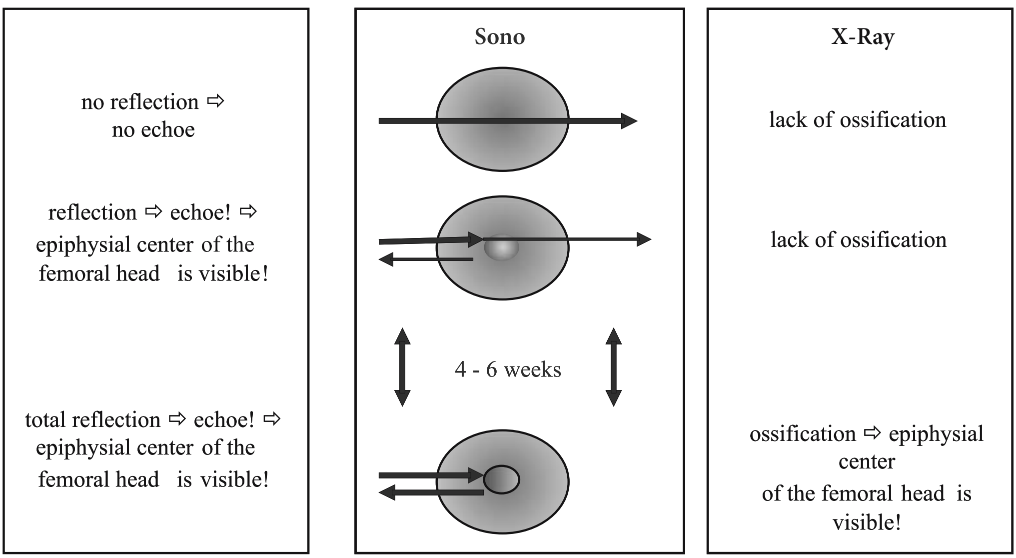


Fig. 2.4. Explanation of the sonographic appearance of the ossific nucleus

consequent physiological incongruities causing the phenomenon of "elastic whipping" or normal movement of the cartilaginous acetabular roof (see Sect. 9.1) when the head rotates in the acetabulum.

2.4.1 Femoral Head Ossification Centre

This may be present at birth. The average age at which echoes appear in a normal mature infant is at approximately 5–7 weeks.

Anatomically, the nucleus is not round but more oval or "arm like". It is not always in the centre of the femoral head and thus its shape and location in the head is variable. These two reasons make it impossible to assess the position of the femoral head in the socket using the ossific nucleus. The concentration of cells with new vessel formation is the first stage of development at the ossific nucleus site (Fig. 2.4). These changes cause echoes on ultrasound and the nucleus becomes visible ultrasonically. However, it will not become visible on an x-ray until calcification occurs at least 4–6 weeks later (see Sect. 5.5.1).

NB. There is a time difference of 6–8 weeks between early ossification being seen on ultrasound and it becoming visible on an x-ray. Ultrasound and an x-ray taken on the same day are therefore not comparable.

2.4.2 Ultrasonic Problems and Difficulties with the Nucleus

- The half moon phenomenon (Fig. 2.5): When the ultrasound beam travelling from lateral to medial meets a large calcified nucleus, the echo is reflected off the lateral side of the nucleus and the medial part is not seen; a large ossific nucleus therefore appears as a crescentic or half moon-shaped echo.
- Diagnostic errors (Fig. 2.6a–c): The nucleus cannot be used on ultrasound, as it is in an x-ray, for assessing the position of the femoral head in relation to the acetabulum. It is not round nor necessarily in the centre of the femoral head and only its outer border can be seen. Any attempts to draw lines on a sonogram similar to these drawn on an x-ray will always give a false impression of the hip.
- The determination of ossific nucleus size: Because the ossific nucleus is not round and is not necessarily in the centre of the femoral head it is impossible to say which section of

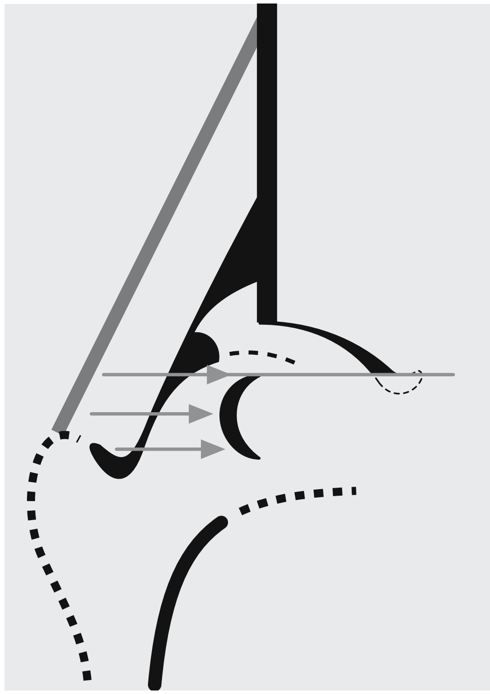


Fig. 2.5. The half-moon phenomenon appears when the femoral head is partly ossified. The ossified femoral capital nucleus blocks the sound waves. It leaves the lower limb of the os ilium in sound shadow, and the sonographic image of the infant hip cannot be used for diagnostic interpretation

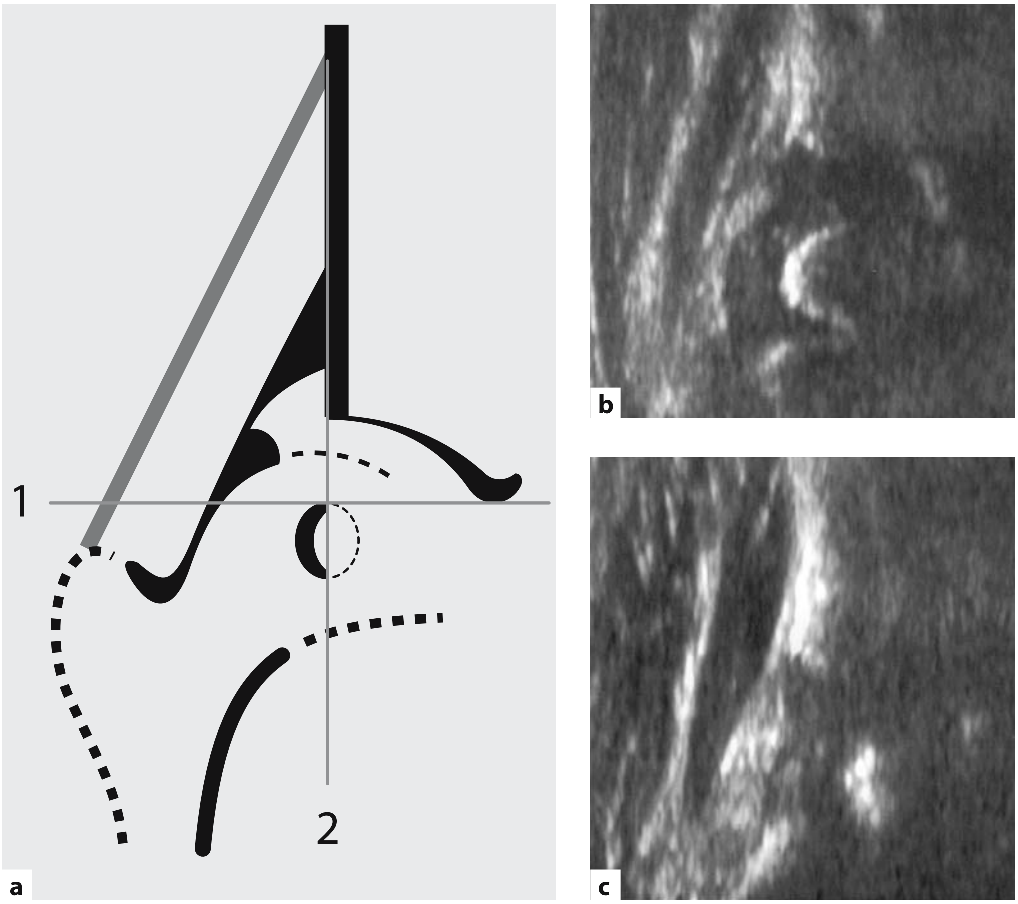


Fig. 2.6. **a** Applying radiological criteria and assessing hip pathology by measuring the ossified capital femoral nucleus gives an erroneous impression of hip subluxation: *1,* Hilgenreiner line; *2,* vertical line. **b** Pseudo-subluxation of the femoral head, associated with the half-moon phenomenon. **c** The same hip as in **b**. Rotating the femur changes the projection of the half-moon phenomenon within the femoral head, "reducing" the pseudo-subluxation

the ossific nucleus the ultrasound beam is encountering. This will also vary depending on the position of the femoral head. If the ultrasound beam hits the largest diameter of the nucleus, a large echo will be seen, whereas if it hits the periphery of the nucleus, only a small reflection will be seen. In these circumstances the majority of the nucleus lies outside the sonographic plane.

NB. It is not possible to perform reproducible measurement of the size of the nucleus with ultrasound.

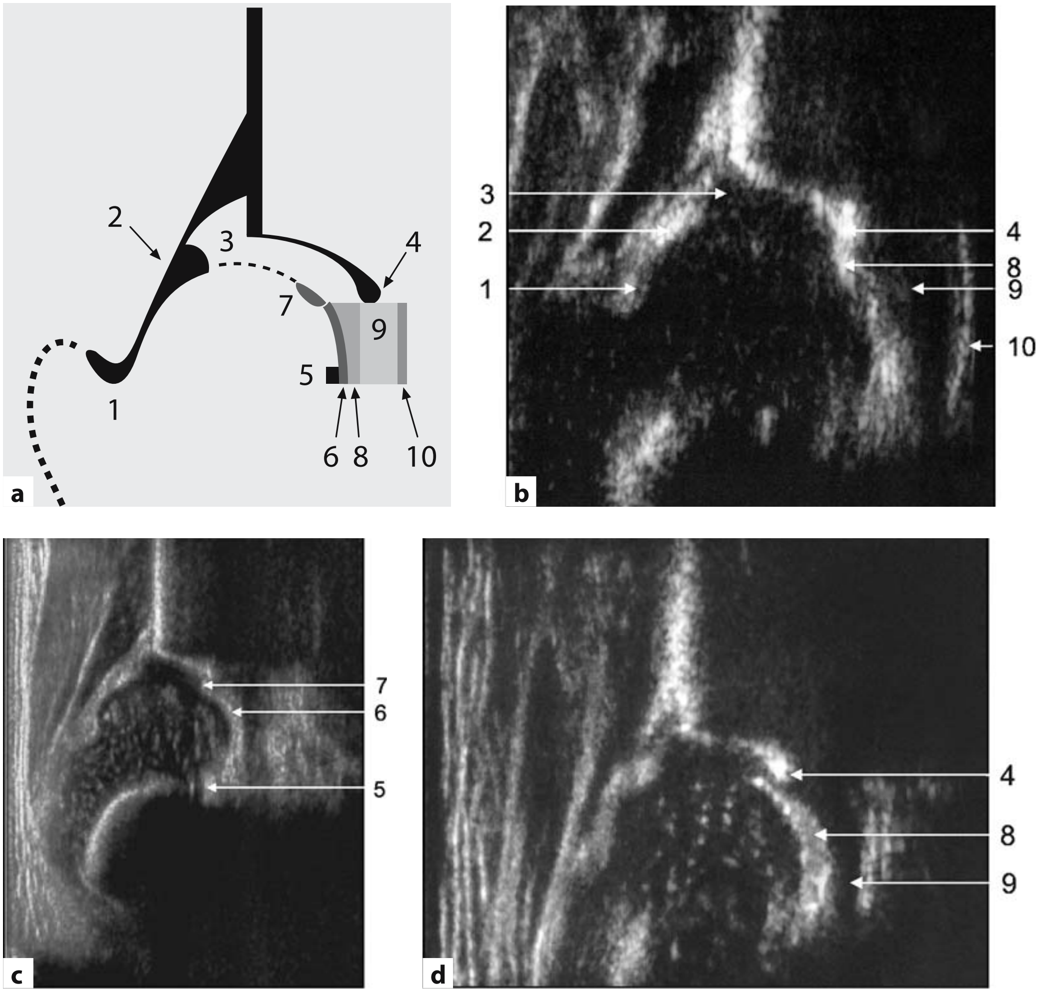


Fig. 2.7a–d. Identifying anatomical structures of the infant acetabulum (as seen on ultrasonography). *1*, Synovial fold; *2*, labrum; *3*, cartilaginous acetabular roof, formed from hyaline cartilage; *4*, lower limb of the os ilium; *5*, transverse ligament; *6*, ligamentum teres; *7*, fovea centralis; *8*, fatty tissue in the acetabular fossa; *9*, triradiate cartilage; *10*, triradiate cartilage perichondrium, on the inner side of the pelvis

- Limitation of ultrasound examination by the femoral head ossific nucleus: The most important reference point in every hip ultrasound is the so-called lower limb of the iliac bone deep in the acetabular fossa. This landmark is essential if one is to be certain one is in the correct plane through the centre of the acetabulum. If the "lower limb" is not visible on the sonogram, no diagnosis can be made as the hip cannot be classified (for exception, see Sect. 3.2.4).

NB. Unless the lower limb of the os ilium is seen, the sonogram cannot be used (with a single exception: Sect. 3.2.4). If there is a large femoral head ossific nucleus, it blocks the ultrasonic beam and prevents visualization of the lower limb, so no diagnosis can be made. In these circumstance another imaging method must be used. The extent of ossification in the hip joint is therefore the limiting factor in hip ultrasound. Thus the use of hip ultrasound is only indirectly limited by the age of the patient.

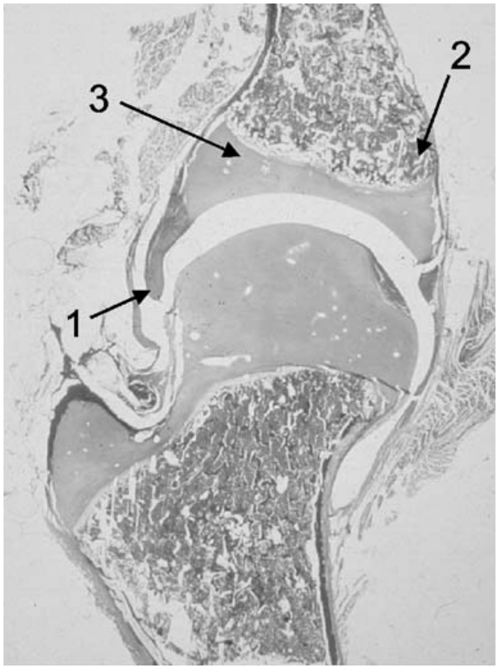


Fig. 2.8. Identifying the anatomical structures of the chondro-osseous acetabulum: *1*, labrum; *2*, lower limb of os ilium; *3*, cartilaginous part of the acetabular roof

2.4.3 Synovial Fold and Joint Capsule (Fig. 2.7a–d)

The lateral side of the femoral head is covered by the joint capsule. This is closely applied to the femoral neck and is continuous with the perichondrium of the greater trochanter. The point at which the capsule is reflected off the neck to become the perichondrium is referred to as the "synovial fold". Seen ultrasonically the synovial fold is a poorly defined bright echo, or two close parallel line echoes.

Beware: The echo of the synovial fold is often mistaken for the acetabular labrum.

If one follows the joint capsule cranially from the synovial fold on the surface of the femoral head, the echo of the acetabular labrum is found on the inner side of the joint capsule. Next to the labrum is the hypoechoic hyaline cartilage portion of the acetabular roof, medial to which are the bright echoes of the bony acetabulum. The inner-most portion of the bony acetabulum is the lower limb of the iliac bone. Caudal to it is the hypoechoic triradiate cartilage. On the lateral surface of the triradiate cartilage is hypoechoic fatty tissue in the acetabular fossa. Between the fatty tissue and the femoral head the bright echoes of the ligamentum teres may be seen. The ligamentum teres inserts onto the central fovea of the femoral head. This insertion gives a strong echo (caution: this echo is often mistaken for the lower limb of the os ilium).

Take care: When following from the synovial fold to the joint capsule, be careful not to follow the echoes of the inter-muscular septum instead of the joint capsule. This mistake is made quite frequently in decentred type III or type IV hip joints.

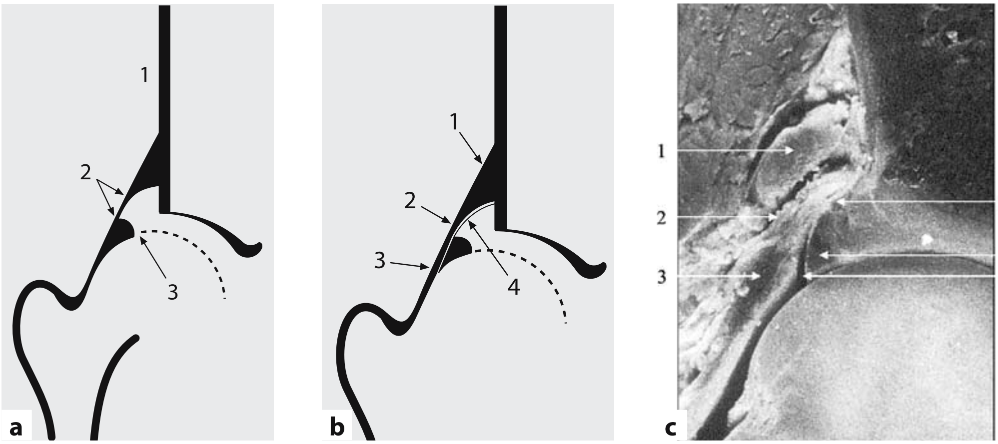


Fig. 2.9. **a** The so-called proximal perichondrium is a highly echogenic structure (*1*). The echo-poor perichondrial gap (*2*) is between the proximal perichondrium (*1*) and the joint capsule. Acetabular labrum (*3*). **b** The "proximal perichondrium" is highly echogenic. Its image comprises four different structures: *1*, tendon of rectus femoris muscle; *2,* proximal insertion of joint capsule with fat pad; *3,* ischio femoral ligament; *4,* perichondrium. **c** *1–4* as in b*;* *5*, labrum; *6*, peri-labral recess

2.4.4 The So-Called Fluid Film

In most cases the femoral head lies so close to the cartilaginous portion of the acetabulum that the narrow joint space cannot be seen. In some sonograms, however, a fine curved anechoic line is seen on the surface of the femoral head. This is known as the fluid film and may show the "vacuum phenomenon" (gas bubbles seen on ultrasound as very bright moving echoes).

2.5 The Acetabulum (Fig. 2.8)

The acetabulum consists of a bony and cartilaginous portion. The cartilaginous portion is composed of the hyaline cartilage of the acetabular roof and the fibrocartilaginous acetabular labrum. The labrum is the most peripheral part of the acetabulum, in the caudal portion of its circumference it bridges the acetabular incisura as the ligamentum transversum. The ligamentum transversum has no ultrasound relevance but is sometimes visible. The fibrocartilaginous labrum is more or less triangular in cross-section and is highly echogenic, whereas the hyaline cartilage of the acetabular roof shows few echoes and looks like an "echo gap" (for exception, see Sects. 5.3, 5.5).

2.5.1 The Perichondrium of the Hyaline Cartilage Acetabular Roof

The perichondrium is the lateral boundary of the cartilaginous acetabular roof. Distally it is continuous with the joint capsule and proximally merges in to the periosteum of the iliac bone. The proximal portion of the perichondrium is fairly thick and gives strong echoes on ultrasound (Fig. 2.9a). It is called the "proximal perichondrium". The distal portion is much thinner and gives fewer echoes or may give no echoes, an appearance that has led to it being called the "perichondrial gap".

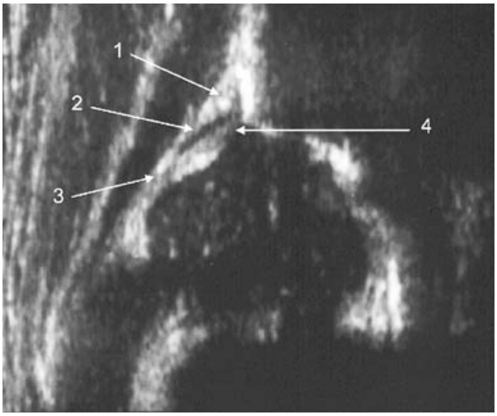


Fig. 2.10. "Proximal perichondrium" and anatomical structures, legend according to Fig. 2.9b

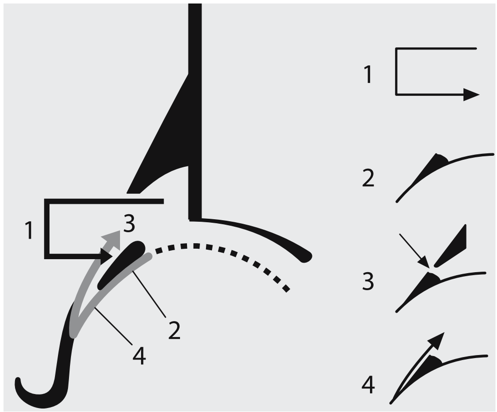


Fig. 2.11. The acetabular labrum can be located using the so-called labrum definitions. On the *right*: symbolic representation of the "labrum definitions"

Attention: The echo of the proximal perichondrium can be mistaken for the echo of the acetabular labrum!

When high-resolution ultrasound equipment is used it can be seen that the strong echoes of the "proximal perichondrium" is made up of three structures (Fig. 2.9b, c): the proximal perichondrium itself, part of the insertion of the joint capsule and the tendon of the reflex head of the rectus femoris muscle. Between these echoes and the echogenic ischio-femoral ligament that lies on the joint capsule, there is an apparent interruption of the echoes, the so-called perichondrial gap.

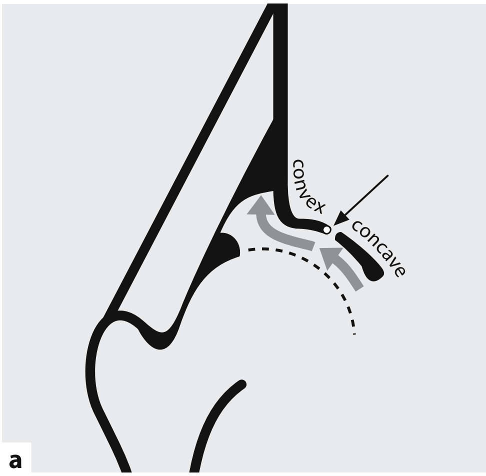
2.5.2 The Acetabular Labrum

The acetabular labrum is triangular in cross-section and is on the inner side of the joint capsule. There is no adhesion between the joint capsule and the labrum and there is a small recess between them. The base of the labrum is fixed to the hyaline cartilage acetabular roof (Figs. 2.8–2.10).

Tips for identifying the labrum:

The acetabular labrum can sometimes be difficult to recognize on a sonogram. In some circumstances (type IIIb joints) the labrum cannot be identified separately from the hyaline cartilage roof which is also echogenic. If necessary in difficult situations, one of the four "guides to the labrum" can be used to locate the labrum (Fig. 2.11).

1. The echo of the labrum is always lateral and distal to the "echo gap" of the hyaline cartilage acetabular roof on the inner side of the joint capsule.
2. The labrum is always in contact with the femoral head.
3. The labrum is always caudal to the perichondrial gap.
4. The labrum is where the contour of the joint capsule diverges from the surface of the femoral head. (This definition is needed to locate the labrum in type III b hip joints.)



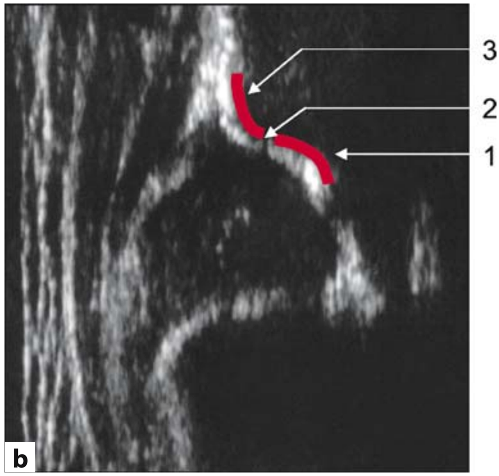


Fig. 2.12. **a** Bony rim definition: The bony rim is the point where the concavity of the bony acetabular roof changes to the convexity of the ilium (the turning point is marked by an *arrow*). **b** *1*, Concavity; *2*, turning point with sound shadow (measurement point); *3*, convexity

If the labrum still cannot be located, then one of the three landmarks of the sectional plane is missing. In this case the ultrasound image must not be used for diagnosis.

2.5.3 The Acetabular Fossa

The anatomy of the acetabular fossa is quite complex and the structures that are present are of varying significance in hip ultrasound (Figs. 2.7, 2.8).

The Lower Limb of the Os Ilium

The lower limb of the os ilium measures 1–3 mm in size depending on the age of the baby. The lower limb must be clearly identified. It is an essential marker of the correct sectional plane and must be clearly seen on the sonogram unless the hip is decentred. Anatomically the lower limb of the os ilium is approximately half way between the anterior and posterior rims of the acetabulum and casts an acoustic shadow. Caudal to the lower limb is the hypoechoic triradiate cartilage. Caudal to this the bright echo of the ischial bone will be seen in some planes (Fig. 3.4).

Fat and Connective Tissue

There is a pad of fat and connective tissue on the floor of the acetabular fossa which may be seen as weak echoes overlying the lower limb of the os ilium.

The Ligamentum Teres (the Ligament of the Femoral Head)

This linear structure may be seen in whole or in part in the floor of the acetabular fossa. It is a strong reflection (echo) from its insertion into the femoral head at the central fovea to its insertion into the lower acetabular margin. The strong echo must not be confused with the os ilium.

The Transverse Acetabular Ligament

This lies inferiorly and forms the continuation of the acetabular labrum over the acetabular incisura. It may well be seen especially in the newborn.

2.5.4 Definition of the Osseous Rim (Fig. 2.12)

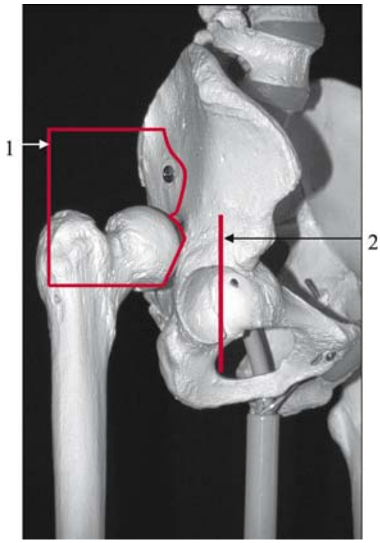
1. The bony rim is the most lateral point of the concavity of the bony socket.
2. The bony rim is the point where the concavity of the bony acetabular roof changes to the convexity of the ilium; in short, where the concavity becomes the convexity (“concavity to convexity”).

NB. It is very important when identifying the bony rim to start from the “concavity” of the acetabular fossa, starting with the lower limb of the os ilium and moving proximally from medial to lateral. If instead you start from the ilium and look caudally from lateral to medial, the normal irregularities in the contour of the ilium can result in inaccurate identification of this important landmark too proximally. Frequently there is a small acoustic shadow just medial to the point where the contour changes at the osseous rim.

Key Points:

- Frontal plane “anatomical projection”, i.e. viewing the ultrasound image vertically as in an antero-posterior x-ray of a right hip joint.
- The shape of the chondro-osseous junction of the femoral shaft changes with development and takes one of three forms.
- The femoral head is not round neither is the ossific nucleus. The ossific nucleus is not anatomically the centre of the femoral head.
- Accurate measurement of the size of the femoral head and the ossific nucleus is not possible ultrasonically. Enlargement of the ossification centre in the femoral head is the limiting factor in hip ultrasound. “Calcification in the head is only a sign of maturity”. [Ultrasonographically, but there is also another interpretation possible (bad joke!)]
- A hip sonogram and an x-ray can only be compared if one remembers that ossification is seen 6–8 weeks earlier on ultrasound than on an x-ray. Sonograms show what will be visible 6–8 weeks later on an x-ray.
- The “proximal perichondrium” is a summation echo from several adjacent structures.
- The lower limb of the os ilium is ultrasonically the centre of the acetabulum.
- The bony rim of the acetabulum is the point where the concavity of the socket turns to the convexity of the iliac bone.

3 The Standard Plane



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3.1 The Principle of the "Standard Plane"

In order to be reproducible the same sonographic section through the hip joint must always be used. This will be explained more precisely in Sect. 3.2. To define a plane, one requires three points in space to be defined.

For hip ultrasound these points are:

1. The lower limb of the bony ilium in the depth of the acetabular fossa (Figs. 3.1–3.4).
2. The mid portion of the acetabular roof.
3. The acetabular labrum.

If any one of these points is missing or not clearly shown, the sonogram is worthless and must not

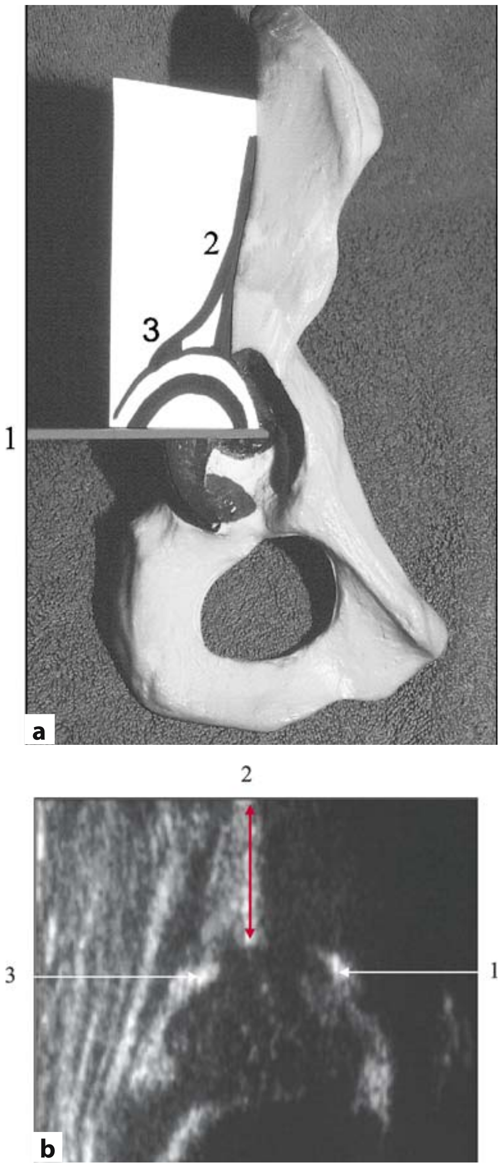


Fig. 3.1. a The sonographic image of the infant hip in the coronal plane has three landmarks: *1*, lower limb of os ilium as rotating axis for the sectional plane; *2*, mid part of the acetabular roof (standard sectional plane); *3*, acetabular labrum. **b** *1*, lower limb of the os ilium; *2*, correct plane; *3*, labrum

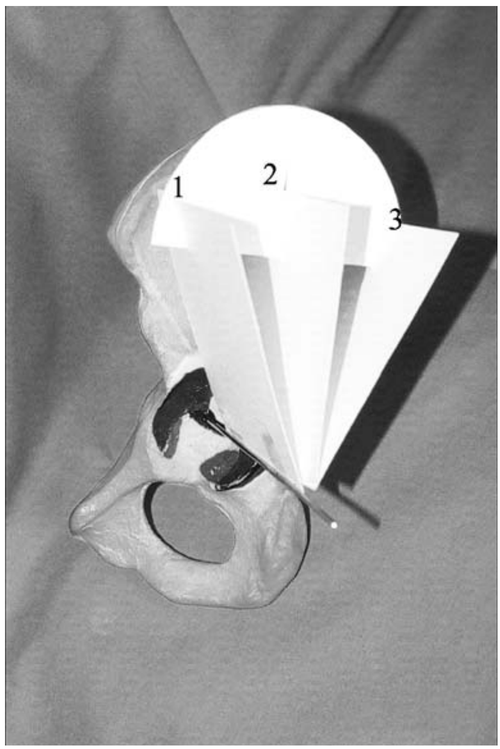


Fig. 3.2. Sonographic images of different sectional planes through the acetabulum. The rotational axis is through the lower limb of the os ilium. *1*, Anterior plane; *2*, standard (middle) plane; *3*, posterior plane

be used for diagnosis. There is only one exception to this rule which will be stated in Sect. 3.2.4.

3.1.1 The Importance of the Three Landmarks

For ultrasound purposes, the lower limb of the os ilium is the centre of the acetabulum. If this landmark is not seen on the ultrasound image, then the sectional plane does not pass through the centre of the acetabulum. Even if the sectional plane and acetabular labrum are correctly shown, no diagnosis can be made in a centred hip joint without the pivotal point of the centre of the acetabulum being seen, i.e. the lower limb of the os ilium.

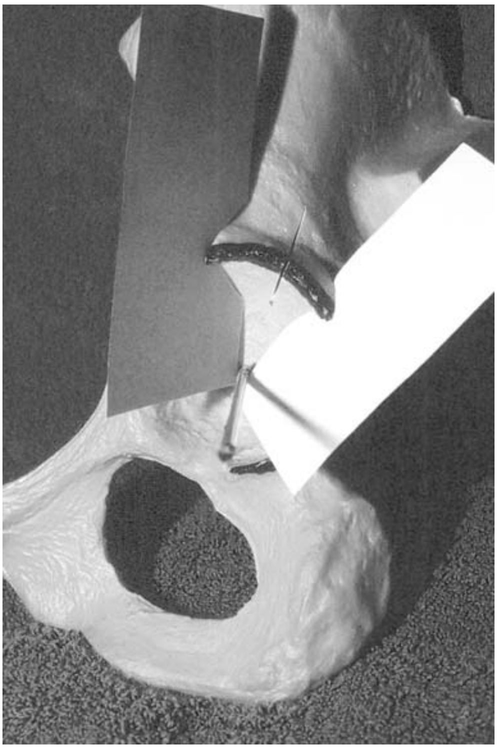


Fig. 3.3. The sectional plane is tilted forward and backward, respectively. The tilting causes deflection of the ultrasound beam, with poor reflection of the labrum, which is inadequately seen

NB. "No lower limb, no diagnosis" (one single exception, see Sect. 3.2.4).

3.2 The Problem of the Variable Bone Coverage of the Femoral Head

For reasons that reach back to evolution, from walking on four feet to the upright biped position (during which the pelvis has rotated), the posterior part of the bony acetabular roof is better developed than the mid or anterior parts (Fig. 3.4). It is possible to differentiate whether the sectional plane passes through the anterior, mid or posterior part by the characteristic shape of the iliac bone immediately above the acetabulum in each of the three planes. If one compares the anterior and posterior sections from the same joint, it is clear that the bony coverage seems better developed posteriorly than in the mid or anterior sections.

3.2.1 Shape of the Posterior Section

If the standard vertical projection is used, the iliac silhouette above the bony rim is concave towards the right of the picture, i.e. away from the transducer. The concavity is the gluteal fossa which is situated in the posterior part of the iliac wing. The bony rim itself appears rounded or "nose shaped".

3.2.2 The Mid Section

The iliac silhouette above the bony rim is straight and parallel to the transducer (and the edge of the monitor).

3.2.3 Anterior Sections (Fig. 3.7)

The iliac silhouette above the bony rim slopes outwards towards the transducer.

A summary is given in Figs. 3.4–3.7.

3.2.4 Exceptions and Variations on the Typical Sectional Silhouettes

The lower limb of the os ilium must always been seen except in markedly decentred hip joints. When the femoral head slides out the socket, it slides not only proximally but also posteriorly.

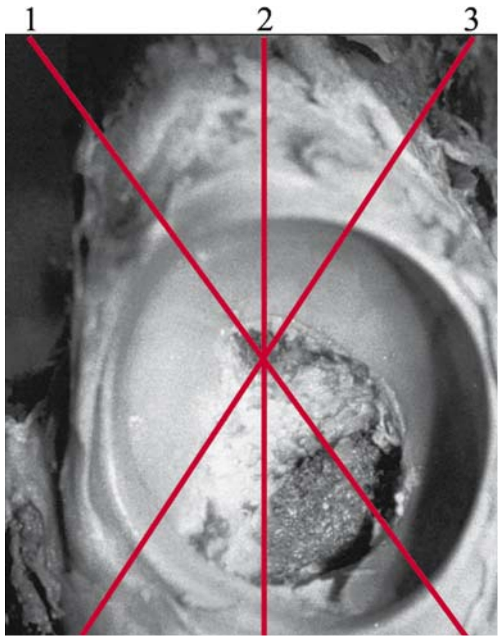


Fig. 3.4. Typical contours and silhouettes of the acetabular roof in: *1*, anterior sectional plane; *2*, standard plane; *3*, posterior sectional plane

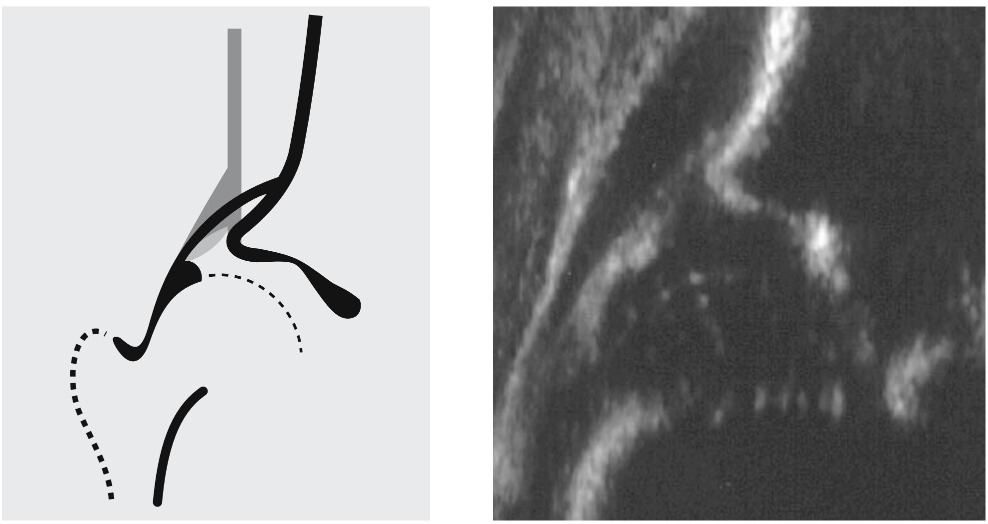


Fig. 3.5. The posterior sectional plane. Using the anatomical projection as a reference, the silhouette of the iliac bone in the posterior sectional plane bends to the right, away from the probe (*solid line*)


Fig. 3.6. The middle sectional planes (the standard plane). The contour and the silhouette of the iliac bone are straight and parallel to the probe

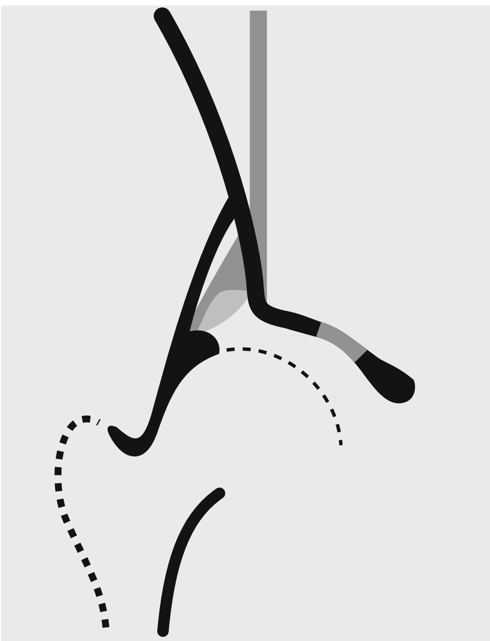



Fig. 3.7. The anterior sectional plane. The silhouette of the iliac bone bends to the left, towards the probe (*solid line*)

The displaced femoral head and the acetabulum, with its lower limb of the os ilium, are therefore in different planes. Therefore if one follows the displaced femoral head, the ultrasound plane is no longer in the standard plane. The direction of displacement of the femoral head means that it is usually the posterior sectional plane that is seen (Fig. 3.8).

In displaced hips the important thing is to differentiate where the femoral head has pressed the hyaline cartilage of the acetabular roof: cranially (type III) or caudally (type IV).
In decentred (=displaced) joints one can differentiate between type III and type IV even if the lower limb of the os ilium is not visible.

Note: The differentiation between type III and type IV is morphological not by measurement.

The system for orientation given in Sect. 3.2 (Figs. 3.4–3.7): Anterior sectional plane, silhouette slanting towards the transducer, mid sectional plane silhouette parallel to the transducer, posterior plane silhouette concave and slanting away from the transducer hold good except in some decentred joints with a markedly flattened dysplastic (socket) when the mid plane looks like an anterior plane.

The only consistently reproducible scan section is the posterior section. This, therefore, is the starting point for a tomogram-like examination of the acetabular roof. This should be used when it is impossible to get an iliac silhouette which runs parallel to the transducer immediately in a standard examination. In these cases the hip joint must be carefully examined to find the standard plane, starting orientation with the posterior sectional plane and rotating slowly “step by

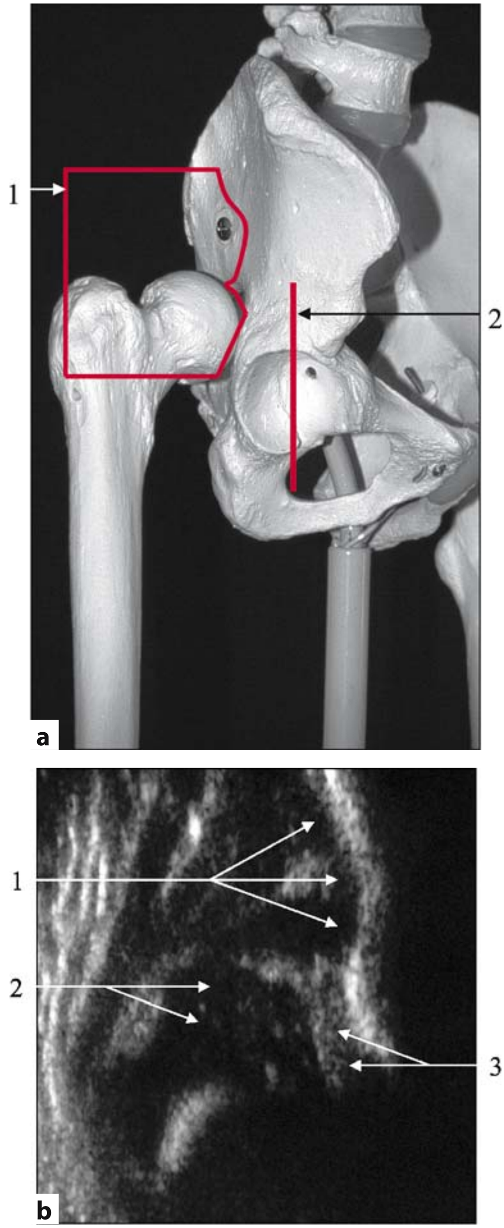


Fig. 3.8. **a** Principles of hip luxation shown on an adult skeleton: the femoral head has decentred dorsocranially. The femoral head is located posteriorly and is not visible in the standard plane but only in the posterior sectional plane. The lower limb of the os ilium will often not be visible in the same plane as the femoral head, as these landmarks are located in different planes. *1*, Plane in the gluteal fossa; *2*, standard plane. **b** *1*, Posterior plane with the concavity of the gluteal fossa; *2*, dislocated head; *3*, deformed and downwardly pressed cartilage acetabular roof (example of a type IV hip joint, according to **a**)

step" more anteriorly until the plane moves out of the gluteal fossa.

3.2.5 Definition of the Mid Section of Acetabular Roof

The mid section is reached when, having identified the posterior plane, the plane rotates about the lower limb of the os ilium until it leaves the gluteal fossa. This is easily identified as the concavity straightens. "Straight" does not necessary mean parallel to the edge of the monitor!

Important Practical Tip

The system:

- Posterior section – goes away from the transducer (iliac contour is concave and goes to the right on the monitor.)
- Mid section – iliac silhouette parallel to the transducer (parallel to the monitor).
- Anterior section – the iliac silhouette angles towards the transducer (iliac echo leans to the left on the monitor).

It usually works in everyday practice to find the standard plane. If, for some reason as described in Sects. 3.2.1–3.2.3, your orientation is difficult to achieve, then find the posterior plane and rotate the transducer in a tomogram-like way from the posterior plane to the exact definition of the mid section (Sect. 3.2.5).

3.2.6 The Question of Reproducibility

The mid portion of the acetabular roof is essentially the weight-bearing portion in the upright, walking position. Although, in principle, every acetabular roof can be examined as in a tomogram with a number of different sections, to get a reproducible standard plane, which can be used for comparisons, only the mid plane must be used (standard plane = measurement plane).

Only a section that is the standard sectional plane can be evaluated and measured. A section which is not in the standard plane is not relevant for diagnosis or treatment (for exception, see Sect. 3.2.4, decentred joints).

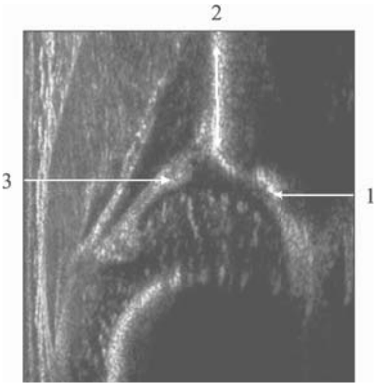
One can only establish whether the sectional plane passes through the middle of the acetabular roof, or too far anterior or posterior, if the lower limb of the os ilium is seen. If it is seen then the middle portion of the acetabular roof is identified by the shape of the iliac contour above the acetabulum (see Sect. 3.2).

Only if the lower limb of the os ilium and the sectional plane are both correct does it make sense to try and identify the third landmark, the acetabular labrum. The acetabular labrum may sometimes be difficult to see, but its position must be identified even if, as in type III b joints (see Sect. 5.3) where the cartilage roof is echogenic throughout, the labrum cannot be seen as a separate structure on ultrasound. Using the "guides" to the site of the labrum it is possible to identify even the small, poorly defined labrum. If it cannot be seen, the sonogram is useless. If the ultrasound beam is vertical to the labrum it can usually be seen well. If, however, the beam is tilted the labrum may not be seen at all (Fig. 3.3).

Key Points:

- A plane needs three coordinates (landmarks).
- The standard plane is defined through:
  - The lower limb of the os ilium
  - subitem>The mid section of the bony acetabular roof
  - The acetabular labrum
- Hip joints must only be evaluated and measured in the standard plane (exception: decentred joints – evaluated but not measured).

4 Identifying the Anatomy and Checking the Landmarks and Tilting Effects



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Before a hip sonogram can be evaluated, the echoes on a sonogram must be identified as anatomical structures in a methodical way. Once this has been done, the sonogram should be checked to see whether it meets the criteria for the standard sectional plane. The anatomical identification should always be completed prior to checking the sectional plane landmarks, never the reverse.

Tilting effects are checked last (Chap. 12).

4.1 Anatomical Identification

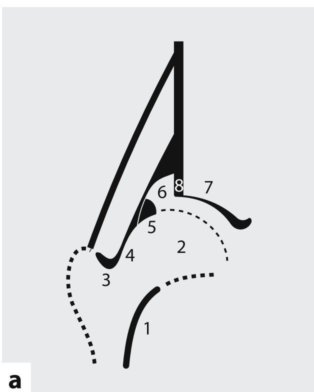
In order to avoid mistakes, the anatomical structures should always be identified in the following order:

1. Chondro-osseous junction (epiphyseal plate of the femur)
2. Femoral head
3. Synovial fold (to avoid confusion with the acetabular labrum!)
4. Joint capsule (avoid confusion with an intermuscular septum)
5. Acetabular labrum (see help points in Sect. 2.5.2)
6. Invariable anatomical sequence of the acetabular roof from lateral to medial
   - a. Labrum
   - b. Cartilage acetabular roof
   - c. Bony socket
   - Sequence a–b–c is always the same: which is equivalent to the “invariable sequence” or “standard sequence”.
7. Define the osseous rim (=the point where the concavity of the socket turns to a convexity) (see Sect. 2.5.4)

4.2 Checking the Landmarks

Following the identification of the anatomical structures, the sonogram is examined to check whether it is in the correct sectional plane. To define a plane in 3D, three coordinates or landmarks are required.

For a diagnostic, measurable sonogram, the three landmarks that must be present are: the



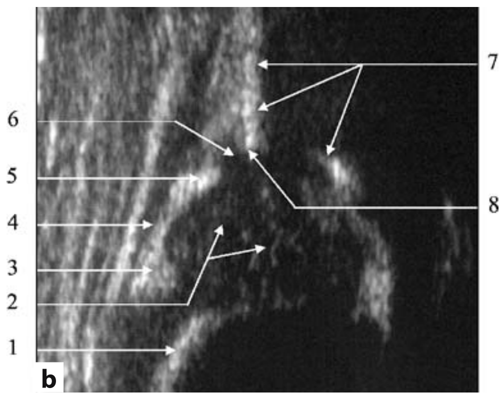
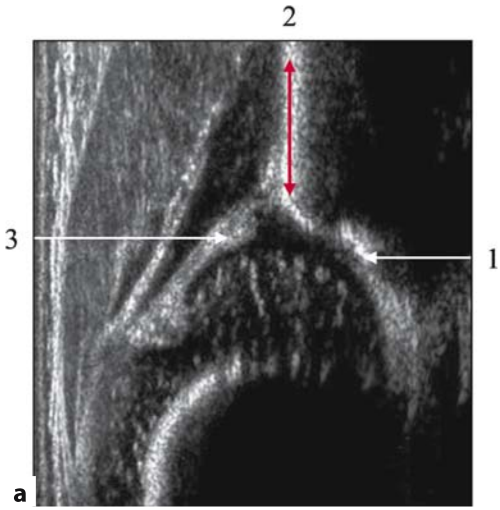


Fig. 4.1. a Correct order of the anatomical identification of infant hip sonographic image: *1*, chondro-osseous junction; *2*, femoral Head; *3*, synovial fold; *4*, joint capsule; *5*, acetabular labrum; *6*, hyaline cartilage preformed acetabular roof; *7*, bony part of acetabular roof; *8*, bony rim: turning point from concavity to convexity. **b** Correct order of the anatomical identification of an infant hip sonographic image (see **a**)



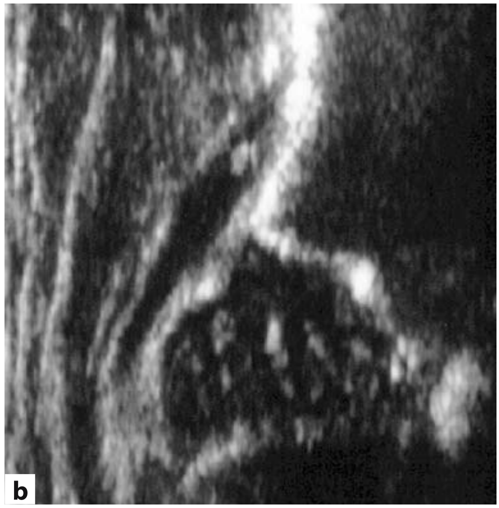


Fig. 4.2. **a** Checklist points of the anatomical identification prior to reading a sonogram. *1,* Lower limb of the os ilium; *2*, standard sectional plane; *3*, acetabular labrum. Sonogram is acceptable for reading only if all three landmarks are present. **b** Image obtained with posterior tilting of the probe: The lower iliac limb is clearly visible; however, the sectional plane is posterior. This sonogram cannot be used for diagnostic interpretation. **c** A sonogram performed through a posterior sectional plane: The lower limb of the iliac bone and the labrum are not visible. This sonogram cannot be used for diagnostic interpretation

lower limb of the os ilium, the mid portion of the acetabular roof and the acetabular labrum.

First check that the tip of the lower limb of the os ilium is shown. It is possible, by tilting the transducer, to produce an iliac silhouette that looks like that of the standard (mid) section but which does not pass through the centre of the acetabulum. In order to avoid this mistake it is essential, when evaluating the sectional plane, to check that the pivot point (inferior limb of the os ilium) is found first.

The most important guiding principle in hip ultrasound is, in short:

Three landmarks

- Lower limb (os ilium)
- Section (mid portion of the acetabular roof, Sect. 3.2)
- Labrum

If just one of these important landmarks is missing, the sonogram must not be evaluated.

Except when, in a decentred hip joint, the displaced femoral head slides out of the socket in a supero-posterior direction and therefore leaves the standard sectional plane. In these circumstances the inferior margin of the os ilium is often not seen and the sectional plane is usually posterior. These sonograms can be evaluated descriptively (anatomically) (whether type III or IV) but may certainly not be measured (Sect. 3.2.4).

NB. Pay special attention to the order of identification of the three landmarks. Only if the lower margin of the os ilium is shown can one proceed to check the sectional plane and lastly the labrum.

Key Points:

- The lower limb of the os ilium must always be present except in decentred hip joints.
- A hip sonogram can only be evaluated if all three landmarks are shown (except in decentred joints, see above).
- Anterior, mid (standard) and posterior sections can usually be distinguished from one another by the shape of the iliac bone proximal to the bony acetabular rim.
- When difficulties arise in finding the standard plane, it can be found by starting in the posterior section and slowly rotating about the lower limb until the standard plane is reached.
- Only sonograms in the standard plane may be measured.
- Anatomical identification always before landmark check!

4.3 Checking a Hip Sonogram

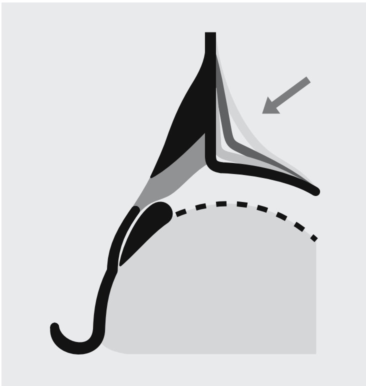
Start always with the anatomical identification first (epiphyseal plate, femoral head, etc. ...: labrum ... concavity–convexity?). Do not accept a sonogram when one of the anatomical points is not clearly identifiable.

A hip sonogram may only be further evaluated for diagnosis if the three landmarks (lower limb of os ilium, mid sections of the acetabular roof, and labrum) are visible and it is in the “standard” plane.

Additional check:

1. Are there tilting effects?
2. Is the correct scale being used? (Minimum 1:1.7) Smaller sonograms may not be used.

5 Definition of Types



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The ultrasound typing correlates with the pathological changes in the hip joint rather than with the height of the dislocated femoral head. The height of the dislocated femoral head does not automatically correlate with the severity of the anatomical deformity.

There are two forms of hip dislocation.

1. The hip joint fails to form properly during embryological development. The femoral head and socket show severe deformities and the femoral head was never in the correct position (teratological form). The cell configuration for the labrum, bony roof and hyaline cartilage were never normal (arthrogryposis multiplex).
2. Initially the femoral head was positioned in the socket but certain biomechanical factors cause the normal development to cease and the femoral head begins to slide out of the socket deforming the acetabulum (developing dislocation of the hip–DDH).

Basic Principles

If a femoral head slides out of the socket, this process of dislocation leads to deformity. This is primarily of the cartilage part of the acetabular roof but, inevitably, the bony portion becomes damaged also. The femoral head leaves "grinding marks" on the acetabular roof during the process of dislocation.

Through accurate analysis of the pathological changes in the cartilage and bony socket it is possible to state the severity of the pathology affecting the hip joint. Eventually these pathological changes need to be reversed by treatment without causing further iatrogenic damage to the femoral head (avascular necrosis). The ultrasound "types" of the hip joint therefore classify the bony and cartilaginous socket. The more accurate and precise the typing, the more appropriate and precise the treatment can be.

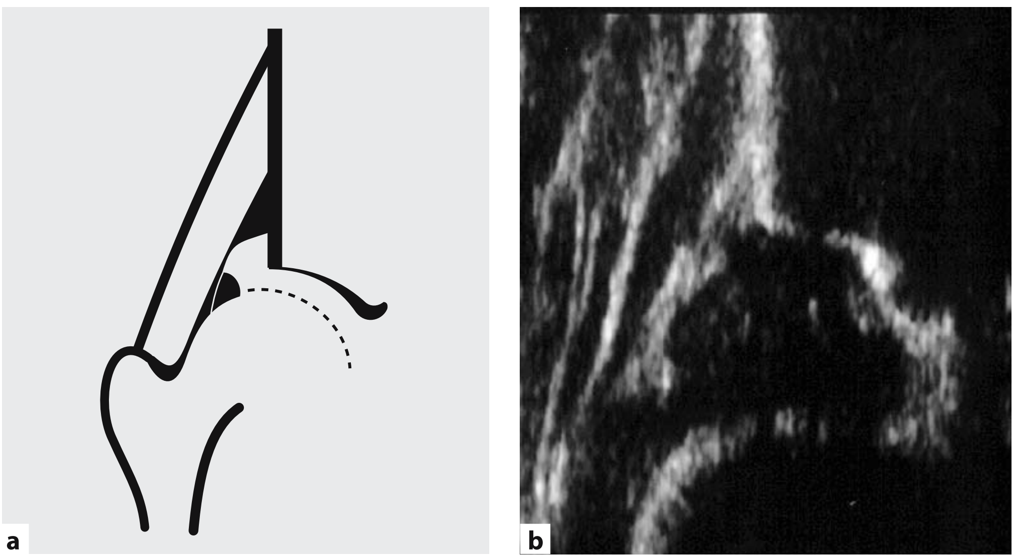


Fig. 5.1. **a** The bony roof is good; the bony rim is sharp; the cartilaginous roof covers the femoral head. **b** Description according to **a**: standard sectional plane; type I hip joint

5.1 Type I

The hip joint is mature. This means that the degree of ossification is appropriate for a hip joint in a 3-month-old. The bony socket is well developed. The bony rim is angular or slightly blunt. The cartilaginous acetabular roof encloses the femoral head holding it firmly in the socket (the cartilage "covers" the head). A type I hip joint may be present at birth when there may even be an ultrasonically demonstrable femoral head ossific nucleus.

Question: When can a type I hip joint deteriorate?

Answer: When there is:

1. A neuromuscular abnormality: This results in an imbalance of muscular forces on the hip joint. These forces affect the growth of the socket enormously. With pathological muscle tension the balance of forces in the hip joint changes and abnormal or inadequate growth occurs (e.g. in diplegia).
2. Hip joint effusion: In cases of "coxitis" the joint congruity alters because of the effusion (distension–dislocation). The femoral head dislocates out of a well-developed socket.
3. Wrong diagnosis: The hip joint was not a type I in the first place.
4. Previously decentred joints: ("secondary dysplasia") hips that have been treated and have become a type I should be followed up radiologically until the end of growth. For unknown reasons, disorders of growth can occur later. An initially "healed" joint may later develop a secondary dysplasia.

An explanation for this phenomenon is partial damage to the chondro-osseous border of the acetabular roof during head displacement. As a result, ossification is incomplete even with correct treatment and finally results in a dysplastic bony acetabular roof.

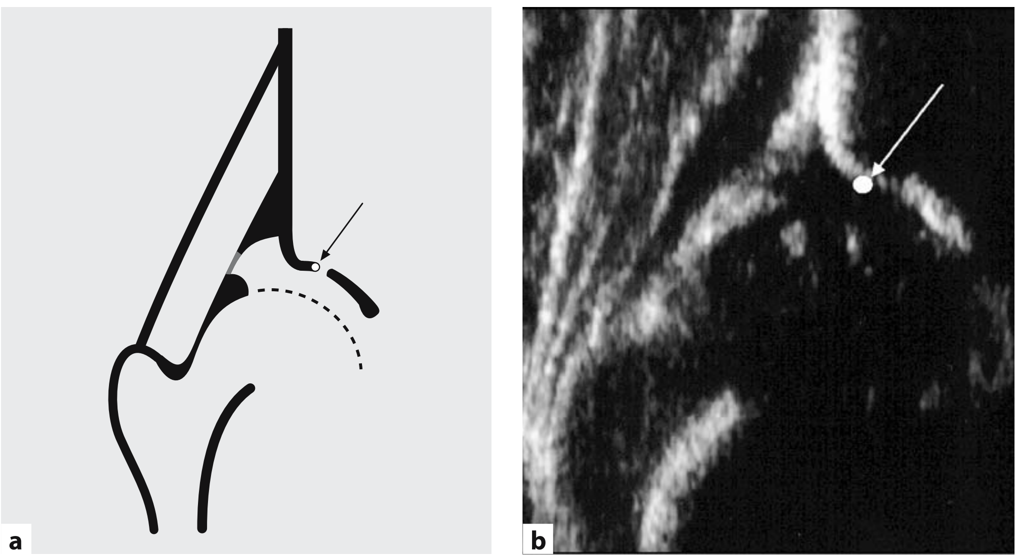


Fig. 5.2. **a** The bony roof is deficient; the bony rim is round; the cartilaginous roof covers the femoral head. *Attention:* The bony rim is described by its shape: sharp/round /flat. Topographically, the bony rim (marked by an *arrow*) is the point of transition from concavity to convexity (measurement point).

5.2 Type II

This is also a centred joint but the bony acetabular roof is "deficiently" developed, the bony rim is rounded and the cartilaginous portion of the acetabular roof seems proportionately larger; however, it encloses the femoral head. The total coverage (bony socket plus cartilage socket) keeps the femoral head firmly in the socket.

Definitions:

- Deficient: A real deficit or dysplasia. Where the bony coverage of the femoral head is inadequate for the age of the infant (IIa, IIb, IIc).
- Sufficient: Meaning adequate. The term "sufficient" is used in cases where the joint is of appropriate maturity for the age yet still physiologically immature. (Type II a+; see Sect. 8.1.1). The difference between types IIa/b and IIc can only be determined by measurement and will be explained in Sect. 8.1.1 on measurement technique. Type D is the first stage of a decentred joint and is explained in Sect. 8.2.2.

5.3 Type III

A decentred (dislocated) joint. The bony socket is poorly developed, the bony rim is flattened and the cartilaginous acetabular roof is pushed cranially, i.e. displaced upwards. Due to the poor bony development, the femoral head has dislocated. As it has dislocated it has pushed the majority of the cartilage roof cranially and only a small part of the cartilage is pressed caudally (downwards) towards the original acetabulum.

Type III is subdivided into type IIIa and IIIb:

- Type IIIa: The femoral head has pushed the cartilaginous acetabular roof cranially, but the shearing forces have not caused histological change in the hyaline cartilage of the acetabular roof. The hyaline cartilage is therefore still hypoechoic and is seen as a "sound hole".
- Type IIIb: Due to pressure and shearing on the deformed cartilaginous roof by the dislocating femoral head, pathological changes to the structure of the hyaline cartilage have occurred. These changes create echoes in the

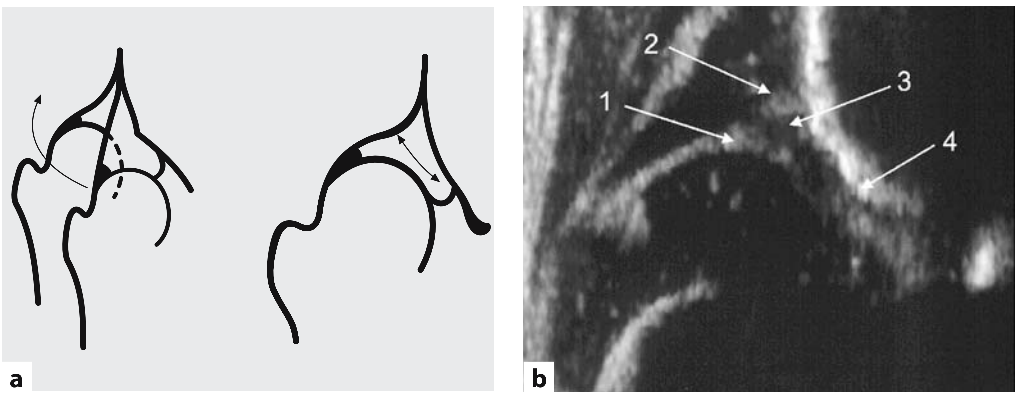


Fig. 5.3. a The decentred femoral head presses the cartilaginous roof upwards . Most of the cartilage is pressed up; a small part is pressed down. The femoral head is in a secondary moulding. The echogenicity of the hyaline cartilage roof is the same as the echogenicity of the femoral head. **b** The bony roof is poor, the osseous rim is flat, and the cartilaginous roof is displaced up. There is no difference in the echogenicity of the cartilaginous acetabular roof compared with the cartilaginous femoral head: both structures are hyaline cartilage. Impression: type IIIa hip. *1*, Acetabular labrum; *2*, "proximal perichondrium"; *3*, cranially displaced hyaline cartilaginous roof; *4*, flat osseous rim

hyaline cartilage. This echogenicity, in the hyaline cartilage of the acetabular roof of decentred hips, is defined as “structural disorder” or “degeneration”. Type IIIb hip joints have become rarities because of early screening and are seen very seldom.

5.4 Type IV

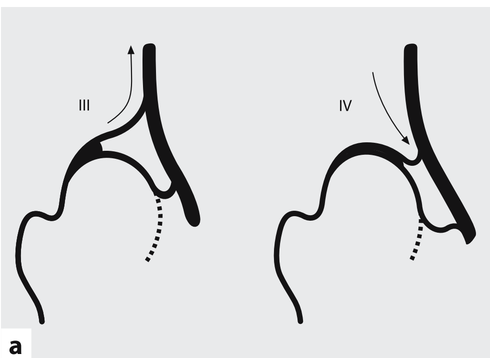
Type IV joints are also decentred. The cartilaginous acetabular roof is pushed downwards (caudally) by the displaced femoral head towards the original acetabulum. Type III and type IV joints are both dislocated joints. The term “subluxed” is a clinical term and must not be used for type III joints.

Attention: A distinction can be made between type III and type IV joints by observing the course of the perichondrium (Fig. 5.4a, b). The perichondrium indicates the whereabouts of the hyaline cartilage acetabular roof: cranial or caudal. The position of the labrum is irrelevant. If the perichondrium slopes cranially, it is a type III joint. If it is horizontal towards the bony socket, or dips caudally and then rises towards the bony acetabular roof (trough shaped), it is a type IV joint.

5.5 Differentiation Between Ossification and Degeneration

5.5.1 Ossification

In type II joints (centred) the wide, as yet unossified, cartilage roof must ultimately ossify in order to turn into a type I joint. This process of ossification of the hyaline cartilage occurs in the same way as the development of the femoral head ossific nucleus. Echoes therefore develop in the hyaline cartilage as a result of the ossification process. As with the echoes that develop in the nucleus (see Sect. 2.4.1), ossification is detected by ultrasound earlier than it can be seen on a x-ray. The hip joint therefore looks better de-



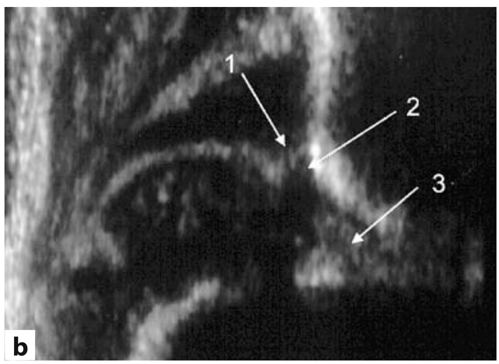


Fig. 5.4. a Comparison between type III and type IV hip joints: in type III hip joints, the perichondrium is displaced upwards. In type IV hip joints, the echo from the perichondrium dips downwards, or runs horizontally to the bony roof; the cartilaginous roof is compressed between the femoral head and the bony roof and is pressed in the direction of the original acetabulum. The cartilaginous acetabular roof no longer covers the femoral head. **b** Sonographic image, according to **a**. *1*, Dip of the perichondrium; *2*, downwardly displaced cartilaginous roof; *3*, fatty tissue fills the empty acetabular socket

veloped on a sonogram than on an x-ray taken at the same time. The x-ray cannot detect the earliest stages of ossification. The sonogram is 4–6 weeks ahead of the x-ray. An example of this "secondary" ossification is the improvement and changing shape of the bony rim. This secondary ossification does not show as echogenicity throughout the hyaline cartilage but rather as an angulated contour to the bony rim in "sufficient" bony coverage (Fig. 5.5).

Thus, an angular contour of the bony rim is always a good prognostic sign.

5.5.2 Structural Disorder (Degeneration)

Degenerative changes in the hyaline cartilage that occur due to pressure and shearing forces lead to echogenicity in the hyaline cartilage defined as "structural disorder". The echoes look the same whether they are due to ossification or degeneration. Which they are due to can only be determined by identifying the type of hip joint.

Attention: Ossification in centred joints. Degeneration in decentred joints.

5.5.3 How to Assess Echogenicity in the Hyaline Cartilage Acetabular Roof

The hyaline cartilage acetabular roof can only be said to be echogenic, whether due to ossification or degeneration, under these circumstances:

1. Comparison with the femoral head (Fig. 5.6). In order to exclude machine-made (artefactual) echoes, the echogenicity of the acetabular roof hyaline cartilage must be compared with that of the femoral head hyaline cartilage.
2. Artefacts (Fig. 5.7). In the proximal portion of the hyaline cartilage acetabular roof, between

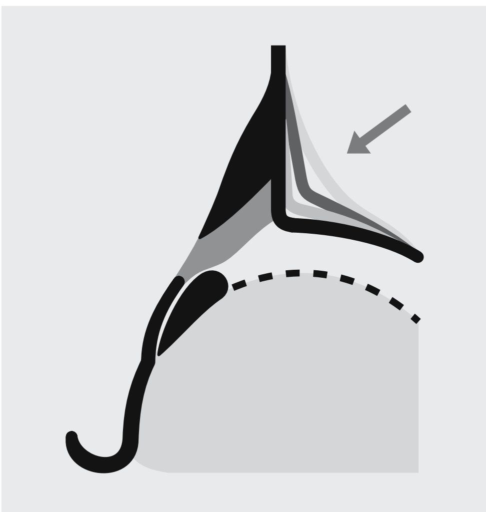


Fig. 5.5. Schematic drawing of the physiological maturation of a deficient acetabular roof: The bony rim undergoes metamorphosis, changing its shape over time and extending towards the cartilaginous acetabular roof. The extension of the bony rim within the cartilaginous roof improves the shape of the bony roof

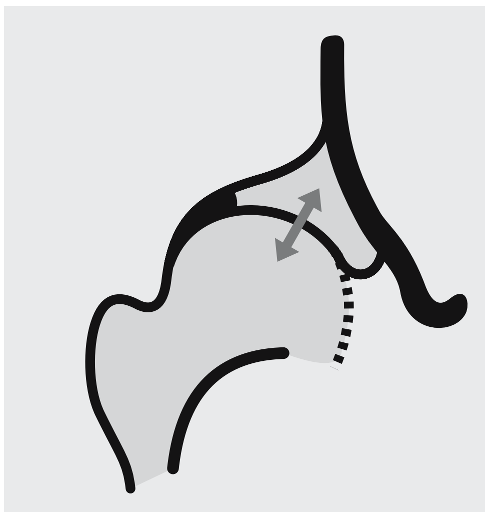


Fig. 5.6. Assessing the echogenicity of the cartilaginous roof: the echoes originating from the hyaline cartilage roof must be compared with the echoes originating from the hyaline femoral head

the proximal perichondrium and the ilium, extra echoes can be found that are artefacts (reverberations) and not structural alterations in the hyaline cartilage. The hyaline cartilage acetabular roof can only be called “echogenic” if the entire hyaline cartilage roof is affected. This is especially important in differentiating type IIIa and type IIIb. During the process of dislocation with the displacement of the cartilaginous acetabular roof, the proximal perichondrium and the adjacent rectus tendon are compressed. These resulting echoes must not be mistaken as degeneration in the proximal portion of the hyaline cartilage acetabular roof.

Key Points:

- There are four main sonographic types, dependant on age, degree of ossification and degree of displacement.
- Type III and type IV are both decentred hips with different deformations of the hyaline cartilage roof.
- “Secondary” ossification means growth of the bony acetabular roof. “Degeneration” means pathological change in the structure of the hyaline cartilage of the acetabular roof.
- Ossification can be differentiated from degeneration by the sonographic type (centred–decentred).

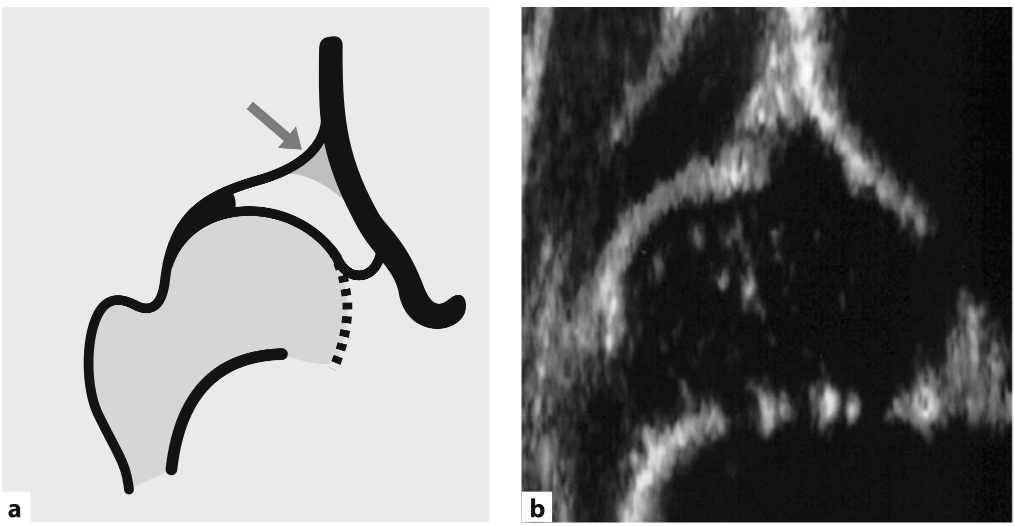
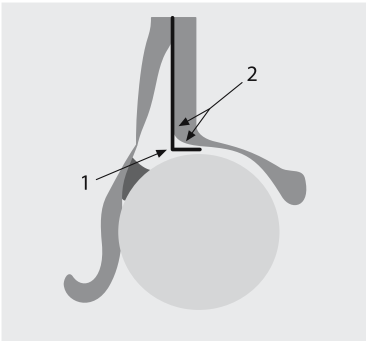


Fig. 5.7. a The echoes originating from the proximal aspect of the cartilaginous roof should not be confused with echoes originating from other structures. **b** Infant hip sonogram showing echogenicity in the proximal part of the hyaline cartilaginous roof: reverberations

6 Ultrasound Classification



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6.1 Description

The structures of the acetabulum, which are of importance for ultrasound, are described. Over the course of time, some standardized terms have proved to be good for this description. It must, however, be understood that a description is only a subjective impression, and therefore cannot replace an objective, reproducible, quantifiable measurement technique. Nevertheless, the description should continue to be taught and learnt during training courses. This way the observer learns to analyse the hip joint systematically and is forced to put the shape and structure of the three essentials – bony acetabular roof, bony rim and the cartilaginous acetabular roof – into specific categories which finally leads to a diagnosis. As the description itself is not sufficient for diagnosis but is complimented by an ever-improving measurement technique, the descriptive terms have been simplified and are summarised in Table 6.1.

6.1.1 Basic Terms and Possible Variations

- The terms used for the bony socket: "good" (type I), "deficient" (type II) and "poor" (decentred joints).
- Deficient is used for type II joints. A possible alternative is the term "adequate". The term "deficient" is used when the bony socket is not developed well enough with respect to the age of the baby. This is the case in type IIa(-), type IIb and type IIc hips.
- The term "adequate" is also used in type II joints; however, only when the bony development is appropriate for the age as in type IIa(+) hips.

For the bony rim the terms "angular" (type I) "rounded" (type II) and "flat" (decentred joints) have been chosen. A variation of the angular bony rim is the "blunt" bony rim (Fig. 6.1a–c); these contours of the bony rim can also be observed on x-rays. Two different joints with almost the same AC angle can show different contours to the bony rim: one may be angular whilst the other is rather blunt or slightly rounded.

The cartilaginous acetabular roof can be either "covering" (covering the femoral head) or pushed aside ("displaced"). The term "covering" is meant for centred hips and means that the cartilaginous acetabular roof overlaps the femoral head and helps to hold it in the socket.

The term "displaced" is synonymous with a decentred hip joint. The femoral head has deformed the cartilaginous acetabular roof. If the term "displaced" is used it must refer to a decentred joint. Further differentiation is necessary:

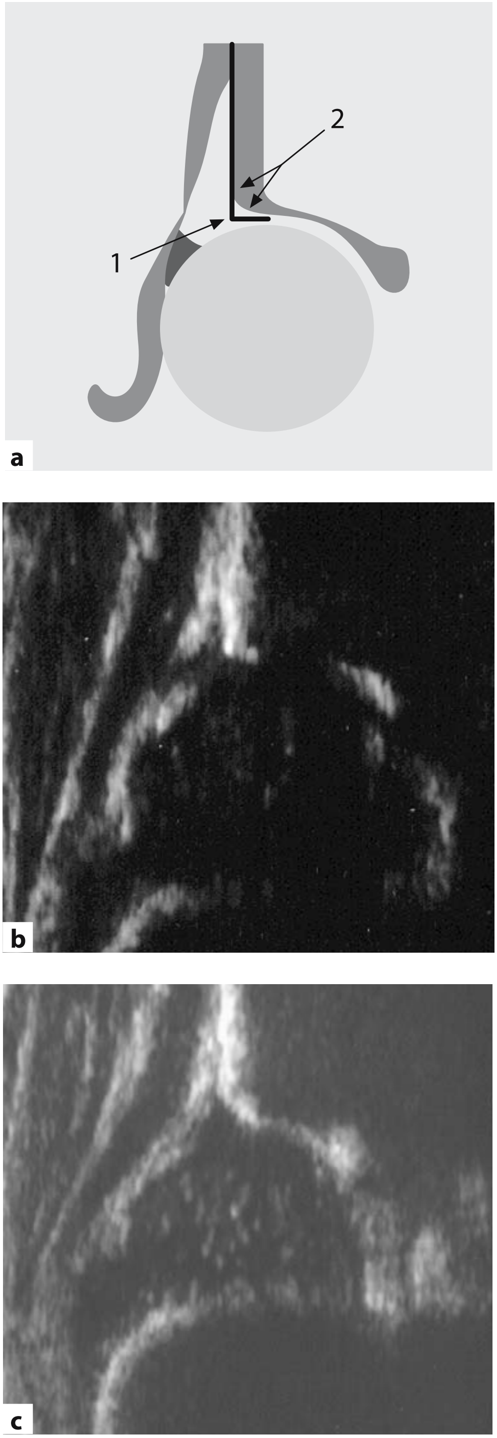
- Pushed cranially with no echogenicity in the hyaline acetabular roof = type IIIa.
- Pushed cranially – echogenicity in the hyaline acetabular roof (disordered structure) = type IIIb (rarity!).
- Pushed caudally = type IV.

Descriptive examples:

1. The bony socket is good, the bony rim blunt, the cartilaginous acetabular roof is covering. Diagnosis = type I.
2. The bony socket is poor, the bony rim is flattened, the cartilaginous acetabular roof is pushed cranially with echoes. Diagnosis = type IIIb.
3. The bony socket is good, the bony rim rounded, the cartilaginous acetabular roof is pushed caudally. This description is impossible because this kind of hip joint cannot exist. The term "good" is used for type I and the term "displaced" is used for decentred joints. These two terms contradict each other. Furthermore, the femoral head would not normally dislocate out of a well-developed bony socket (for exception, see Sect. 5.1).

Table 6.1. Synopsis of sonographic hip types

Type according to Graf	Bony roof/ bony roof angle α	Superior bony rim (bony promontory)	Cartilaginous roof/ cartilage roof angle β	Age
Type I mature hip	good α ≥ 60°	angular / slightly rounded (“blunt”)	covers the femoral head I a → β < 55° (extending far distance over the femoral head) I b → β > 55° (extending short distance over the femoral head)	any age
Type II a (+) physiological immature → appropriate for age	adequate (satisfactory) α = 50–59° (minimal degree of maturity is attain – look at the “sonometer”)	rounded	covers the femoral head	0 to 12 weeks
Type II a (-) physiological immature → maturational deficite	deficient α = 50–59° (minimal degree of maturity is not attain – look at the “sonometer”)	rounded	covers the femoral head	> 6 to 12 weeks
Type II b delay of ossification	deficient α = 50–59°	rounded	covers the femoral head	> 12 weeks
EXEPTION: Type II coming to maturity	deficient	angular (!)	covers the femoral head, (echogenic because of ossification!)	any age
Type II c (critical age) II c stable / II c unstable	severely deficient α = 43 – 49°	rounded to flattened	still covers the femoral head β < 77°	any age
Type D decentering hip → β > 77°	severely deficient α = 43 – 49°	rounded to flattened	displaced β < 77°	any age
Type III a eccentric hip → α < 43°	poor α < 43°	flattened	pressed upwards – without structural alteration (devoid of echoes) proximal perichondrium goes up to the contour of the iliac wall	any age
Type III b eccentric hip → α < 43°	poor α < 43°	flattened	pressed upwards – with structural alteration (they are echogenic) proximal perichondrium goes up to the contour of the iliac wall	any age
Type IV eccentric hip → α < 43°	poor α < 43°	flattened	pressed downwards (horizontal or mulded proximal perichondrium	any age



6.1.2 Exceptions to the Systematic Description

The descriptive terms for a certain type usually keep to the horizontal lines shown in Table 6.1. If the descriptions come from a different type, the initial diagnosis is usually wrong. There is only one exception to this rule (Table 6.1 variation) "bony acetabular roof deficient, bony rim angular and cartilage acetabular roof covering": this is the only description which is an accepted exception to the rule.

Explanation: The description "deficient" signals a type II joint. The cartilaginous acetabular roof "covering" could be either a type I or a type II joint. (In the case described above, the cartilage roof is usually noticeably wider than in a typical type I joint.) The description of the bony rim being "angular" fits with a type I joint. This obvious discrepancy is explained by secondary ossification (Fig. 6.2).

Such joints, by measurement of the their bony coverage, are type II joints. However, the ossification occurring in the cartilage roof at its junction with the bony acetabulum has already caused the osseous rim to change from round to angular. A similar phenomenon can be seen on an x-ray. When a dysplastic joint is being treated, the first sign of recovery is a small angular contour on the bony rim even though the entire socket, according to the high acetabular roof (AC) angle, is still dysplastic.

Fig. 6.1. a Examples of: *1*, sharp osseous rim; *2*, blunt osseous rim. **b** The bony roof is good; the osseous rim is sharp; the hyaline cartilage roof covers the femoral head. Type I hip. **c** Example of a blunt osseous rim. Compare with the image in **b**

6.2 Systematic Reporting of a Sonogram

The clinical report of a hip sonogram must contain the following points:

1. A statement about the age.
2. Description – Congruity!
3. Type
4. Alpha angle, beta angle.
5. Further management (follow-up, treatment, or discharge).

The first step in compiling a report on a sonogram is the anatomical identification (epiphyseal plate – femoral head – synovial fold – labrum – invariable sequence – identification of the bony rim).

The second step: check the three landmarks and tilting effects.

The third step: description of the structures: bony socket – bony rim – cartilaginous acetabular roof.

By now a preliminary hip type can be stated but it must be confirmed by the fourth step: measurement with alpha and beta angles. The descriptive findings and the hip type by measurement must coincide (be congruent). If there is a discrepancy it must be verified whether the description or the measurement is incorrect. For practical reasons it is recommended that the age (in weeks) is noted on the sonogram in addition to the name and date of birth.

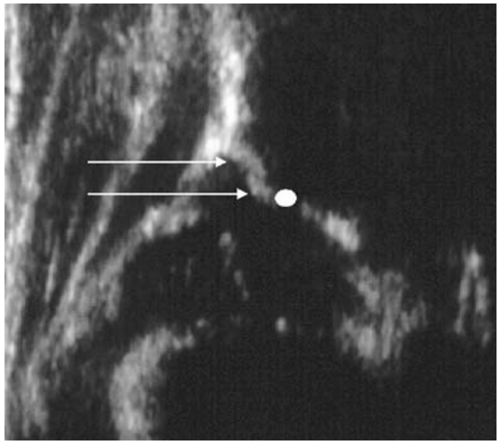
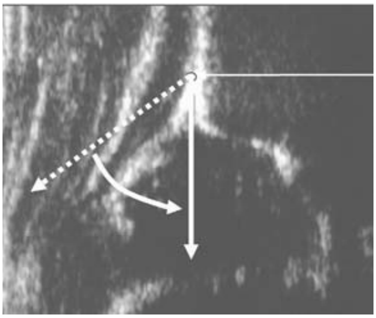


Fig. 6.2. Typical "high" sharp osseous rim, which is the sonographic expression of physiological ossification in type II hips. *Two arrows* mark the osseous rim; a *circle* marks the turning point

Key Points:

- Four major hip types with subtypes (watch the age!).
- The description states the preliminary hip type which must be confirmed by measurement. The description is subjective and cannot replace the measurement (do it by facts not by feeling!).
- Use the correct systematic procedure:
  - Age
  - Description
  - Typing through … {congruity is necessary!}
    - description
    - measurement
  - Further management

7 Measurement Technique



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The measurement lines that have been adapted for sonographic practice do not have strict mathematical definitions. Two angles emerge from the lines; these are the bony angle alpha which quantifies the bony socket and the cartilage angle beta which quantifies the cartilaginous acetabular roof. With these two angles, the entire socket with its bony and cartilaginous parts can be accurately assigned to a specific hip type. This measurement system with alpha and beta angles has the advantage that it is not dependent on either the position of the baby or the projection. It is not tied down by the position of the femoral head and is therefore irrespective of the position of the leg. Furthermore it is not dependent on the presence of the femoral head ossification centre. Other measurement systems with factors, quotients etc., do not improve the measurement results and precision.

All measurement techniques which include the size of the femoral head, the "centre" or the nucleus are no more than eyeballing: the head is not round but more or less oval, no centre can be accurately defined and the nucleus is not the centre of the femoral head!

7.1 The Bony Roof Line (Fig. 7.1a)

The inferior rim of the os ilium is a pivot point from which a line is drawn laterally "tangential" to the bony roof.

Attention: For practical reasons, the definition reads "tangential" to the bony roof rather than tangential to the bony rim.

Problems:

1. The osseous rim artefact (Fig. 7.1b). If the wrong focus is used a pointed strip may be seen on the bony rim. It is important that this osseous rim artefact is not mistaken for the actual osseous rim.
2. Problems with the lower limb of the os ilium (Fig. 7.1c). The lower limb of the os ilium must be a clearly defined echo and must not be a faint or fading echo.
3. A further problem for the identification of the lower limb of the os ilium is caused by the anatomical circumstances. Caudal to the lower limb of the os ilium is the hypoechoic zone of the triradiate cartilage. Lateral to the lower limb the echoes of the fatty tissue in the acetabular fossa are seen. Even further laterally, the echo of the ligamentum teres runs caudally to cranially to the central fovea of the femoral head. Therefore it is possible, with bad tuning of the equipment or a bad scanning technique, that the echoes of the fatty tissue obscure the precise definition of the os ilium. The lower limb is not seen as a spot but is striped caudolaterally. The second error is to mistake the lower limb for the central fovea. This is, however, easy to avoid as gentle rotation of the femoral head causes the echo of the central fovea to vanish, whereas the lower limb of the os ilium stays in position (Fig. 7.1d).

7.2 Base Line (Fig. 7.2a–c)

First the upper-most portion of the hyaline cartilage roof must be found. This is the point where the proximal perichondrium turns into the periosteum. Anatomically, this is the upper insertion point of the rectus tendon. From this pivot point the base line is drawn caudally tangential to the echo of the os ilium.

Problems:

1. The available measurement guide that the base line is laid on may be very short.
2. The so-called upper-most point as a necessary starting point for the base line cannot be identified. In this case it is necessary to use the so-called subsidiary line through the acoustic shadow of the wing of the os ilium with a replacement base line. (Auxiliary base line or help line.)

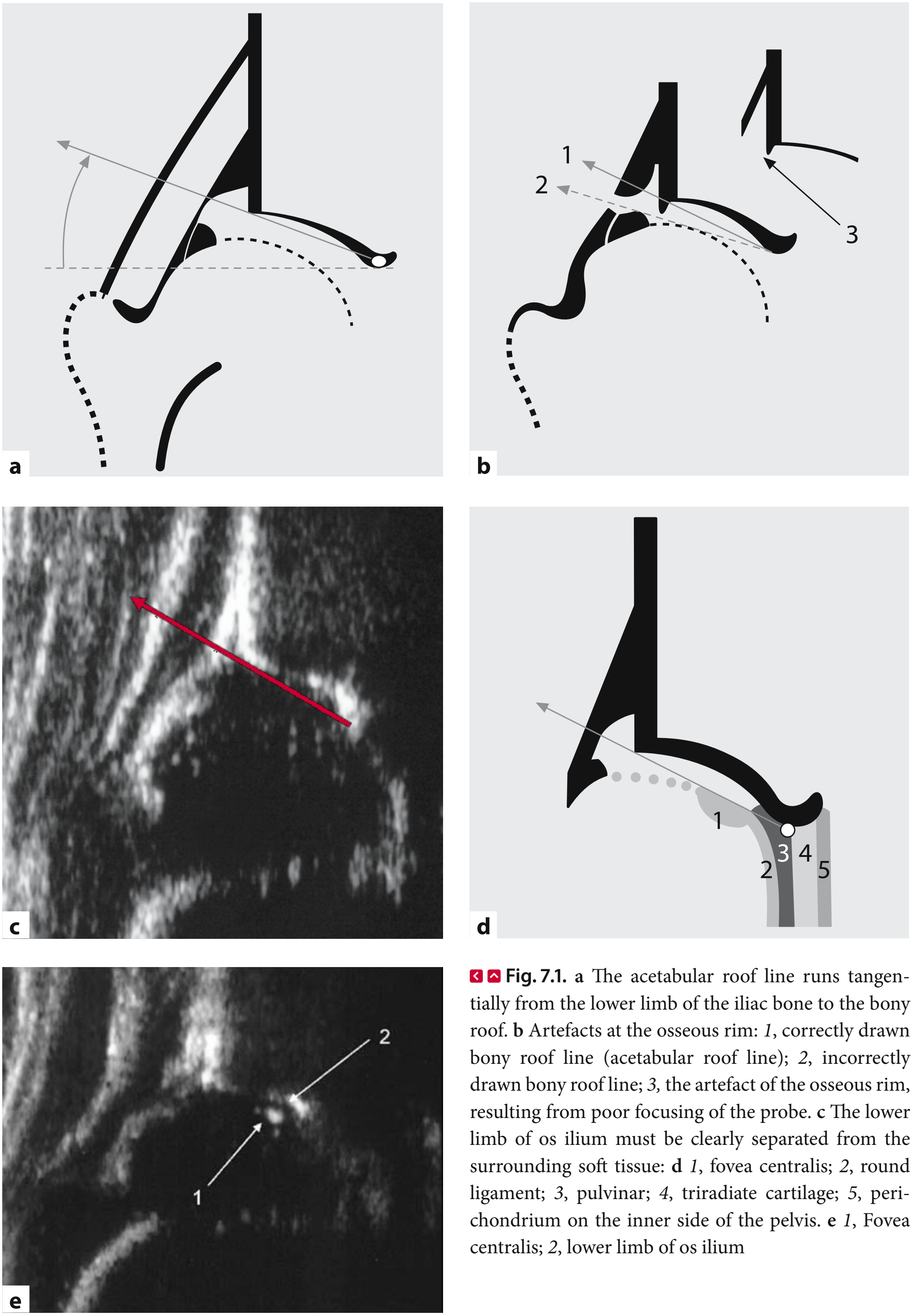


Fig. 7.1. **a** The acetabular roof line runs tangentially from the lower limb of the iliac bone to the bony roof. **b** Artefacts at the osseous rim: *1*, correctly drawn bony roof line (acetabular roof line); *2*, incorrectly drawn bony roof line; *3*, the artefact of the osseous rim, resulting from poor focusing of the probe. **c** The lower limb of os ilium must be clearly separated from the surrounding soft tissue: **d** *1*, fovea centralis; *2*, round ligament; *3*, pulvinar; *4*, triradiate cartilage; *5*, perichondrium on the inner side of the pelvis. **e** *1*, Fovea centralis; *2*, lower limb of os ilium

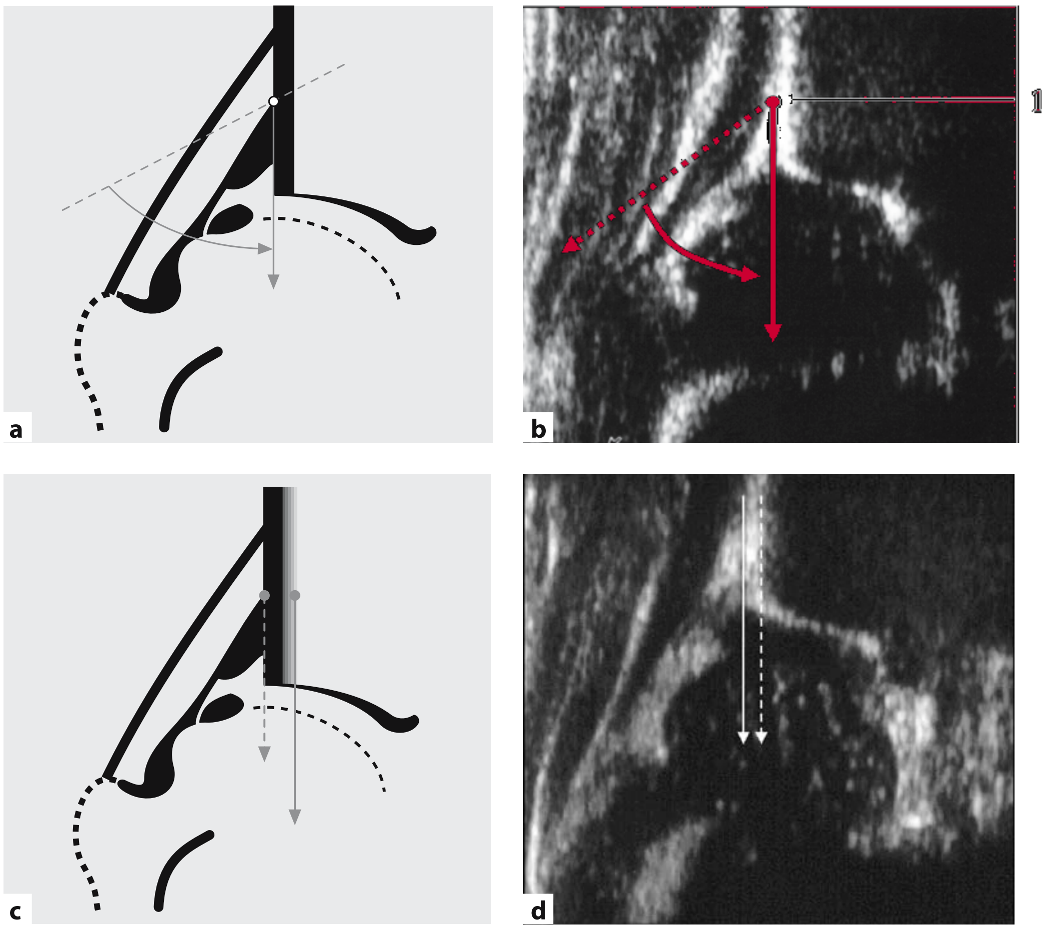


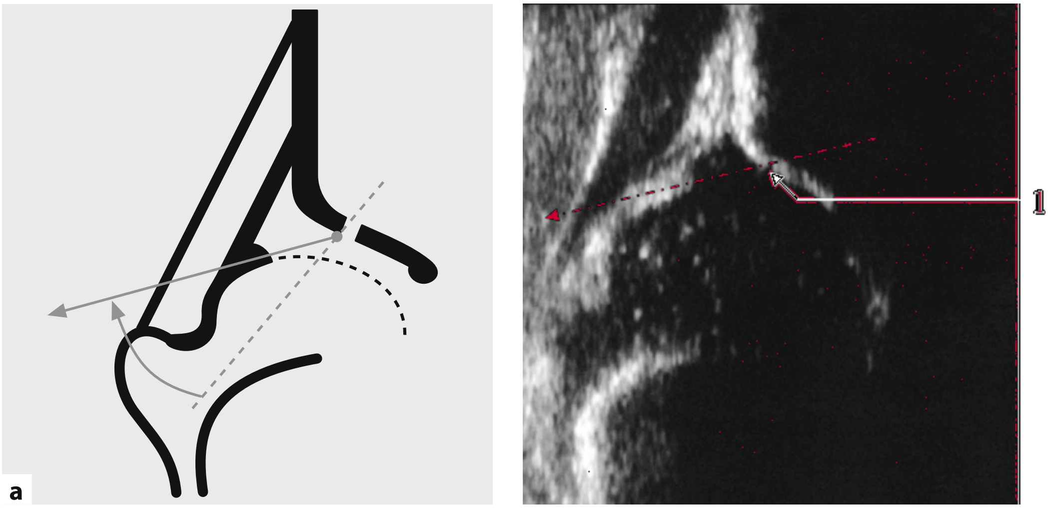
Fig. 7.2. a The base line runs tangential to the os ilium at the top of the cartilaginous roof. **b** *1*, Turning point of the perichondrium to the periosteum (insertion point of the rectus tendon). **c/d** Base line with auxiliary line.

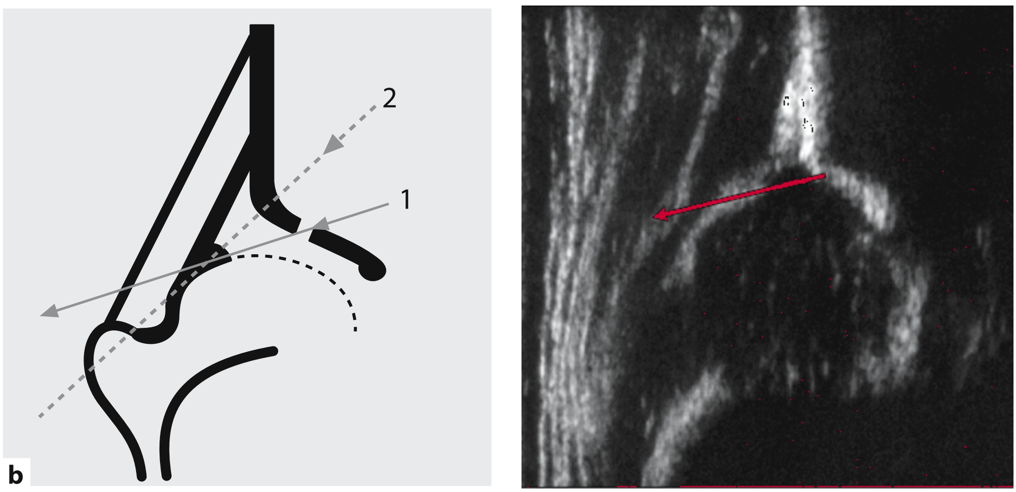
7.2.1 Auxiliary Base Line (Help Line) (Fig. 7.2c/d)

When the ultrasound beam is reflected after having passed through the muscles, the perichondrium and the hyaline acetabular roof, it hits the lateral wall of the os ilium, penetrates it superficially and is then totally reflected. Thereby, an acoustic shadow is caused. This line is consequently parallel to the base line and the alpha angle with the bony roof line will be the same whether the base line or the auxiliary base line are used. The bony angle, alpha, quantifies the bony acetabular roof.

7.3 Cartilage Roof Line (Fig. 7.3a–c)

This is sometimes called the "inclination line". It is drawn from the bony rim through the centre of the acetabular labrum.





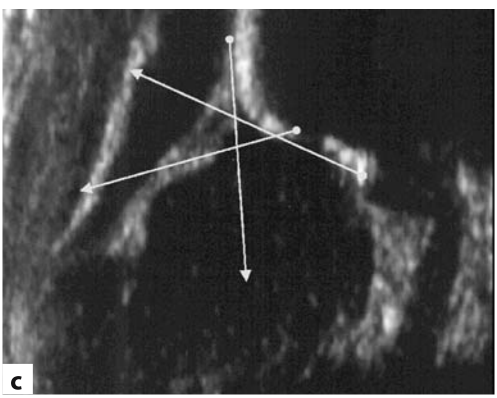


Fig. 7.3. **a** The cartilaginous roof line connects the osseous rim (turning point of concavity to convexity) with the middle of the labrum. *1,* Turning of concavity to convexity, marked with a small acoustic shadow. **b** *1*, Correctly drawn cartilaginous roof line; *2*, incorrectly drawn cartilaginous roof line. **c** Bony roof line, base line, and cartilaginous roof line do not always intersect at the same point

Problems:

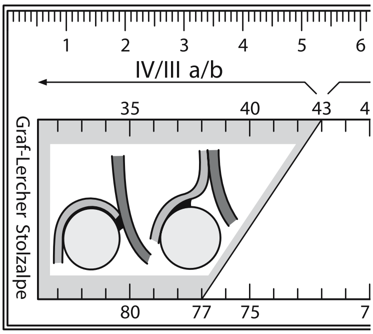
1. The bony rim cannot be pin-pointed because the osseous rim definition "concavity to convexity" is not being properly applied. The bony rim is not necessarily the intersection point between the base line and acetabular roof line. The base line, acetabular roof line and cartilage roof line seldom intersect at the same point (Fig. 7.3b); this only occurs in type I joints with an angular bony rim.
2. The "centre" of the acetabular labrum: Older definitions took the tip of the acetabular labrum as the second measurement point. Unfortunately, however, the tip of the labrum cannot always be identified despite high-definition and well-adjusted equipment. Due to this lack of precision, the second measurement point which is currently being used is defined as the "middle" of the echo of the acetabular labrum.

The angle between the base line and the cartilage roof line is the cartilage angle beta. This quantifies the cartilaginous acetabular roof.

Key Points:

- Measurement lines giving the bone angle alpha and the cartilage angle beta.
- Magnified scale on the sonograms of at least 1:1.7, otherwise the measurements are not accurate enough.
- The bony rim must be clearly identified as a measurement point.
- The bony rim in the description means the shape of the whole area (angular, round, flat). The bony rim for the measurement is an exact point ("concavity to convexity").
- The base line, cartilage roof line and acetabular roof line seldom intersect at one point. Only in type I joints with a really sharp bony rim do the lines intersect at one point. But this type is seldom seen (20% of all type I joints); most of type I joints have a "blunt" bony rim).
- Sonograms must only be measured in the standard plane.

8 Classification Using the Sonometer



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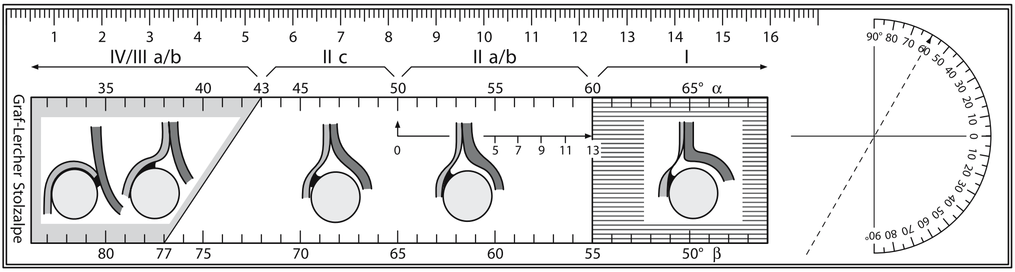


Fig. 8.1. Sonometer

If all the hip types with their alpha and beta angles are entered in a line, a table called the sonometer results. Using this, all joints can be classified according to their type, degree of maturation and their angle measurements taking into account the age of the joint.

The following questions can then be answered – *Is the hip joint for the baby's age*:

1. Normal?
2. In need of monitoring?
3. In need of treatment, or in some cases close monitoring with possible treatment later?
4. Definitely in need of treatment?

An alternative system to the sonometer is the maturation curve which underlies the sonometer. However, the classification is not as rigid, but one and two standard deviations can also be used to indicate the requirement for monitoring and treatment.

8.1 The Alpha Values

When all the alpha values are placed along one line, this can be divided into three large sections (Fig. 8.1):

1. The middle section from 43° to 59° (type II joint).
2. 60° and more (type I joint).
3. 42° and less (decentred joint; for exception, see Sect. 9.2).

The important transition points are firstly from type II to type I and secondly the change from type II to decentred (stable or unstable?).

NB. 420 or less means that the socket is so flat that the femoral head cannot be kept in the original acetabulum by the cartilaginous acetabular roof and therefore dislocates out of the socket. Whether it is a type III or type IV joint depends on the deformity of the acetabular roof and not on the alpha value. Therefore the classification of type III and type IV cannot be carried out with the alpha value. The classification of type III and type IV is anatomical and not a measurement.

By the end of the 12th week of life, a type I joint must be attained, therefore an alpha value of at least 60° or more.

8.1.1 Subdivision of the Type II Joint

- Type IIa: Alpha value between 50° and 59°, physiologically immature joint. Type IIa joints can be subdivided into type IIa(+) or type IIa(-) dependent on the age.
- Type IIa (+): During the first 3 months of life the hip joint matures in an exponential fash-

ion. To be on the safe side we always deal only with a linear maturation. In a newborn the minimum alpha value that can be expected to become a type I by the end of the third month is alpha 50°. Ossification will have to progress in a linear fashion from birth to 3 months and to have reached a certain degree of ossification each week. A hip joint that attains this minimum degree of maturation or more is called a type IIa (+), e.g. a 6-week-old baby with alpha 55° or more is a type IIa (+).

- Type IIa (-): Should the hip not reach this minimum linear degree of maturation, it is called a type IIa (-) and by today's standard it should be treated. For example, a 6-week-old baby should have a minimum alpha value of 55° if it is to become type I by 12 weeks. If alpha is 55° or more the joint is a type IIa (+). If alpha is less than 55°, e.g. only 50°, it is lagging behind the minimum expected maturation and is a type IIa (-).
- Type IIb: The alpha value is between 50° and 59° but the baby is older than 3 months of age. This joint is dysplastic.
- Type IIc: The alpha value is between 43° and 49°. This hip socket is severely dysplastic and is close to decentring. Type IIc joints are, however, still centred (Sect. 9.2) and they can be seen at any age.

NB. Due to the inherent imprecision of the measurement, a differentiation between type IIa (+) and type IIa (-) should not be made before the 6th week.

NB. The difference between type IIa and type IIb is only the age. A bony head coverage which is acceptable for a 4-week-old infant is dysplastic in a 4-month-old infant because of the slowing down in the ossification rate.

NB. The highlight of the present standard of hip sonography is not to detect dislocations (type III, type IV) but to detect pre-dislocations and to treat hip joints before they dislocate. Don't forget that the term "DDH" means "developmental" ...

8.1.2 The Sonographic Alpha Value and the Radiological AC Angle

The alpha value in the ultrasound and the AC angle in the x-ray have an approximate relationship to one another.

Rule of thumb: Alpha + AC = 90°.

8.2 The Beta Value

Because of large individual variation of the cartilage portion of the acetabular roof and the definition of the cartilage roof line, the beta value shows more statistical variation than the alpha angle.

Note: Alpha determines the hip type, beta gives more individual differentiation. This can be demonstrated by the difference between the type IIa and type IIb. (Beta is only used for classification in one circumstance; see Sect. 8.2.2.)

8.2.1 Type Ia and Type Ib Hips

In normal hip joints with an alpha value of 60° or more (type I joints), the cartilaginous acetabular roof can be at different stages of development even if the bony coverage is identical. On the one hand it can extend a long way out over the femoral head with a consequently small beta value and on the other hand it can be rather short so

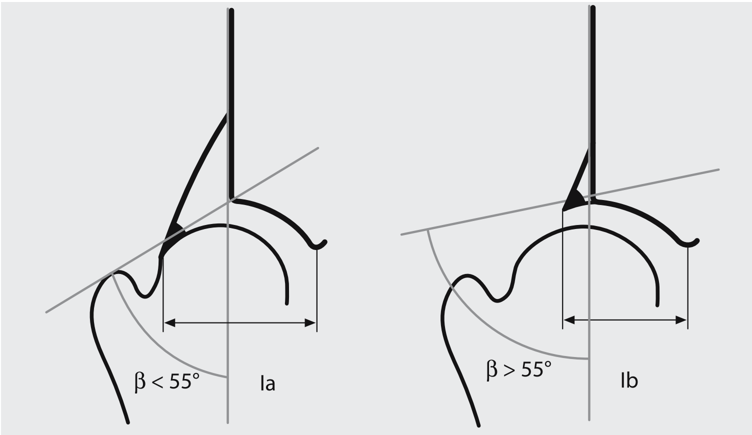


Fig. 8.2. Type Ia and type Ib hips differ in the size and form of their cartilaginous roof. Type Ia hips show a wide cartilaginous roof covering the femoral head. Type Ib hips have a narrow cartilaginous roof. The combined, bone plus cartilage, roof shape is different in these types

that the beta value is larger. Type I joints with beta values less than 55° are hip joints where their cartilage roof was proportionately a long way over the femoral head and they are classified as type Ia joints. Hips joints where the beta value is more than 55° are classified as type Ib joints.

The hip type is determined by the alpha value. Within the hip type the beta value can show different variations in the cartilage roof and characterize the appearance of the hip joint.

NB. By today's standard, type Ia and type Ib joints are, with their identical bony coverage, characterized as normal joints. It is therefore not justified to assume that a type Ib joint is any worse than a type Ia joint. The relevance or otherwise of this subdivision will only be determined by very long-term follow-up studies.

Hypothesis:

- Extreme type Ia (with an extremely wide cartilaginous roof) leads to very wide bony coverage and may cause early impingement in adult hip joints.
- Extreme type Ib (with an extremely short cartilaginous roof) leads to rather short head coverage in adults with consequent labral lesions and bony rim overloading.

Statistically, the average beta value in a type I joint seems to be 65°.

8.2.2 Type D Hip

In untreated type IIc joints where the bony coverage is so poor, decentring can occur. The cartilaginous acetabular roof bends cranially (beta angle increases), whereas the alpha value (bony coverage) stays the same. If the beta angle is more than 77° in a hip joint with an alpha in IIc range, the hip joint is described as "about to decentre" or type D (Fig. 8.3).

As described in Sect. 8.2.1, the alpha value generally states the type. The only exception applies to type IIc. In this case the beta value establishes whether it is a type IIc (beta less than 77°) or type D (beta greater than 77°).

The type D hip is therefore the first stage of decentring (dislocation). It should never be called a type IId because all type II joints are centred.

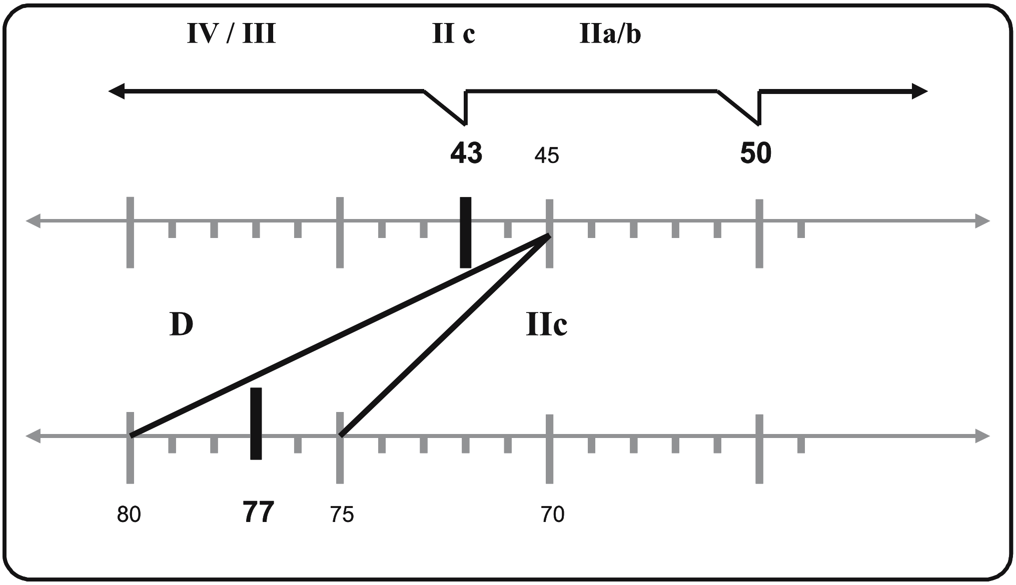


Fig. 8.3. Example demonstrating the difference between type IIc and type D hips: in hip joints with an alpha value in the type II range, the beta value determines whether the hip is classified as type IIc or type D. Separation angle = 77°

Type IIc:
Alpha value between 43° and 49° (type IIc range); Beta value less than 77°.

Type D:
Alpha value between 43° and 49° (type IIc range); Beta value greater than 77°.

8.3 Classification in Premature Infants

Premature infants are classified according to their calendar age. The clinical significance is, however, related to the gestational age.

For example, with a 4-month-old infant born 6 weeks early the alpha value is 57°. The classification is made and according to the calendar age is a type IIb. (Treatment consequence: monitoring or even treatment.) However, after taking into account that the infant was born 6 weeks early it falls within the 3-month limit and therefore may be allowed a certain deficiency in maturation. Therefore, in view of the prematurity, although it is noted as a type IIb hip with deficient ossification, it will only be monitored with no treatment at that stage.

8.4 Certainty of the Diagnosis

The diagnosis is secured not only by the alpha value but also by the type, which is crucial. The type is determined as a result of using several parameters:

1. Description of:
   - The bony roof
   - The osseous rim
   - The cartilaginous roof
2. Measuring the alpha and beta angles
3. The age of the infant

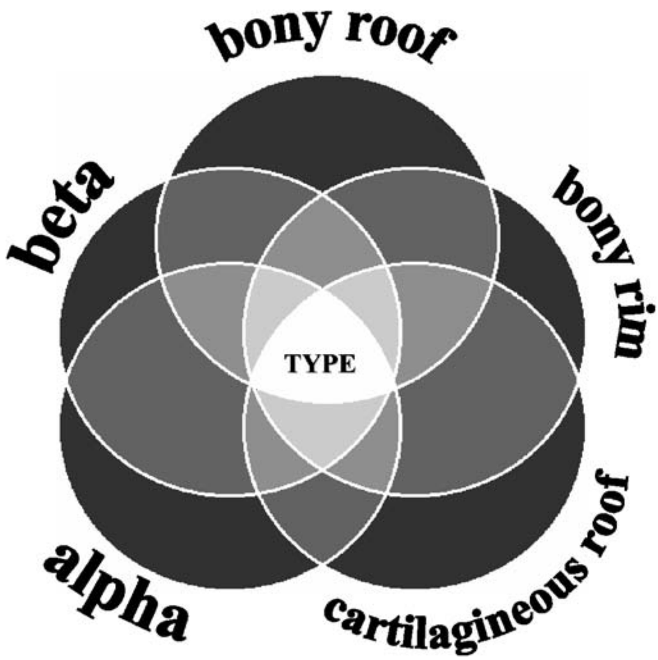


Fig. 8. 4. The combination of many parameters reduces diagnostic errors

The more parameters used to make the diagnosis the more reliable it becomes. To use the alpha value only for diagnosis means degrading the ultrasound (alpha value) to the inaccuracy of an x-ray (AC index).

Key Points:

- Using the sonometer, joint sockets are quantified depending on the age and the degree of ossification.
- Alpha states the type. Beta makes the precise differentiation within the type. Exception: in type IIc where the beta value establishes whether it is a type IIc or a type D joint.
- Premature infants are classified to type according to the calendar age. However, decisions about management are made according to the gestational age.

9 Instability

Contents

Problems and questions:

- How much movement is the femoral head allowed within the joint when the femur is put under pressure?
- When does the degree of movement exceed the line of tolerance and become harmful to the hip joint?
- How can "instability" which is insignificant and usually disappears without any adverse affect on the hip joint, as for instance with a loose joint capsule, be differentiated from those types which are absolutely pathological and need to be treated immediately?

In principle it is necessary to differentiate between normal physiological movement (elasticity) and true pathological instability (Fig. 9.1.b).

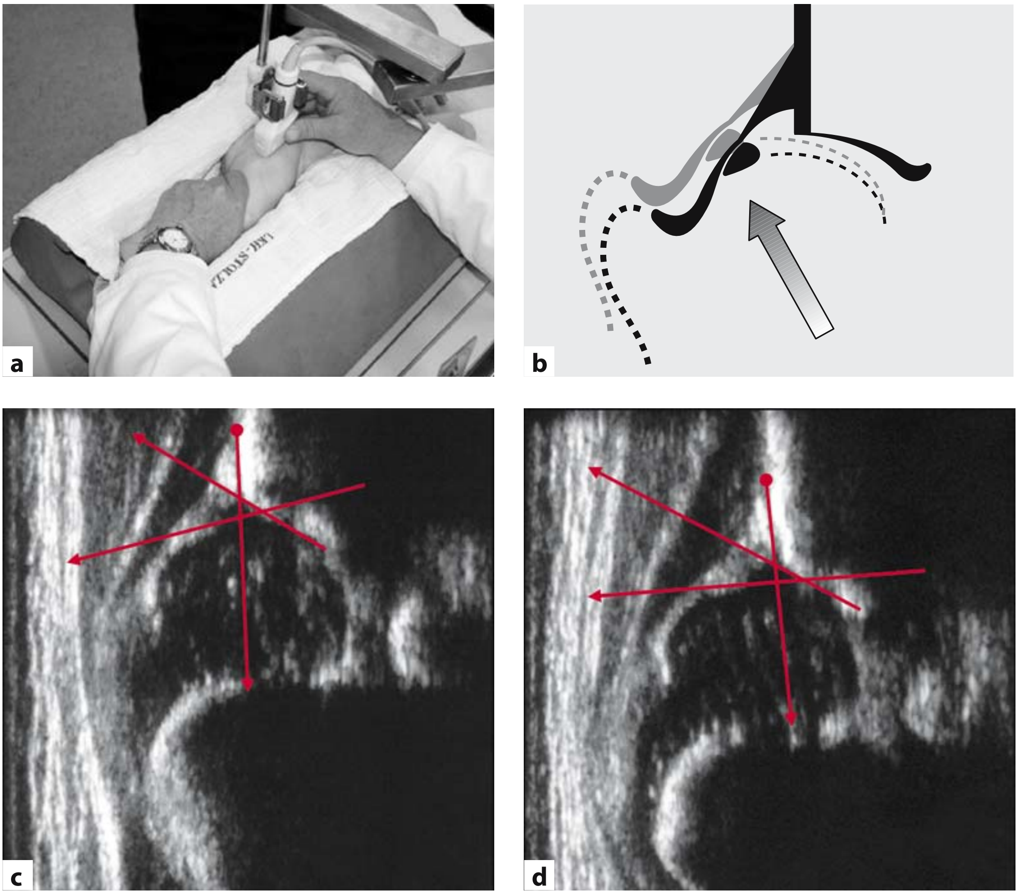


Fig. 9.1. a Clinical example of the stress test. The left hand pushes or pulls the leg, while the right hand guides the transducer. **b** Example of elastic whipping. Even when the hip has good bony coverage, the joint capsule can be deformed under pressure from the femoral head with resultant deformation of the cartilaginous roof. **c** Hip without stress applied. Note the position of the labrum in comparison to **d**. **d** The same hip joint as in **c** with stress applied. The bony coverage is identical, the labrum is pressed upwards, consequently increasing the beta value

9.1 Elasticity "Elastic Whipping" (Fig. 9.1.b–d)

As the infant hip joint is more an oval joint than a round one, physiological incongruities occur in the joint during movement. This is especially so during rotation but also during abduction and adduction. Adaption therefore takes place in the hyaline cartilage acetabular roof and in the acetabular labrum.

This slight up- and downward movement of the labrum (springing) and even of the cartilage roof, which can be seen even in fully matured hips, must not be mistaken for pathological instability. This is the so-called elastic phenomenon which is the result of mechanisms for functional adaptation. This elastic movement can be intensified by a loose joint capsule.

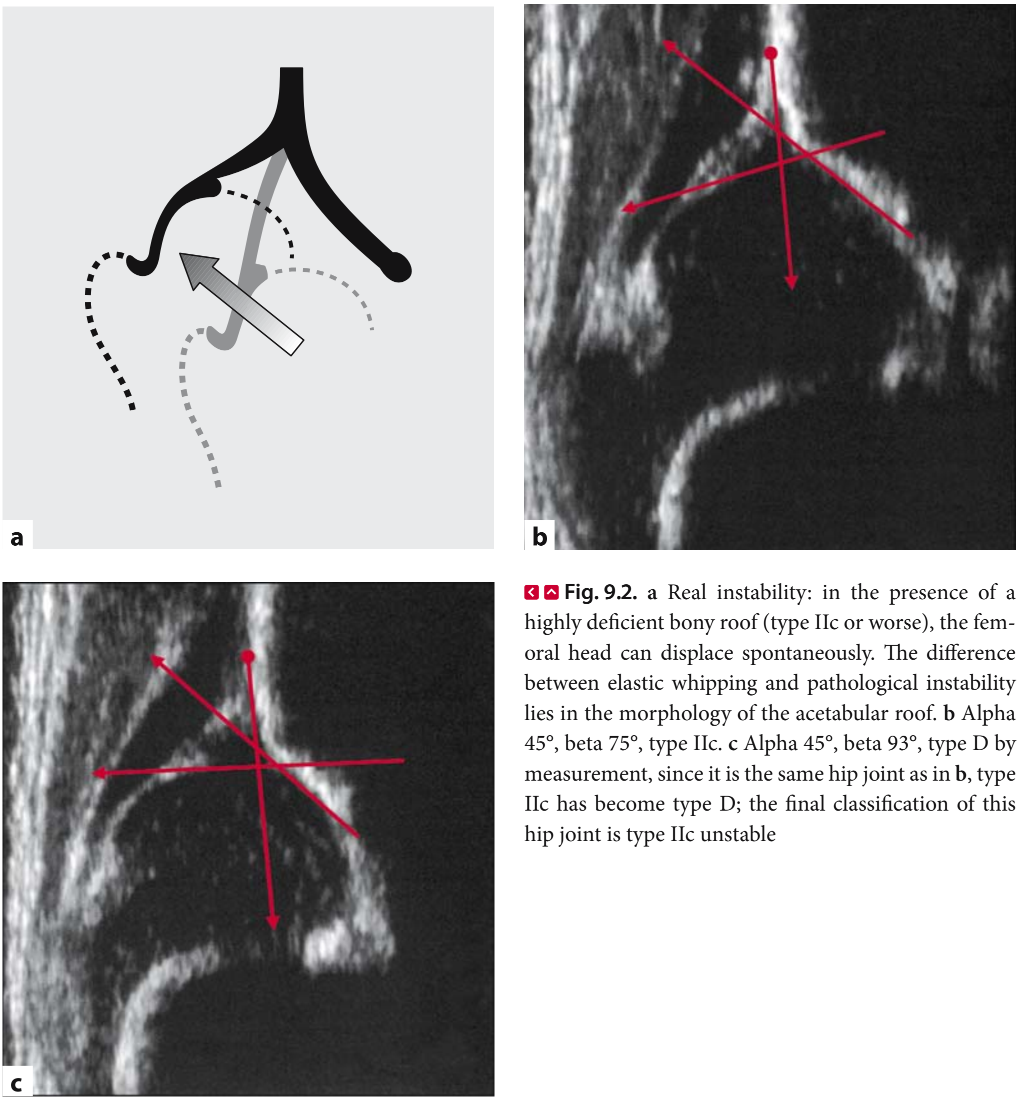


Fig. 9.2. **a** Real instability: in the presence of a highly deficient bony roof (type IIc or worse), the femoral head can displace spontaneously. The difference between elastic whipping and pathological instability lies in the morphology of the acetabular roof. **b** Alpha 45°, beta 75°, type IIc. **c** Alpha 45°, beta 93°, type D by measurement, since it is the same hip joint as in **b**, type IIc has become type D; the final classification of this hip joint is type IIc unstable

9.2 Pathological Instability

9.2.1 Note This Statement

"Type IIc joints are usually sonographically unstable."

Explanation:

"Usually" in the sense that in type IIc joints (as described in Sect. 8.2.2) can be made into decentred joints (type D) under pressure.

"Sonographically unstable" means that this decentring phenomenon can be observed on the monitor. It does not have to be clinically confirmed (is the clinical examination safe?).

The transition from stable to unstable is important for treatment decisions. It barely needs to be stated that all decentred joints are by nature unstable.

9.2.2 Definition of Pathological Instability

If a type IIc joint can be made, with pressure, into a type D joint, it is called type IIc unstable. If the type does not alter when pressure is applied (stress) then it is a type IIc stable.

Hip joints are classified in their resting position, without stress: this means that, for example, a type III hip joint which, under pressure, becomes a type IV joint, is classified as a type III joint.

9.3 Summary of the Principal Differences Between Elasticity and (Pathological) Instability

The gliding movement of the femoral head, which pushes aside the joint capsule, the acetabular labrum, or the hyaline cartilage acetabular roof, with pressure applied to the femur, is acceptable as long as the bony acetabular roof is adequate or good. This acceptable movement is called elasticity or elastic whipping. This can occur with the bony roof covering in the following sonographic types: type I, type IIa and type IIb (alpha more than 50°).

If, however, the bony coverage is highly deficient and drops to the critical level of a type IIc joint or even worse, the distortions of the cartilaginous acetabular roof and the labrum can be damaging to the hip joint. Shearing forces have an increasingly deleterious effect on the cartilaginous roof and the developmental zone (epiphyseal plate); the movement become increasing damaging and decentring occurs. This is real instability which is pathological (alpha less than 50°).

10 The Terminology of Dislocation

Dislocation is the "permanent separation" of articular surfaces. The term subluxation "a little bit dislocated" is a clinico-radiological term and does not relate to anatomy. It should not therefore be used in sonographic classification. Sonographically, a distinction is made between centred and decentred joints.

Centred joints are type I and type II joints.

Decentred joints are type D, type IIIa and b and type IV.

The treatment and the prognosis of these hip types is different. The terms dislocation or subluxation should not be used. They are not specific enough. They signal a "bad" hip, but the exact pathology and therefore its consequences cannot be determined ("bad weather" gives no indication as to what type of weather to expect!)

Key Points:

- The alpha value determines the hip type, the beta value is responsible for the precise differentiation within the type. **NB.** The exceptions: type IIc, type D.
- Type D hip is the first stage of decentring.
- A subdivision of type IIc into type IIc stable and IIc unstable.
- The classification of premature infants is made according to the calendar age, the management is according to the gestational age.
- The distinction between elasticity and instability.
- The term "subluxation" is not precise and does not describe the anatomy. Therefore it should not be used.

11 Scanning Technique

Contents

The lower limb of the os ilium, the correct scan section and the acetabular labrum must be displayed simultaneously. Each of these three structures is very small and they are found within an area of a few millimetres. The difficulty arises when one or two of the necessary structures are displayed, the third one is often missing. As one attempts to find the third missing landmark one of the previously shown structures disappears and so on.

With an incorrect examination technique the baby quickly becomes restless which makes it even more difficult to get the three landmarks simultaneously. This problem can only be solved by a meticulous scanning technique in which the time factor plays an essential part.

Motto: Speed and precision are everything!

For the most part, careful organization and the scanning technique are not taken seriously enough. The technique described here is easy to teach and learn and guarantees a good-quality sonogram independent of the cooperation of the mother and child or the skill of the examiner.

NB. Hip sonography does not need experienced or skilful examiners but a standardized, reproducible technique which can be performed by everybody.

11.1 Preparation

- In order to save time the preparation is of great importance, independent of the scanning method.
- The examination must be completed before the baby becomes restless and starts to cry. A standardized examination calls for standardized positioning and, in due course, for a probe-guiding system as well.
- Outside the examination room there should be a changing table so that the mother can undress, and if necessary, clean the child calmly.
- Inside the examination room a second changing table or something similar should be placed. This is so that the blanket which the child may be wrapped in and the nappy (diaper) can be removed. This table can also be used if there is to be a clinical examination following the ultrasound examination. The other things the mother brings, including the baby's basket, clothes, bottle, and notes can be placed on it as well.
- The cradle which allows a standardized position and also a standardized scanning technique is placed on a table. The examination should be conducted standing rather than sitting. The table height should be such that both arms can rest comfortably on the edges of the cradle.
- The baby's head is near the examiner's right hand and the mother is opposite on the far side of the examining table.
- The ultrasound apparatus is on the right of the examiner.

11.2 Leading and Guiding the Mother

The mother, or the accompanying person, is often nervous. Clear instructions help to minimize organizational chaos and transmit an air of calm and trustworthiness.

The appropriate data for patient identification are entered on the computer before the mother and child enter the examination room.

The examiner stands at the examination table and greets the mother without shaking her hand. (The mother usually has both hands full and may have to put the child in an awkward position in order to shake hands.)

The examiner points out the changing table and tells the mother, "Please put your baby on the changing table and remove its nappy (diaper)" or "Please put down your bag".

Next, the examiner points to the far side of the examination table and instructs the mother, "Come over here please and give your baby to me".

The examiner takes the baby and places it in the cradle with its right side up so that the right hip joint can be examined first. The mother should not place the baby in the cradle herself because, if this happens, the position is usually incorrect and moving the baby into place causes unnecessary irritation. The examination should start with the right hip because in this way the baby can see the monitor which usually attracts its attention.

Instruction to the mother: "Please put your hand on the baby's shoulder"

Note: It is important that this instruction is given to the mother so that the mother does not hand the baby over entirely to the examiner. Mothers tend to step aside feeling insecure once the examiner has taken the child. It is important that the mother holds the shoulder rather than the hands because this would restrain the infant, leading to struggling especially in older infants. The baby is in the "spontaneous position", this means that the legs are gently bent. Neither the mother nor the examiner should pull the legs straight under any circumstances. This would also lead to struggling (Fig. 11.1a, b).

11.3 Scanning Procedure

11.3.1 Right Hip Joint

Step One: The left hand gently grasps the right leg of the infant and rotates it gently inwards so that the knee lies within the side of the cradle and does not protrude out over the bolster (Fig. 11.1.a).

At the same time the fingers are placed on the greater trochanter and spread slightly so that the greater trochanter lies between the thumb and middle finger as shown in Fig. 11.1.b.

Step Two: The right hand reaches for the gel, applies it directly to the skin, puts the gel back in its storage place, takes the transducer and places it on the hip joint.

Step Three: Transducer positioning: placed on the hip joint parallel to the bolsters of the cradle and held vertically (not parallel to the spine! not tilted!) (Fig. 11.1.c).

Position of the fingers: thumb in front of and straight, middle and forefinger behind the transducer. The middle finger is not only in contact with the transducer but also with the baby's skin. The fingers should not be flexed, otherwise the fingernails could scratch the baby and cause it to struggle.

Step Four: Both the examiner's wrists are gently supported by the bolster of the cradle (make sure that the lower part of the right arm is also placed on the bolster).

Check the correct position of the baby and fingers before looking up at the monitor!

Before anything else, the position of the fingers, transducer and hands must be visually checked.

Fingers: The thumb to the front; middle and forefinger behind the transducer gently grasping it.

Fingers straight: Middle finger in contact with the transducer and the baby.

Transducer: Vertical and parallel to the bolsters of the cradle.

Hand: Both wrist joints, especially the right, gently propped on the side of the cradle.

11.3.2 Obtaining the Picture

Step One: The transducer is moved backwards and forwards from the basic position in order to



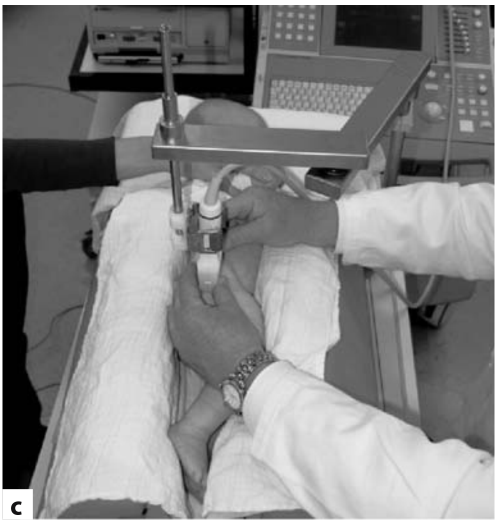


Fig. 11.1. **a** Correct position of the infant in the cradle. The infant spontaneously assumes a natural position with legs slightly flexed and internally rotated. **b** Placement of the examiner's left hand during right hip ultrasonography. The trochanter is held between the thumb anteriorly and the index and middle fingers posteriorly. **c** Correct position of the probe guide system (Sonoguide), held parallel to the cradle bolsters with tilt prevented by the Sonoguide

find the round structure of the hip joint. The examiner faces the monitor.

Movement: forwards backwards, forwards backwards (Fig. 11.2a).

Step Two: As soon as the hip joint is seen as a whole, concentration must be on the lower limb of the os ilium. As it is very small, the parallel movement of the transducer must be small as well. As soon as the lower limb of the os ilium is seen, the ultrasound picture must be frozen immediately.

Movement: smaller – smaller – smaller – stop!

The main movement to find the lower limb of the os ilium: forward – backwards – forward – backwards (where is the joint?)

Smaller – smaller – smaller – stop (where is the lower limb?)

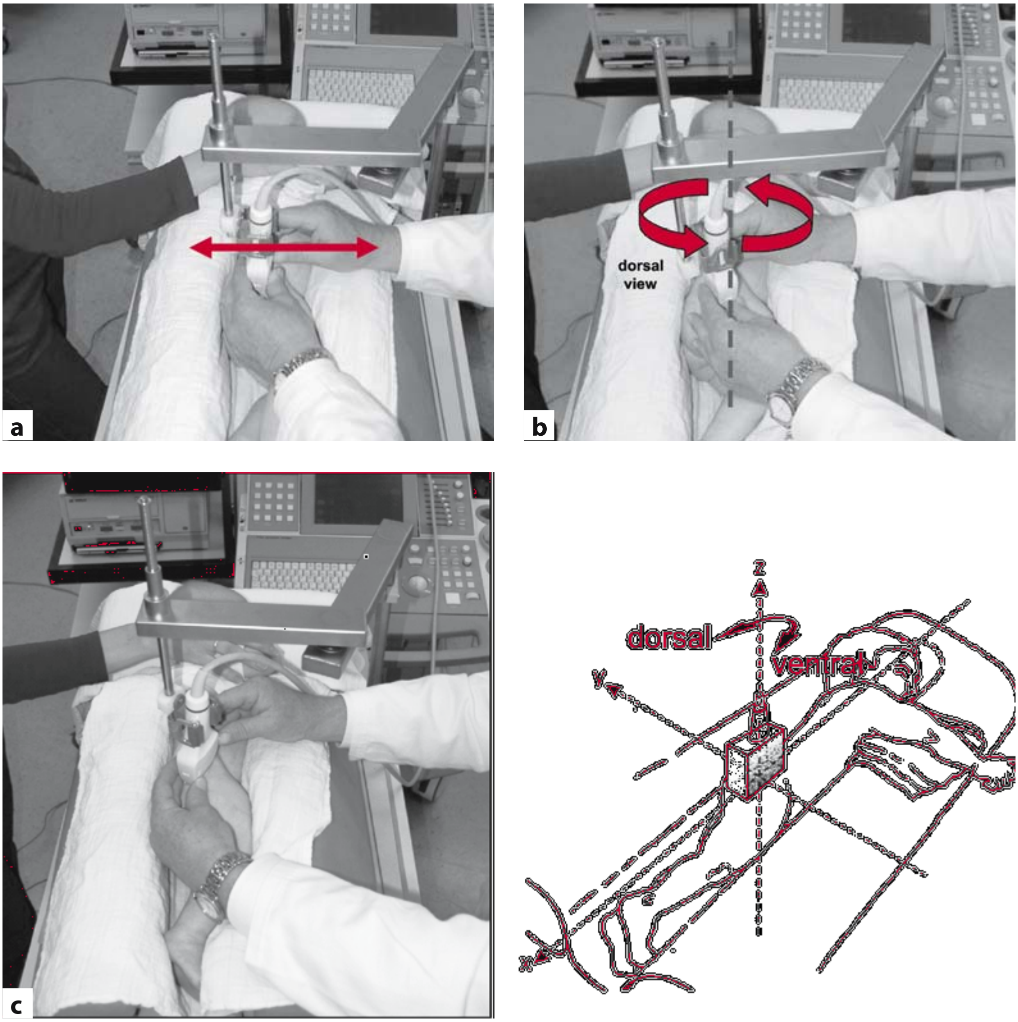


Fig. 11.2. a Start the examination with forwards–backwards … to look first for the hip joint and finally for the lower limb of the os ilium. **b** Correction of the sectional plane by rotating the probe after finding the lower limb. **c** Rotating the probe, about the axis of the lower limb

Step Three: By looking at the frozen picture the examiner has the chance to decide on the section of the acetabular roof and to think about whether the transducer has to be adjusted and in which direction. If required, correction of the sectional plane is now carried out. The examiner must look at the transducer and, without tilting it, turn it in the direction of the expected sectional plane. Whilst doing this the transducer must not be tilted.

Keyword: Rotation of the probe (Fig. 11.2b, c).

Step Four: The examiner looks once again at the monitor and searches for the lower limb as in steps one and two through parallel movement of the transducer.

Fig. 11.3a–c. Turning the baby from the right to the left side. **a** Pulling on the leg and the left arm; **b** rotation; **c** final position

Step Five: As soon as the lower limb is seen, freeze once more and the sectional plane is now checked again. If it is correct, the examination is usually complete because the acetabular labrum is automatically displayed. If the sectional plane is not correct, a further readjustment (probe rotation) must be carried out and the lower limb found once more through parallel movement of the transducer.

Note for the scanning technique:

Forwards – backwards – forwards – backwards, smaller – smaller – smaller – stop, rotate the probe, forwards – backwards – forwards – backwards, smaller – smaller – smaller – stop.

NB. Whilst correcting the sectional plane it is important to look at the transducer in order to avoid tilting it unintentionally.

11.3.3 Obtaining the Sonogram of the Left Hip Joint

After obtaining the sonogram of the right hip joint, the examiner turns the child over (Fig. 11.3a–c): the examiner's left hand grasps the baby's ankles, the examiner's right hand gently pulls the left arm towards him. This way the child can be turned over within the cradle without having to lift it out. The mother then places her hand on the infant's shoulder once more (Fig. 11.4.a).

Step One: The examiner's left hand is placed flat on the left hip joint so that the trochanter can be felt between the thumb and forefinger. The lower part of the left arm rests gently on the infant's leg in order to stop it coming out of the cradle; this gently rotates the leg inwards (Fig. 11.4a, b).

Step Two: The transducer is held again, but this time between the thumb and forefinger. Again, it is positioned vertical and parallel to the bolsters of the cradle (Fig. 11.4d).

Step Three: Forwards – backwards – forwards – backwards and so on (Fig. 11.4.d) (to show the lower limb of the os ilium); rotate the probe (Fig. 11.4.e); forwards – backwards – forwards etc.

11.4 Errors

(Fig. 11.5a–d, right side; Fig. 11.6a–d, left side)

No changing table present, examination performed while sitting down. Result: child becomes restless while being undressed and there is a loss of time whilst the mother and examiner both sit, and the examiner is sitting in a rather twisted position (Fig. 11.7a, b).

The examiner approaches the wrong side of the examination table (the right and left hand take over different functions – the more dextrous hand must hold the transducer!).

The mother has not been given the opportunity to undress and clean the child outside the examination room. (If the child is undressed in the examination room it tends to become restless.)

The baby's legs are straightened or its hands are held (the child starts to struggle).

The transducer is aligned with the spine, the fingers are flexed instead of straight (oblique ultrasound beam produces a poor reflection: the flexed fingers hurt the baby and cause struggling).

Attempting to show the lower limb of the os ilium by tilting and turning whilst looking at the monitor (while doing this the lower limb of the os ilium usually disappears).

The hand positions for the right and left hip are confused with one another (coordinated scanning movement is therefore impossible).

Feeding the child during the examination. If the child needs to be fed, it should be done prior to the examination.

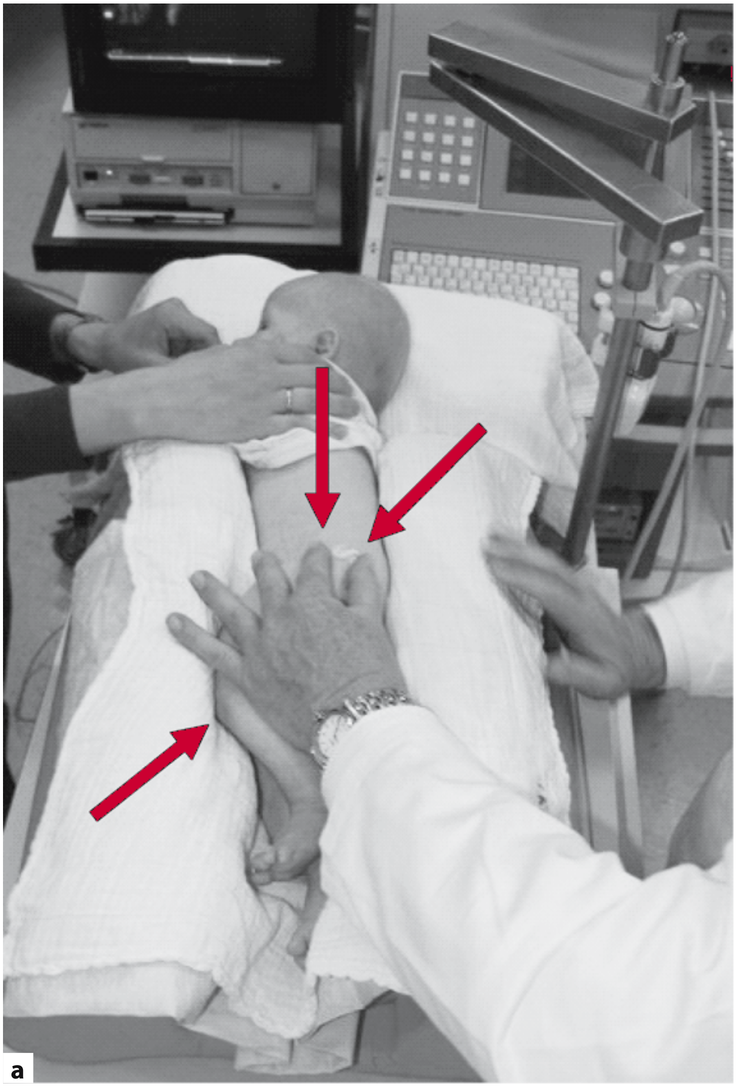
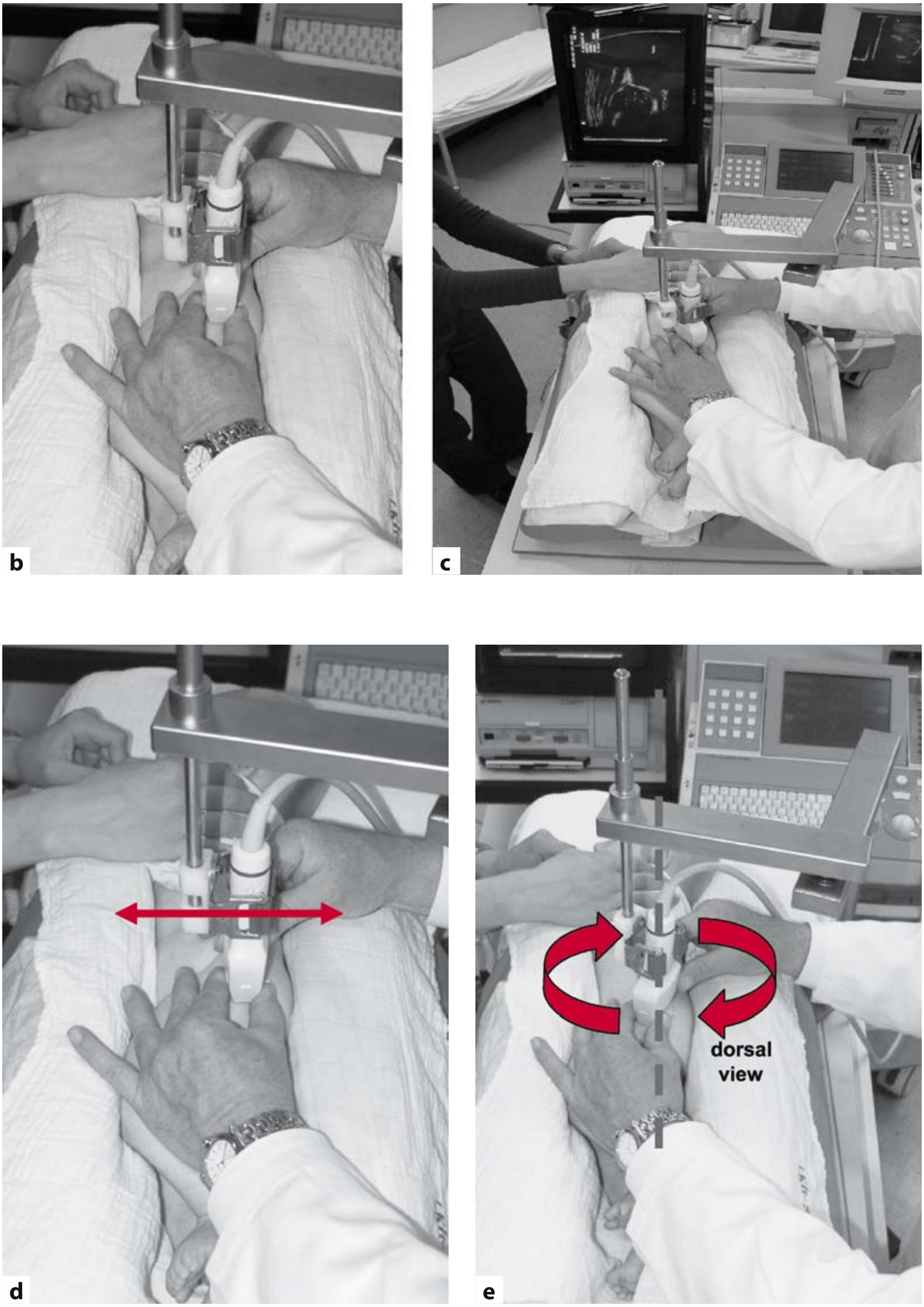


Fig. 11.4. **a** Correct position of the fingers of the left hand. The greater trochanter is fixed between the thumb and the first finger. **b** Correct position of the probe, parallel to the cradle bolsters and not tilted. **c** The hand of the mother is on the baby's shoulder. In the background, the monitor with the correct projection of the sonogram. **d** Looking for the hip joint and the lower limb by forwards – backwards – forwards – backwards – smaller – smaller – smaller – stop. **e** Rotation in the correct sectional plane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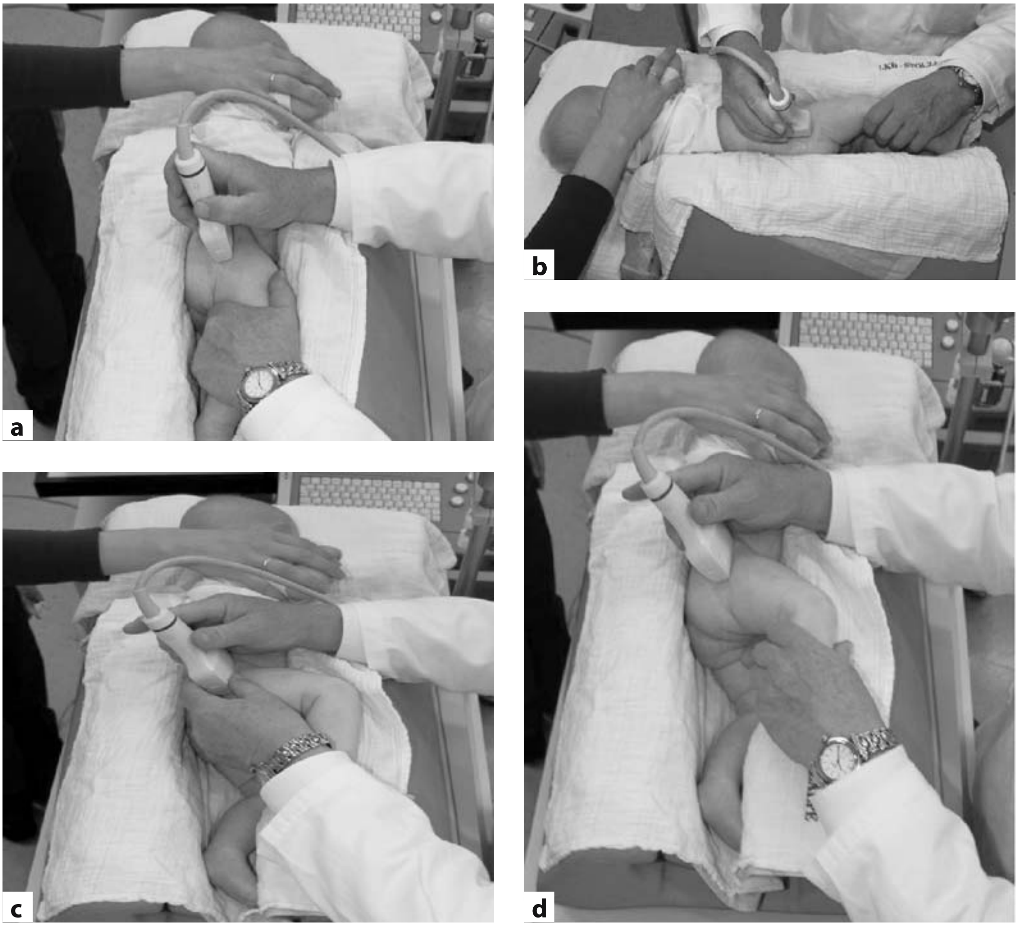


Fig. 11.5. **a** Incorrect position, the position of the left hand is not correct, the probe is tilted. **b** Incorrect position, the left hand pulls on the leg of the baby, the probe is tilted. **c** Incorrect position, the right leg is outside the cradle with external rotation of the hip joint, the probe is tilted. **d** Incorrect position of the baby, the leg of the baby is not fixed, the baby can struggle and the probe is tilted

Fig. 11.6. **a** Incorrect position, compare the correct position in Fig. 11.4b. **b** Because of the incorrect position in **a**, the baby moves its leg. **c** Incorrect position and handling, don't pull on the leg and tilt the probe! **d** Incorrect position, the left leg is not fixed, the probe is tilted

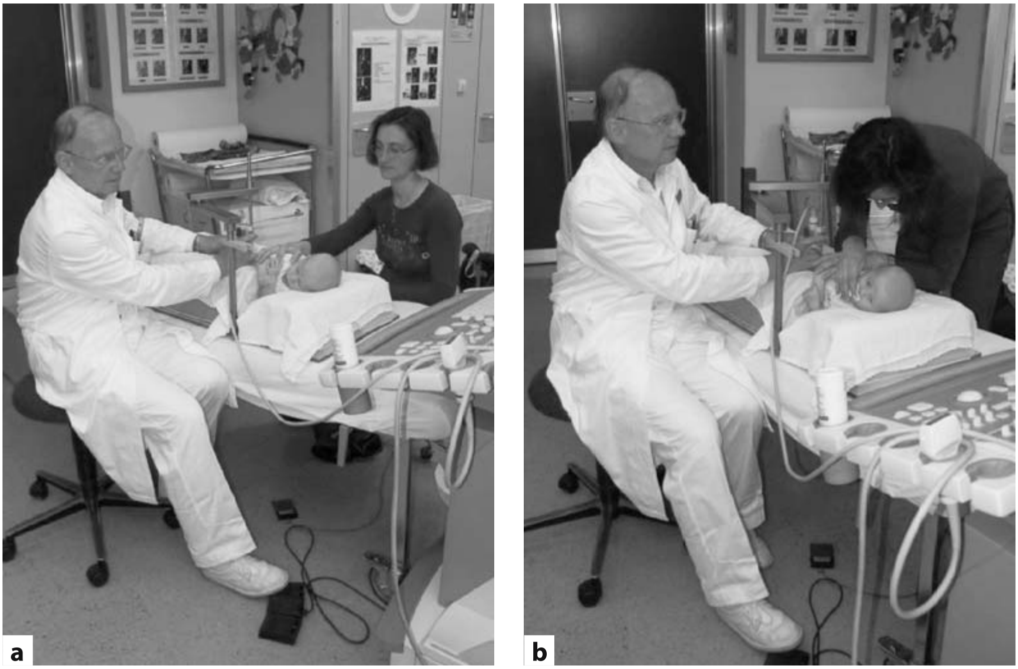


Fig. 11.7. a Incorrect position of the examiner and the mother. **b** If the baby starts crying, the mother stands up and blocks the view of the monitor

Key Points:

- Efficient preparation, changing table, examination table with cradle, examiner stands to conduct the examination.
- Clear instructions and guidance for the mother.
- Standard positioning.
- Standard scanning technique.
- Avoid errors such as tilting the transducer (uncoordinated random searching), use the probe guide system!
- The clinical examination should follow after the ultrasound examination.

12 Errors Due to Tilting the Probe

Contents

Because of the different speeds of the ultrasound beam in the tissues, there is diffraction and refraction of the ultrasound waves which depends on their angle. These can distort the image. Research has shown that an oblique ultrasound beam, as produced by sector scanners and also where the transducer is tilted (linear transducer), can lead to serious errors in diagnosis. It is therefore essential to make sure that the transducer is straight when it is placed on the baby.

12.1 Antero-posterior Tilting

In these circumstances a sonogram similar to that of the standard section is produced. However, correct identification of the osseous rim in order to delineate the base line is barely possible because of the poor definition of the perichondrium and of the ilium. At the same time the lower limb of the os ilium cannot be clearly depicted but a “fading echo” leads to false delineation of the acetabular roof line.

12.2 Postero-anterior Tilting

Here the sectional plane appears to be posterior. To the surprise of the examiner, this posterior plane does not disappear even when the transducer is turned anteriorly. Because the curvature of the os ilium does not change, the examiner uses one of these images for the final assessment because it is not possible to get a better scan section. The examiner assumes falsely that this is a normal variant with a raven-like extension of the osseous rim.

12.3 Cranio-caudal Tilting

In this case the lower limb of the os ilium is usually not clearly seen. Poorly defined fading echoes of the lower limb result.

12.4 Caudo-cranial Tilting

This is probably the most serious of all the mistakes that can lead to important misdiagnosis. In caudo-cranial tilting, the errors add up.

By tilting the transducer the mid part of the acetabular roof looks as though it is the posterior section. The examiner now turns the transducer more anteriorly, because he assumes that he is too far posterior, until an apparent mid sectional plane appears on the monitor. In fact the ultrasound plane is now in the anterior section of the acetabular roof. With this tilting error the bony socket worsens.

Because of the great difference in the ultrasound speed in hyaline cartilage, soft tissue and bone, the diffraction and refraction phenomenon is intensified because of the tilted ultrasonic waves. This causes distortion of the image.

Because of the summation of the errors due to diffraction and refraction of the tilted ultrasound beam and the incorrect identification of the section of the acetabular roof, a normal hip joint can be made to look decentred.

The tilting effect can be identified by characteristic alterations in the landmarks. By strictly observing the criteria of the so-called usability test, useless sonograms can be discarded. If one considers the most serious of errors, the caudo-cranial tilting, inexperienced examiners can sometimes find it difficult to detect this distortional error. In this case the epiphyseal plate of the femoral neck can help. If the ultrasound waves come caudo-cranially, the osteochondral junction (epiphyseal plate) of the femoral neck is no longer seen, at least not in its typical shape. This chondro-osseous junction is not relevant for

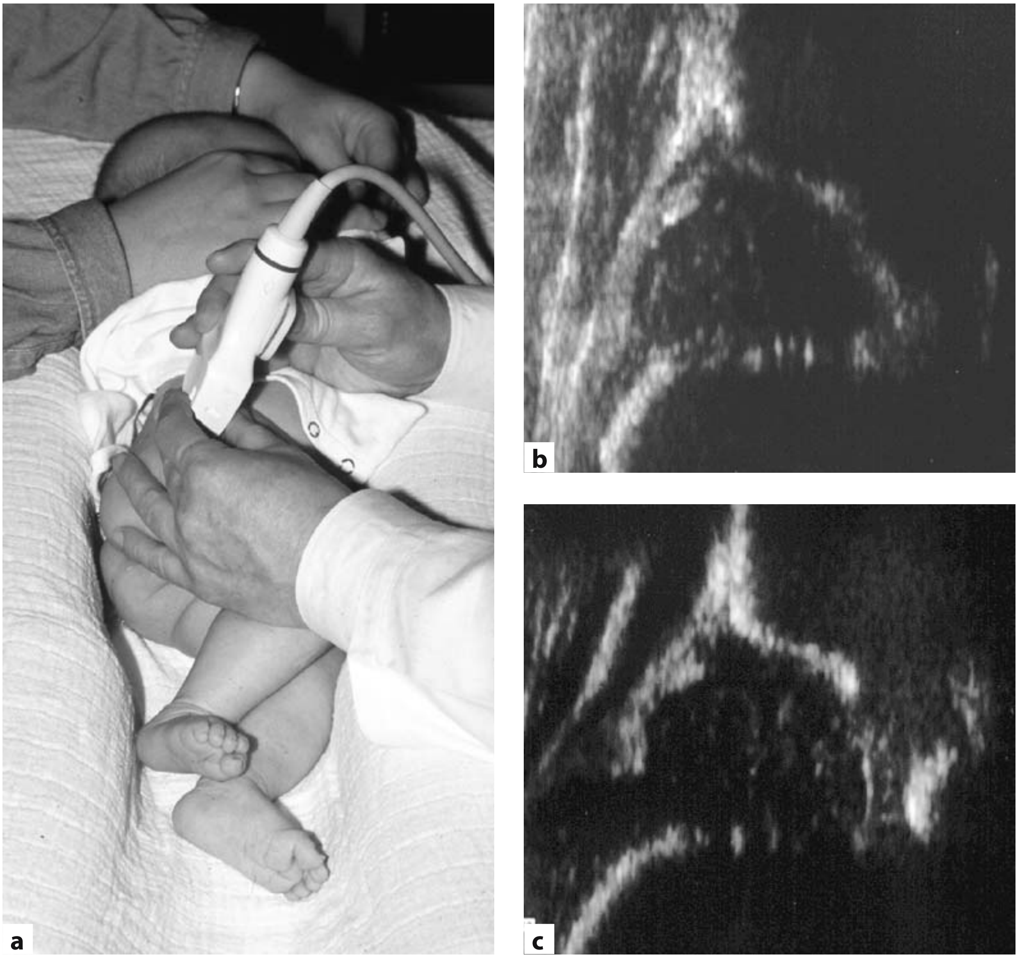


Fig. 12.1. **a** The probe is incorrectly positioned, producing a misleading image. In this case the probe is tilted posteriorly, causing deflection of the ultrasound beam in the sagittal plane. **b** Image of an immature hip, generated with the probe tilted posteriorly as shown in **a**. The contour of the "proximal perichondrium" and the silhouette of the os ilium are blurred. Compare with the correctly executed image in **c**. **c** Correct image

the classification of the type; however, it is of significance firstly for orientation in the image and secondly for detecting the classical caudo-cranial tilting mistake. If the scanning technique which we teach is adhered to, tilting errors are ruled out as far as possible.

12.5 Cradle and Probe-Guiding Equipment (Figs. 11.1c, 11.4b)

To facilitate a quick, easy scan, standardized positioning and a standardized scanning technique are needed. In combination with the cradle, a probe-guiding device, approved and designed by Prof. Graf, is recommended. It is suitable for all

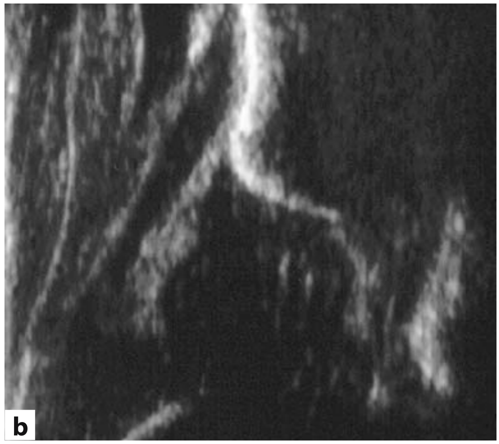
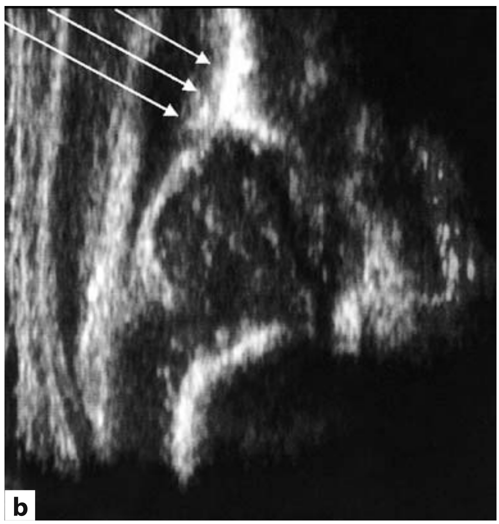
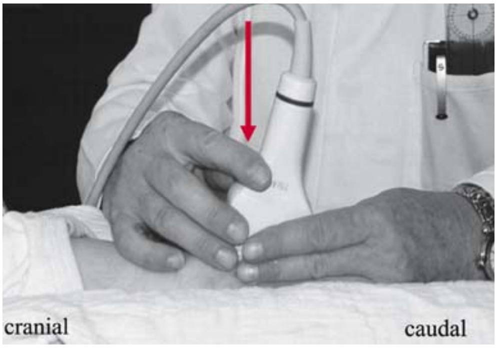


Fig. 12.2. a The probe in this example is tilted anteriorly and the direction of the ultrasound beam is postero-anterior. **b** The image is produced while tilting the probe anteriorly, as shown in **a**. The image plane misleadingly appears to be posterior only because of the tilted probe. Compare with a correctly executed image in Fig. 12.1c

Fig. 12.3. a The probe is tilted, with cranio-caudal direction of the ultrasound beam. **b** Image generated with tilting of the probe as described in **a**. The lower limb of os ilium is not visible. Compare with a correctly executed image, as seen in Fig. 12.1c





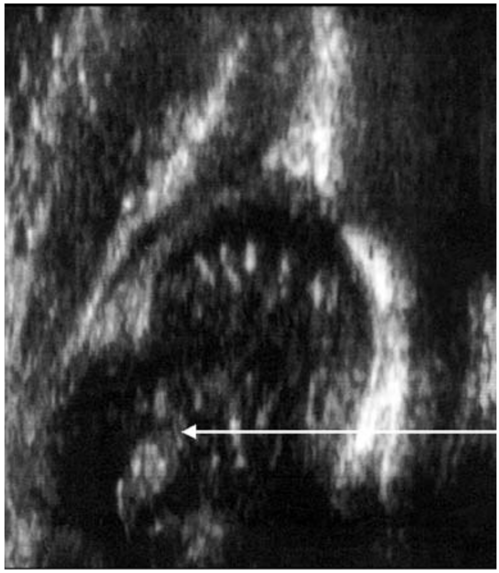


Fig. 12.4. a The probe in this example is tilted cranially, with deflection of the ultrasound beam in the frontal plane. **b** Sonographic image performed as described in **a**. The sign of caudo-cranial tilt is disappearance of the osteochondral junction of the proximal femur (*1*) from the sonographic image. The image can be misleadingly read as pseudo-subluxation

conventional transducers and only allows such scanning movements as are necessary for the hip joint. Movements which lead to tilting of the transducer's longitudinal or transverse axis are automatically blocked. Using the cradle in combination with the probe-guiding device does not only make scanning infant hips much easier for inexperienced practitioners but also reduces the examination time to a few minutes and improves the standard of the sonograms.

- Address for purchasing the cradle and probe-guiding device:

Sonofix Sonoguide, Barbara Leban, Panoramaweg 12, 8061 Rinnegg/St. Radegund, Tel./Fax: +43–3132–4685, e-mail: johannleban@tele2.at

Key Points:

- Tilting the incident sonic wave causes distortion of the image.
- Do not use sector scanners.
- Linear transducers must not be tilted.
- A normal hip joint can be made to appear abnormal by tilting. However, an abnormal hip joint cannot be made to look normal.
- Use a cradle and a probe guide.
- Do not accept sonograms without the chondro-osseous border!

13 Documentation and Quality

Contents

The basis for diagnosis is a printed sonogram which must fulfil certain quality requirements. For legal reasons, it is not enough to simply give descriptive findings without hard-copy documentation. The examination must therefore be substantiated by a sonogram to which the written report is added.

13.1 Image Documentation

13.1.1 Minimum Requirement

The scale should be at least 1:1.7, better still 1:2.

The three landmarks are clearly seen (lower limb, section, labrum), chondro-osseous border?

Two images, in the standard section, of each hip joint.

13.1.2 Suggestions

- The measurement lines should be drawn on one of the sonograms.
- Image projection as in an antero-posterior x-ray of the right hip (anatomical projection).
- In unstable hip joints: at rest position and stress position.
- Chondro-osseous junction visible.

13.2 Written Report

Apart from the usual personal data and date of the examination, the report should contain the following points:

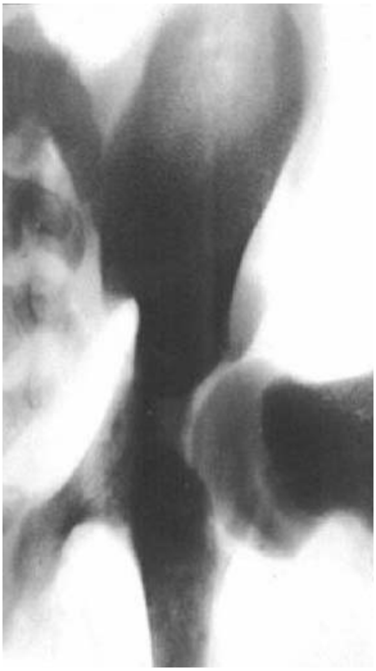
- Age
- Description
- Type
- Alpha and beta values
- Management (e.g. follow-up only or suggestions for treatment)

13.3 Tips for Checking and Ensuring the Quality of One's Own Sonograms

The following criteria need to be checked in order to assess one's own sonograms, and those of others, for "usability" and quality:

- Is the minimum projection scale met?
- Are all points of my anatomical identification clearly visible?
- Are the three landmarks clearly visible and identifiable? (If any of the three reference points is missing the sonogram must not be measured.)
- Have tilting errors been made?
- Are the measurement lines drawn properly? (Measurement lines are only allowed on sonograms in the standard section.)
- Are the patient's name or code, age, right/left joint and date of examination recorded?

14 Principles of Ultrasound-Based Management



Contents

14.1 Basic Biomechanical Aspects Behind the Principles of Treatment

The value of hip ultrasound is measured by the rate of, and success of, treatment. Inexact diagnoses, e.g. "dislocation" or "subluxation", or the general term "dysplastic hip" inadequately describe the patho-anatomical condition of the hip joint.

This can be illustrated by a simple example: "fever" is not a diagnosis. Nobody would treat a febrile child with broad-spectrum antibiotics without making a diagnosis. It can be done, but the success of treatment will be small and the damage probably large. The best possible treatment for a hip disorder (traction, splints, etc.) can only be selected with an accurate diagnosis. Just as an antibiotic will be chosen once the sensitivities are known, so the hip must be clearly seen (by sonography) and the diagnosis made (classification by type).

The basis for any treatment must therefore be an analysis of the patho-anatomical appearances of the hip joint. If the diagnosis is accurate then the success of a specified treatment can be determined. Advantage can be taken of the age-related growth potential, whilst the treatment can take into consideration the biomechanics. Treatment used to be based on clinical or radiological findings; however, ultrasound-based management is decided after determining the patho-anatomical situation of the bony and cartilage socket. If tried and tested principles of treatment are followed, correlated with the ultrasound findings, the treatment should be adequate.

Starting treatment without using an imaging method that can visualize the hip joint is obsolete. Even in the treatment of hip maturation disorders, "do no harm" should be the guiding principle. Over-treatment not only has the potential to harm the joint but is also a handicap for the child, a great emotional burden for the parents, and a financial burden for the general public. "Preventative treatment" is just as obsolete as treatment with antibiotics without a diagnosis. The optimum combination of diagnosis and treatment requires a great deal of organizational effort and calls for cooperation between paediatricians and orthopaedic surgeons.

Important formula:

Result = Diagnosis + Treatment

Hip ultrasound is only responsible for the diagnosis and has no influence on the final result if the treatment is inappropriate.

14.2 Goals of Treatment

1. To reverse the patho-anatomical deformity of the joint back to the normal status for the age.
2. To make full use of the ossification potential of the hip joint.
3. We know today that the growth and ossification potential of the hip joint are age related. Therefore, accurate diagnosis and starting necessary treatment as soon after birth as possible is recommended.
4. To avoid damage, especially to the growth zones in the hip socket as well as avoiding necrosis of the femoral head.

14.3 Stages of Treatment

The first step must always be the analysis of the patho-anatomical state of the hip joint.

Sonographic typing defines the patho-biomechanical state of the joint. As the femoral head "slides out", mechanical deformity of the socket results. Treatment must therefore be chosen which is able to reverse the forces in the hip joint in such a way that the deformity can revert to the normal status for the age. The worst-case (decentred) hip joint needs an initial stage of preparation and three stages of treatment.

14.3.1 The Preparation Stage

The period of treatment can be considerably shortened by using early ultrasound diagnosis. Unfortunately, for whatever reason, there will be cases when treatment is started so late that the dislocated femoral head cannot be re-centred in the acetabulum either manually or with any other measure. These are usually older children who have clinical abnormality and already suffer from adductor contractions. In these cases, the hip joint must first be loosened. This can be achieved, depending on the severity, either through a special medically supervised exercise programme or, in severe cases, by traction or an adductor-tenotomy. A Pavlik harness applied in a correct position for this patho-biomechanical situation can also work (but is only recommended when the doctor knows how to apply it in this special biomechanical situation).

14.3.2 The Reduction (Fig. 14.1)

Decentred joints must be reduced. This is possible manually, through traction, or through a reduction device (e.g. Pavlik harness).

All decentred joints (type IV, IIIa, IIIb, D) need reduction. The dislocated femoral head is reduced back into the original acetabulum.

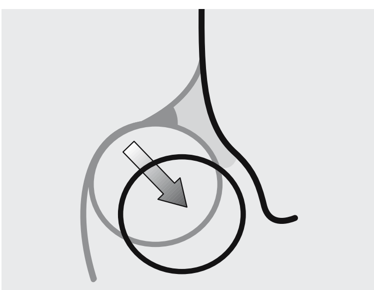


Fig. 14.1. The reduction phase. The decentred femoral head must be reduced

Complete reduction sometimes cannot be achieved because of the deformed, more or less pressed down cartilaginous roof. The required minimum is a position of the head in "front of the door" of the acetabulum, to give the head the possibility to bed down into the depth of the acetabulum by micromovements.

14.3.3 Retention

A femoral head which has been reduced into the original acetabulum will, however, dislocate back into the secondary moulding. This hip joint is unstable. Therefore, all hip joints which have been reduced and all unstable joints, such as type IIc unstable, must be subjected to the retention phase. Any retention device is suitable that fulfils the following basic principles:

- Flexion of at least 90°, better still 100°.
- Maximum abduction of 45° as measured from the central line. (These result in a squatting position.
- Relative immobilization of the joint for approximately 4 weeks.

A device that fulfils these requirements is suitable for retention. On average the retention phase takes 4 weeks. During this time the deformed cartilage has the opportunity to develop back to its original shape, and it becomes congruent with the femoral head. With relative immobilization the stretched and flapping joint capsule shrinks. Firm fixation is necessary in this phase to avoid redislocation. A plaster cast in a squatting position is suitable as a retention device. Any other device that can maintain such a position, e.g. a properly applied Pavlik harness, is also suitable.

In this retention phase the harness must be tightened and the baby fixed in the flexion–abduction squatting position! In this treatment stage (retention!) the baby is not allowed to move the hip joints and struggle!

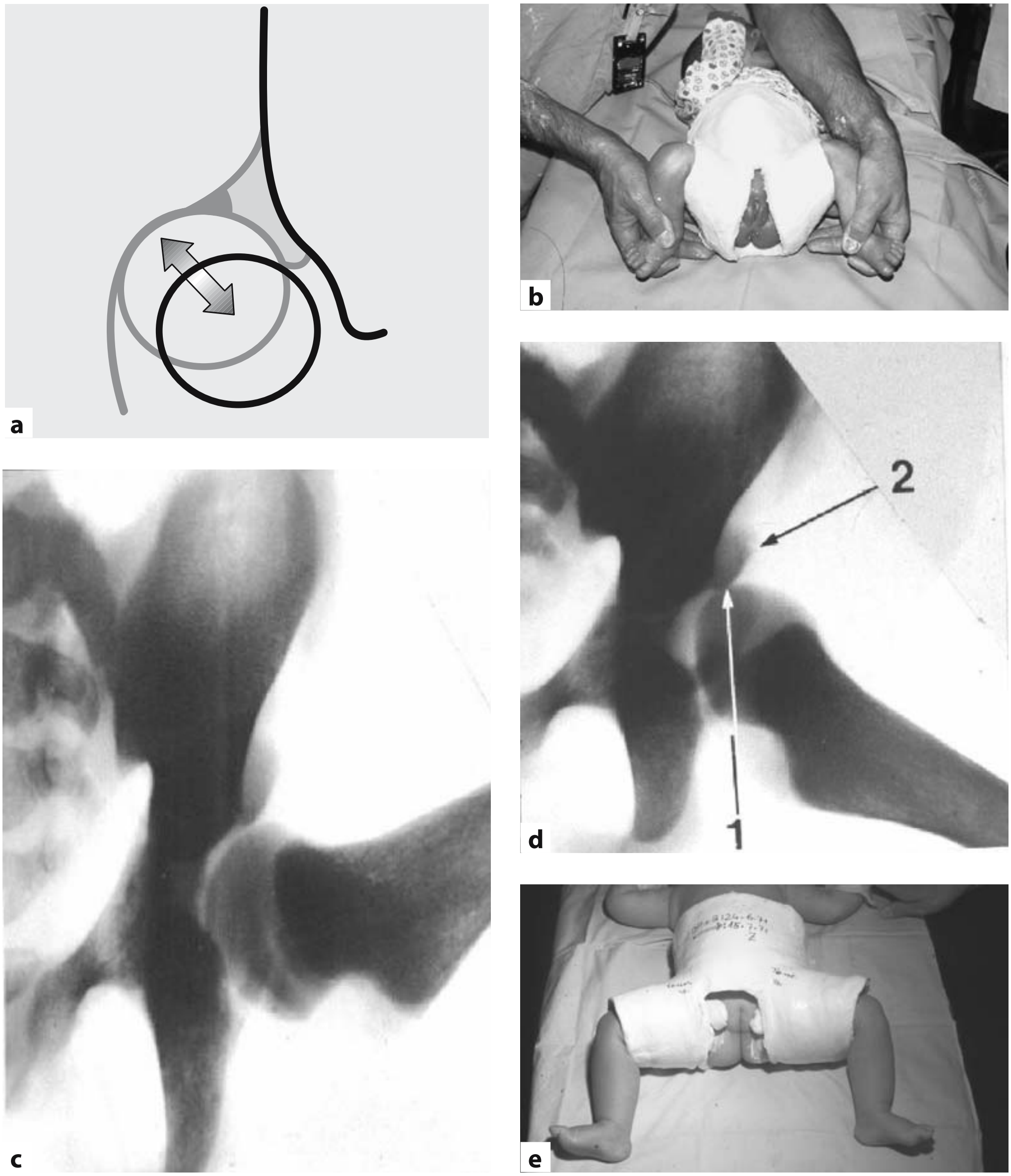


Fig. 14.2. **a** The retention phase. The hip joint is unstable, the hyaline cartilage roof is deformed and the joint capsule is lax. The femoral head must be pressed downwards in order to avoid shearing stress to the deformed hyaline cartilage roof. **b** Retention phase. The baby is fixed in the flexion abduction position in a plaster cast. **c** X-ray of a cadaver. The hip joint is fully reduced and should be retained in this position. **d** X-ray of a cadaver. Incorrect reduction with only abduction and no flexion! Compare with **c**; *1* downwardly pressed part of the hyaline cartilage roof (so-called inverted limbus); *2*, upwardly pressed part of the hyaline cartilage roof. **e** Historical Lorenz cast in 90° abduction and no flexion is strictly forbidden!

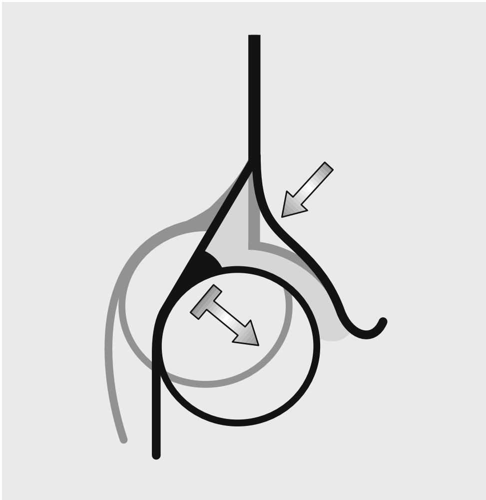


Fig. 14.3. The maturation phase: The poorly formed bony roof *(black arrow)* must remodel by extending into the unossified cartilaginous roof. During this stage, the squatting position should be enforced in order to avoid excessive pressure on the cartilaginous roof

14.3.4 The Maturation Phase (= Ossification Phase)

All joints that have completed the retention phase and have turned into stable joints as well as types IIc stable, type IIa (-)and type IIb, require a maturation device until they are completely healed, i.e. when the hyaline cartilage is ossified according to the age or type I. The maturation device should, if possible, maintain the squatting position whilst allowing an increasing amount of movement in the hip joint. A typical maturation device is a harness or any device which allows mild struggling in a squatting position (Fig. 14.4a, b).

Extension is strictly forbidden and may cause redislocation by pressing the cartilaginous roof upwards.

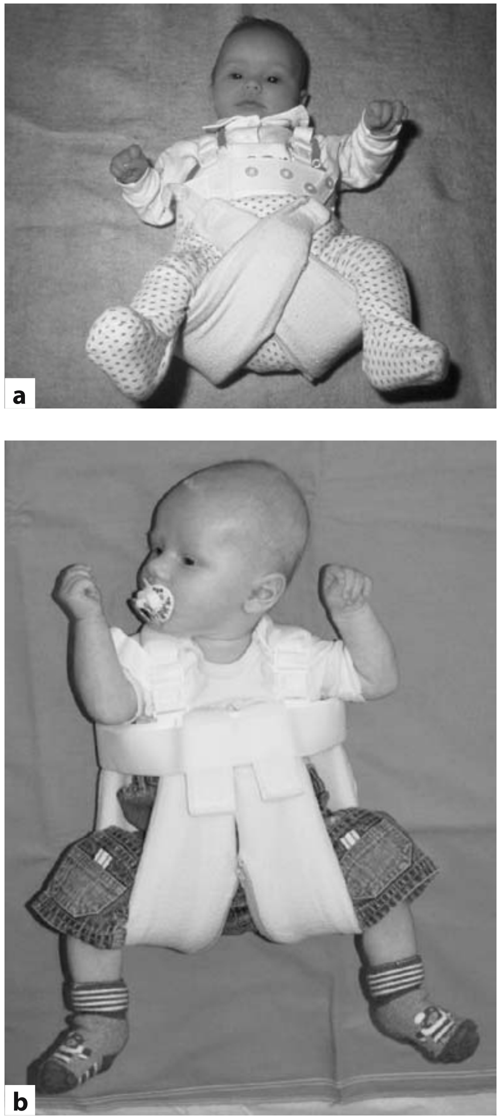


Fig. 14.4. a. Harness, according to Mittelmeier–Graf, for the maturation phase mild abduction, using cross straps. **b** Harness, according to Mittelmeier–Graf, using parallel position of the straps to avoid over-abduction, flexion bolsters are used under the thighs. The squatting position is enforced

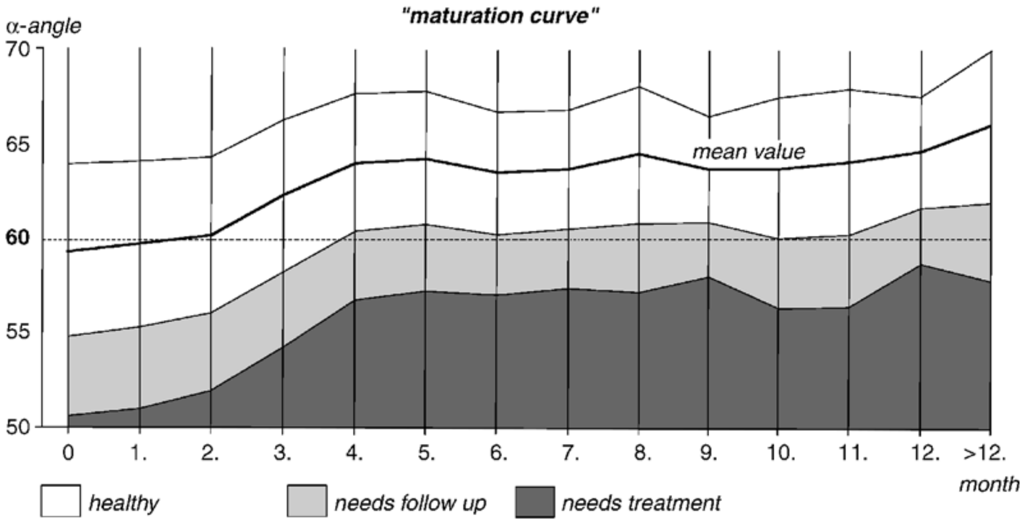


Fig. 14.5. Maturation curve

14.3.5 Maturation Curve

Developmental observations on healthy infants have shown that the bony socket grows in a specific way. Essentially the maturation curve shows that the potential for maturation and thus the increase in the alpha value is greatest during the first 6 weeks of life. The increase in the alpha value and thus the process of ossification is still good between the 6th and 12th week of life. However, after the end of the 3rd month the ossification potential begins to level out and continues to rise only slowly.

Conclusion: This means that with early diagnosis there is the potential for maturation over a relatively long period of time. The later the diagnosis and the beginning of treatment, the smaller the potential for maturation and the shorter period of time available to achieve an optimal result.

Diagnosis and treatment should start by the beginning of the 6th week at the latest!

A summary of the treatment is shown in Table 14.1. A long-term result of treatment is demonstrated in Figs. 14.6–14.12 (23 years follow-up).

Table 14.1. Therapeutic principles

Phase	Type	Procedures
1. Reduction	Decentred hips (D, III, IV)	Manually, by extension, Pavlik
2. Retention	Unstable hips (IIc unstable)	"Human position", plaster according to "fettweis"
3. Maturation	Stable "dysplastic" hips (IIc stable, IIb, IIa-)	Harness according M. Graf / Pavlik

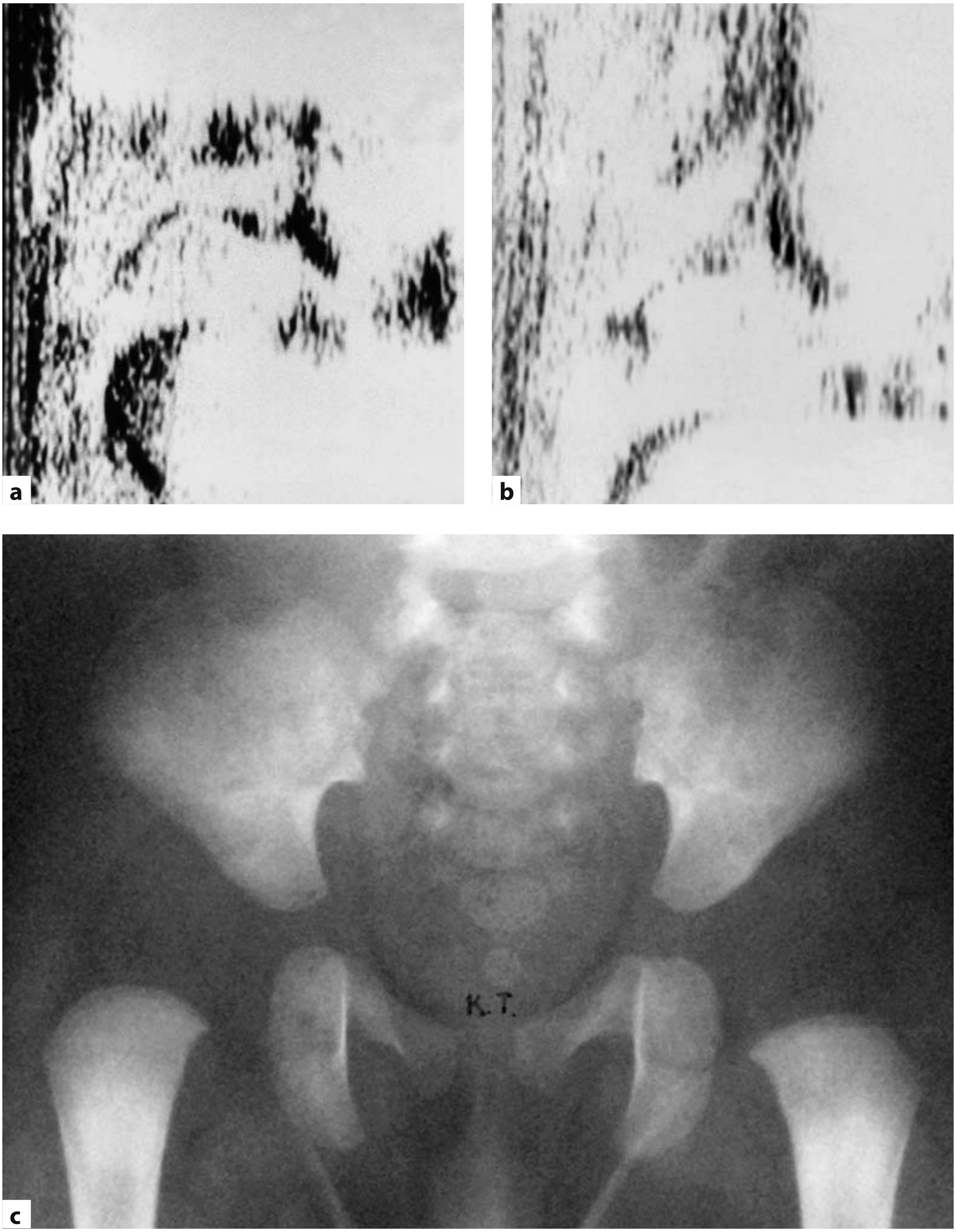
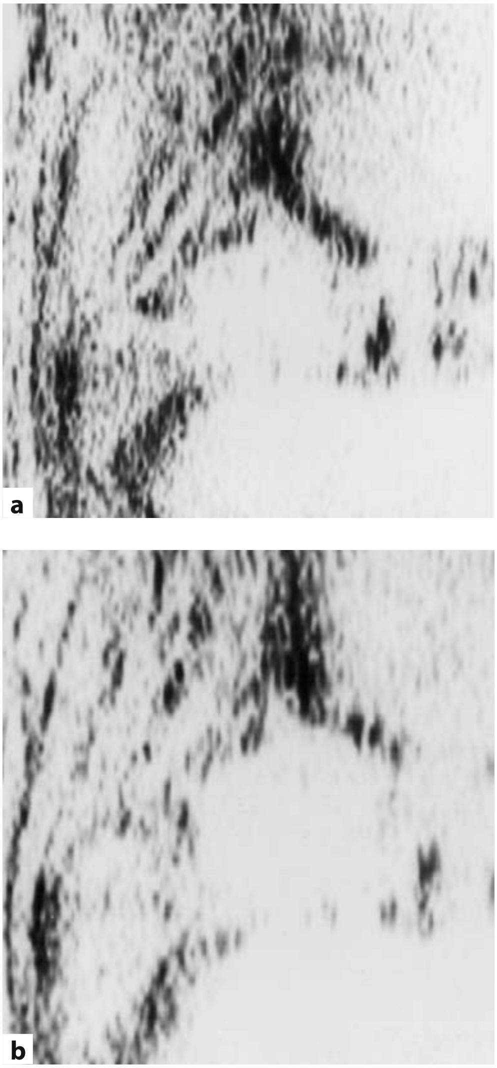


Fig. 14.6. **a** Routine sonogram of a 4-week-old baby in 1983. The bony roof is poor, the osseous rim flat, the hyaline cartilage deformed and pressed downwards, type IV, on the right hip joint. **b** Left hip joint in the same baby at the same time. The bony roof is poor, the osseous rim is flat, the hyaline cartilage roof partially pressed upwards, type IIIa hip joint. **c** X-ray according to **a** and **b**



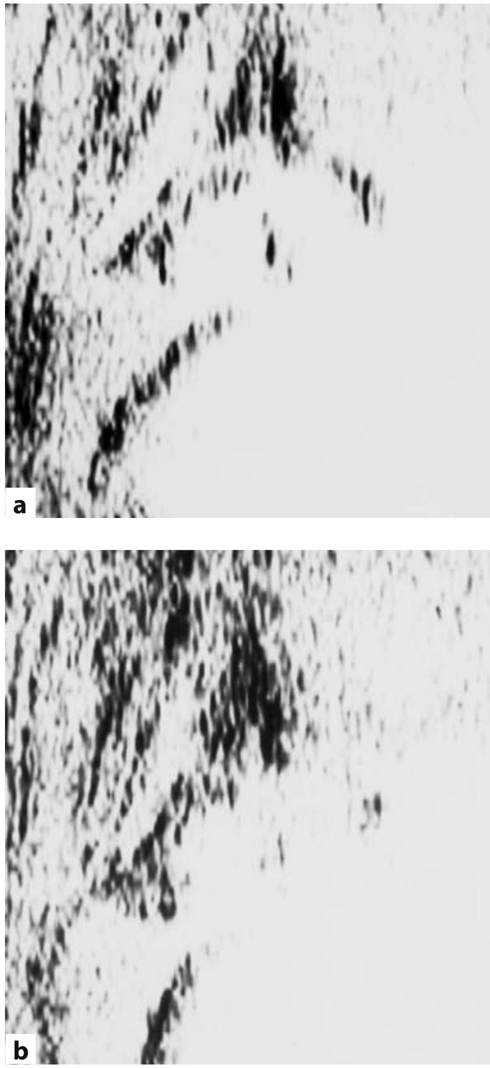


Fig. 14.7. a Right hip joint after reduction and retention for 4 weeks in a modified plaster cast. The hip joint is centred and stable compared with the same hip joint in Fig. 14.6a. **b** The same hip joint as in Fig. 14.6b after reduction and 4-week retention, centred stable hip joint. The quality of the sonogram in **a** and **b** are of the standard of 1983!

Fig. 14.8a, b. Sonograms after 6 weeks of treatment in a harness for maturation. The nucleus is appearing

Fig. 14. 9. The hip joint is now 4 months of age. Compare the situation after the steps of reduction, retention and maturation, the right side was a type IV, the left side a type III joint

Fig. 14.10. The same hip joints as Fig. 14.9, at 1.5 years of age

Fig. 14.11. The same hip joints at 10 years: completely normal joints bilaterally

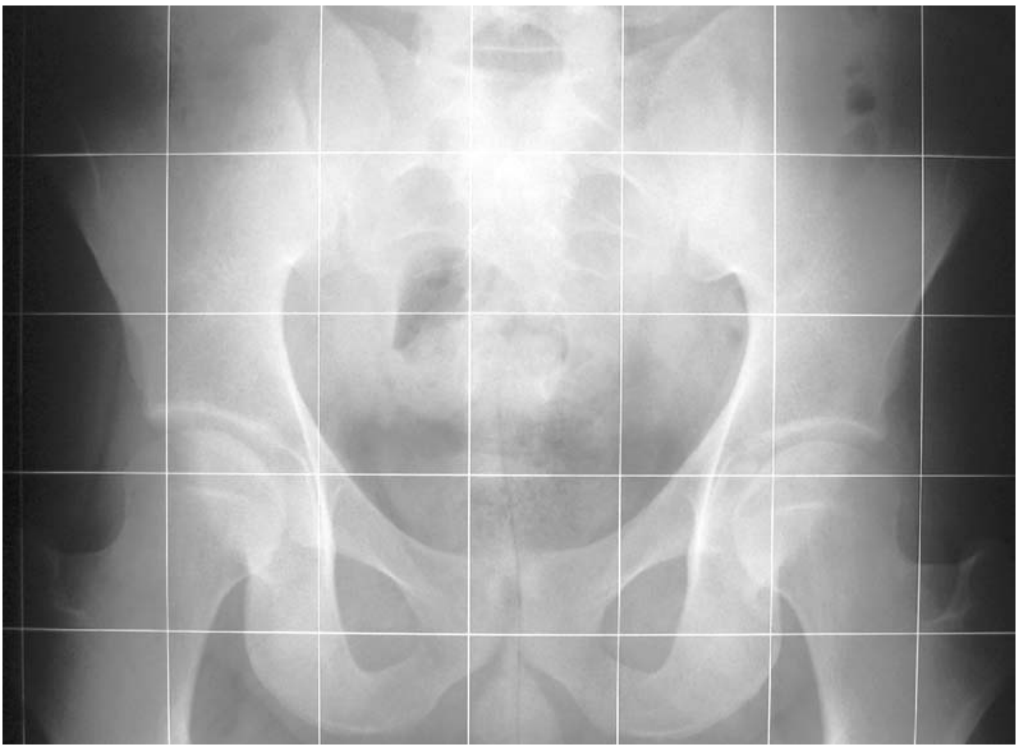


Fig. 14.12. The same hip joints at the age of 22 years

14.4 Why Errors Occur

There are two main problems:

14.4.1 The Problem of the Doctor

- Incorrect hip ultrasound and thus incorrect determination of the patho-anatomical findings.
- Loss of time. The best time for maturation is missed because the treatment is started late, i.e. after the 6th week of life, or the treatment is changed several times because the wrong treatment has initially been selected and thus the main period of maturation cannot be taken advantage of.
- Selection of the wrong device.
- There are specific devices for each phase of treatment. These are constructed so that their mechanics are suitable for reduction, retention or maturation of the hip joint. A maturation device requires a stable hip joint and usually cannot cause reduction and is inadequate for retention.
- A retention device, like a plaster cast, is especially designed for the mechanical needs of the retention phase. A stable joint such as type IIb would therefore be over-treated in a plaster cast. In the same way it would be wrong to treat a type III joint with a simple splint.

14.4.2 The Parental Problem (Compliance Problem)

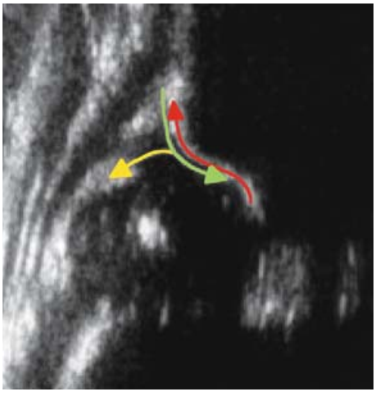
Prescribed devices are not worn or the position is changed. The baby is not taken to the necessary check-ups.
The retention phase is especially dangerous. At this stage of treatment the femoral head must be held securely in the original acetabulum for a certain period of time. All devices that the parents can remove themselves are dangerous in this phase. Successful treatment can be endangered through parental non-compliance.

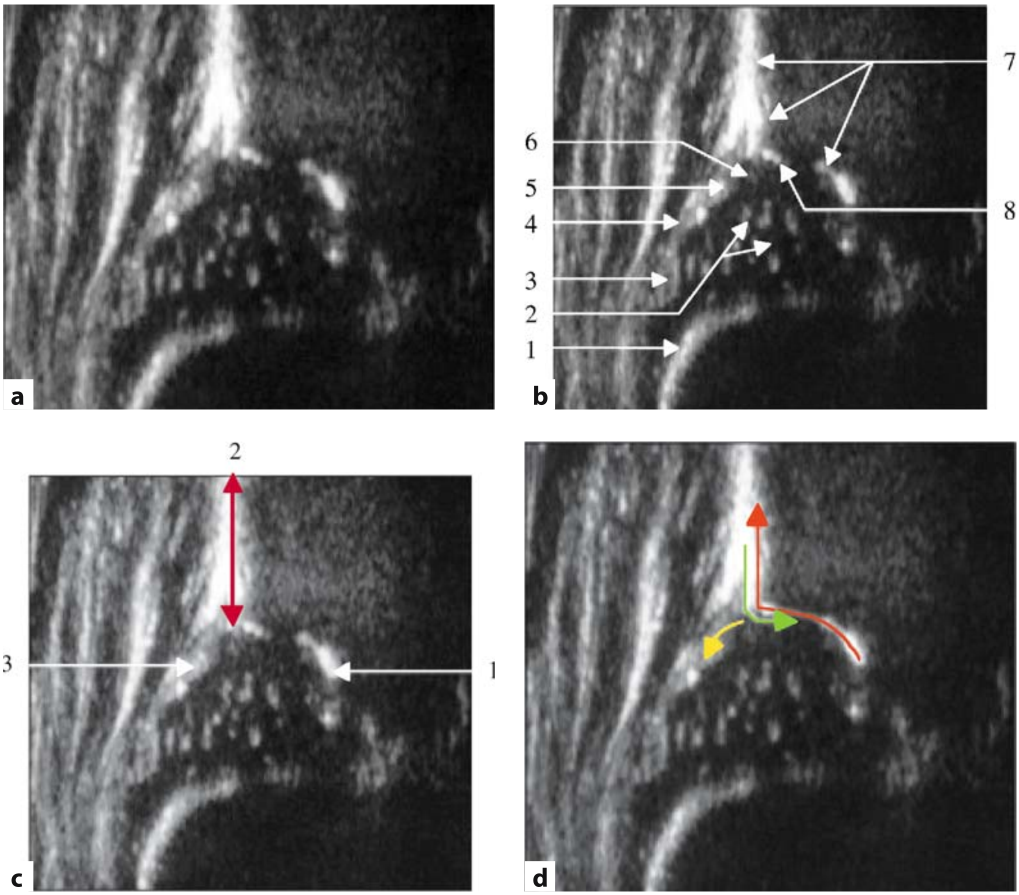
Key Points:

- Hip ultrasound enables accurate analysis of the patho-anatomical situation in the hip joint. During treatment the hip joint goes through three essential patho-anatomical phases: repositioning, retention and maturation.
- In each of these phases a form of treatment must be selected which is bio-mechanically suitable for the specific phase.
- Because of the maturation curve, the best result is achieved if the diagnosis is made as early as possible so that the hip joint has lots of time available when there is good potential for maturation.
- Wrong diagnosis (no hip sonography performed), the wrong selection of treatment and poor parental compliance can cause irreversible damage to the hip joint.

Motto: Better hip ultrasound today than a limp tomorrow!

15 Appendix





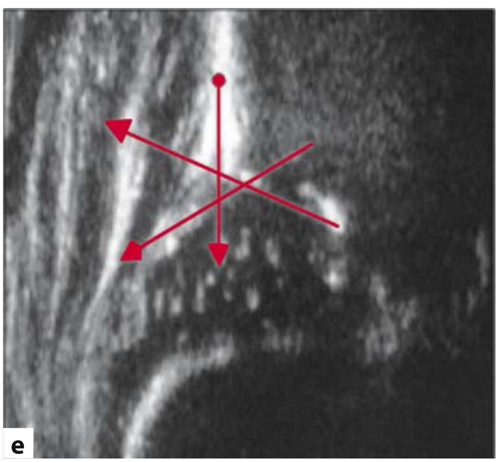
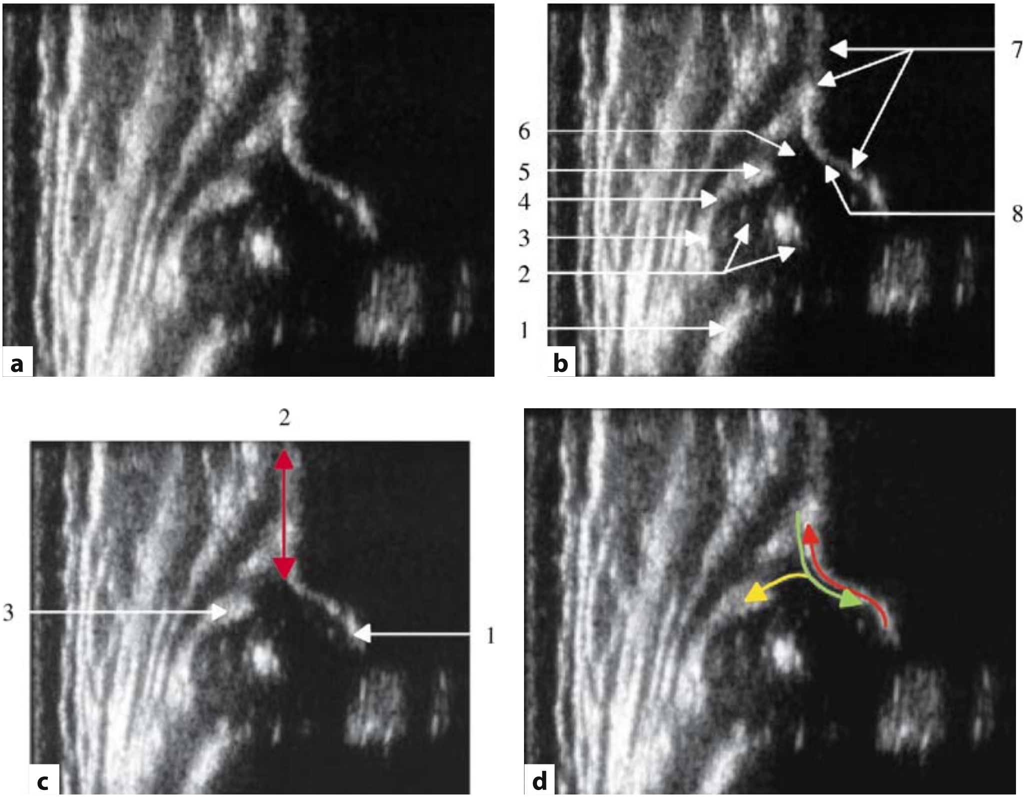


Fig. 15.1. a Twelve weeks, right hip. **b** *1*, Chondro-osseous junction; *2*, femoral head; *3*, synovial fold; *4*, joint capsule; *5*, labrum; *6*, cartilage; *7*, bone; *8*, bony rim. **c** Usability check: *1*, lower limb; *2*, plane; *3*, labrum. **d** Bony roof (*red*): good; bony rim (*green*): blunt; cartilage roof (*yellow*): covers the femoral head. Type I. **e** Measurement: alpha: 64°, beta: 60°. Final type: Ib



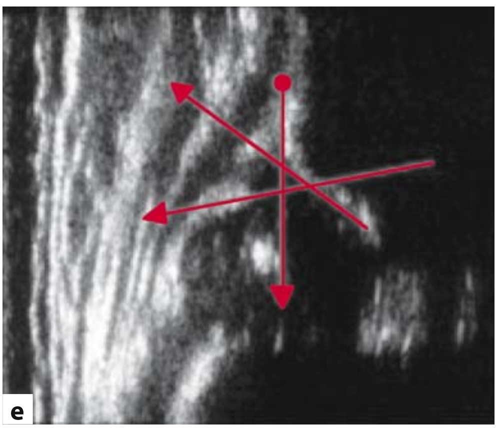


Fig. 15.2. **a** Six months, left hip. **b** *1*, Chondro-osseous junction; *2*, femoral head; *3*, synovial fold; *4*, joint capsule; *5*, labrum; *6*, cartilage; *7*, bone; *8*, bony rim. **c** Usability check: *1*, lower limb; *2*, plane; *3*, labrum. **d** Description: The bony roof (*red*) is deficient, the bony rim (*green*) is round and the cartilage (*yellow*) is covering the femoral head – type II. According to the age, type IIb. **e** Measurement: alpha: 54°, beta: 78° – type II, according to the age type IIb

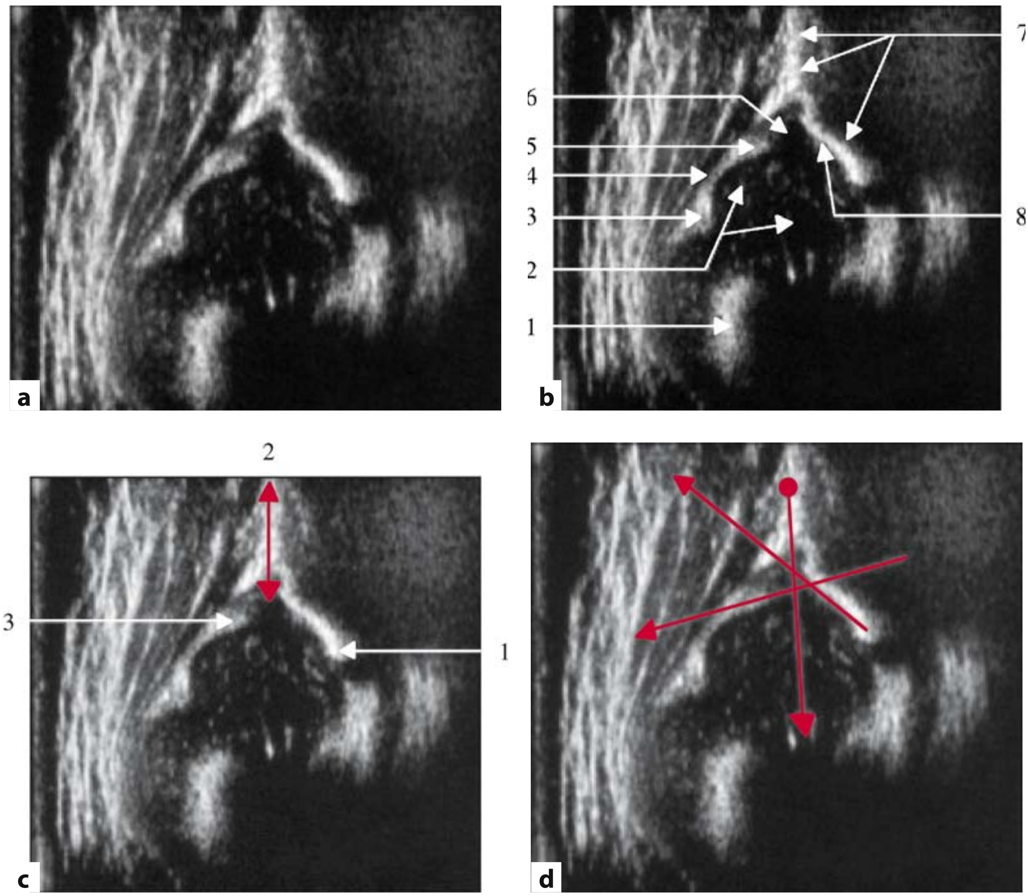
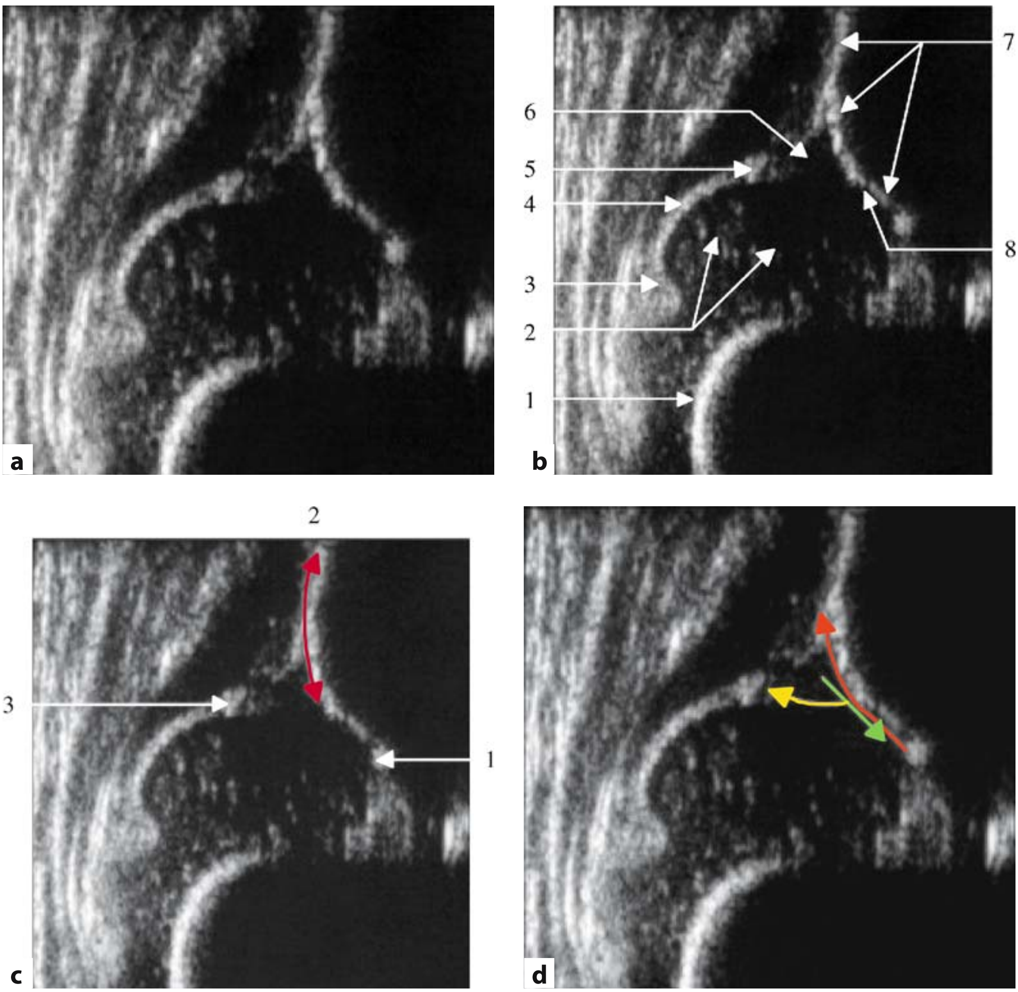


Fig. 15.3. **a** Six weeks, right hip. **b** Anatomical identification: *1*, Chondro-osseous junction; *2,* femoral head; *3*, synovial fold; *4*, joint capsule; *5*, labrum; *6*, cartilage; *7*, bone; *8*, bony rim. **c** Usability check: *1*, lower limb; *2*, plane; *3*, labrum. **d** Description: The bony rim (*red*) is severely deficient, the bony roof (*green*) is rounded to flat, but the cartilage roof (*yellow*) is still covering the femoral head. Type II. Measurement: alpha: 48°, beta: 76°, final type: IIc



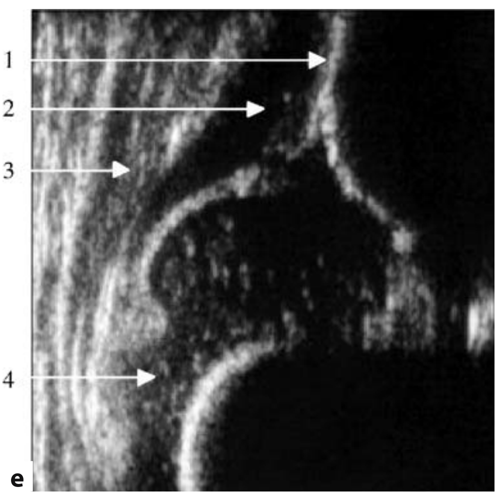


Fig. 15.4. **a** Four Weeks, left hip. **b** Anatomical identification: *1*, Chondro-osseous junction; *2*, femoral head; *3*, synovial fold; *4*, joint capsule; *5*, labrum; *6*, cartilage; *7*, bone; *8*, bony rim. **c** Usability check: *1*, lower limb; *2*, plane (it is posterior, but the hip is decentred so this sonogram is usable); *3*, labrum. **d** Description: The bony roof (*red*) is poor, the bony rim (*green*) is flat and the cartilage (*yellow*) is displaced **e** *1* Os ilium; *2*, gluteus minimus; *3*, gluteus medius; *4*, greater trochanter

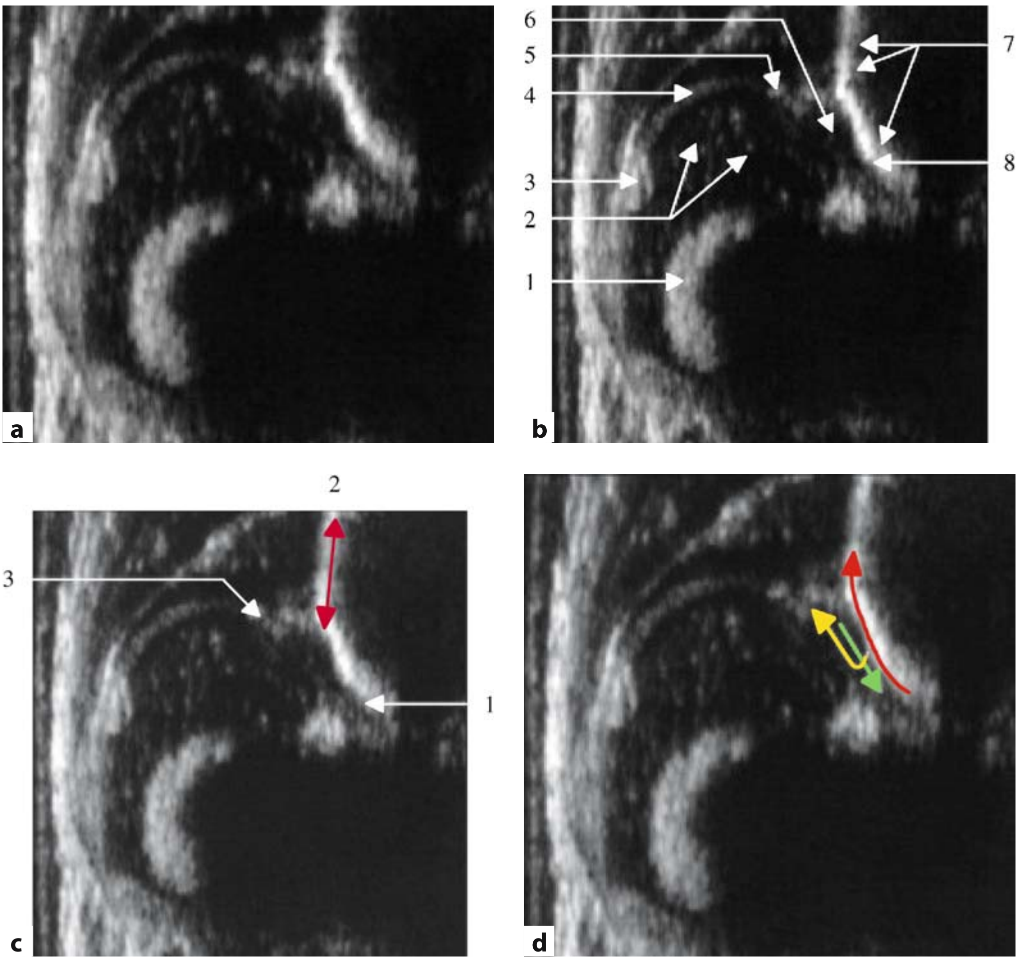


Fig. 15.5. **a** Two weeks, right hip. **b** Anatomical identification: *1*, Chondro-osseous junction; *2,* femoral head; *3*, synovial fold; *4*, joint capsule; *5*, labrum; *6*, cartilage (pressed downwards); *7*, bone; *8*, bony rim. **c** Usability check: The lower limb (*1*) is missing, the plane (*2*) is posterior (*3*), labrum is present. This sonogram is usable, because the hip decentred. **d** Description: The bony roof (*red*) is poor, the bony rim (*green*) is flat and the cartilage is pressed downwards. This is a type IV

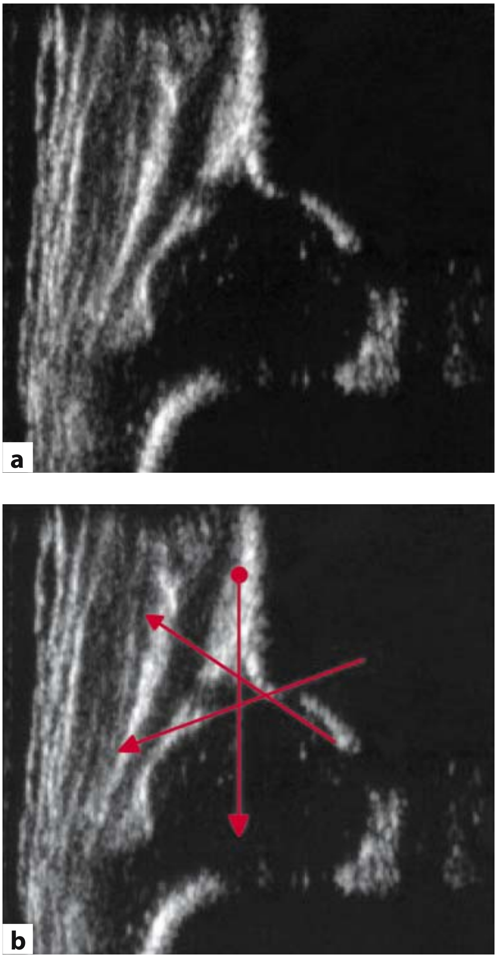


Fig. 15.6. a. Eleven weeks, right hip. **b** Measurement: alpha: 55°, beta: 69°, according to the age, type IIa(-)

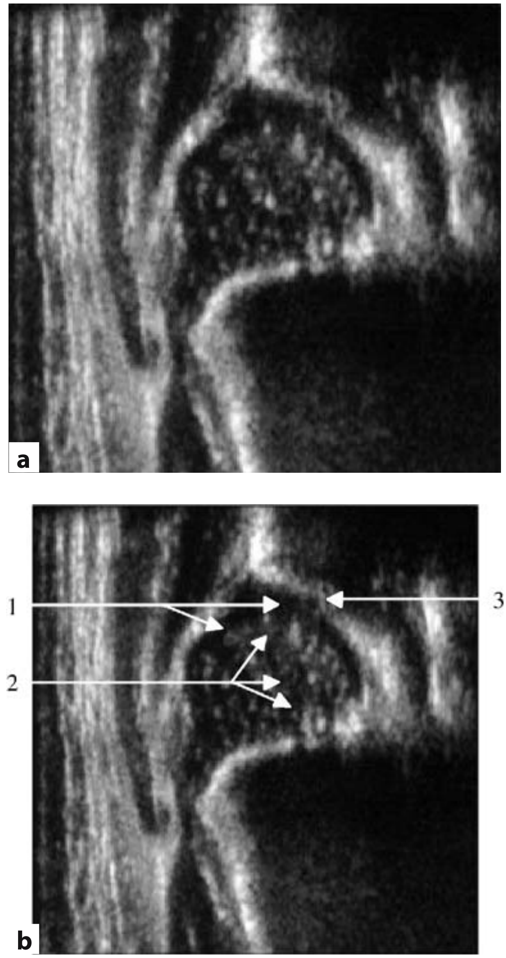


Fig. 15.7. a Two weeks, right hip. This sonogram is not usable, because the lower limb is missing, but the hip is centred. **b** *1*, Zona annularis; *2*, zona centralis; *3*, the lower limb is missing

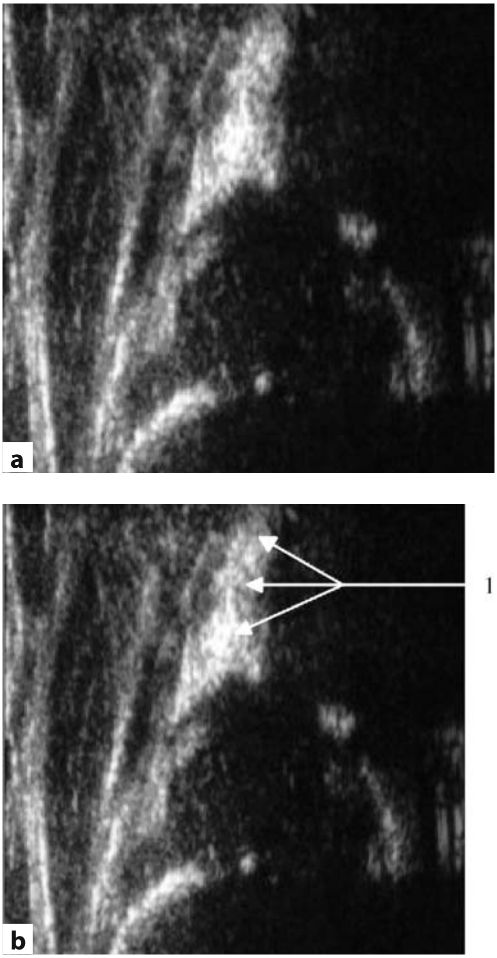


Fig. 15.8. **a** Four months, right hip. Please do not forget to check for tilting error. This sonogram is not usable. Tilting error (ventral – dorsal). **b** *1*, Blurred and oblique os ilium

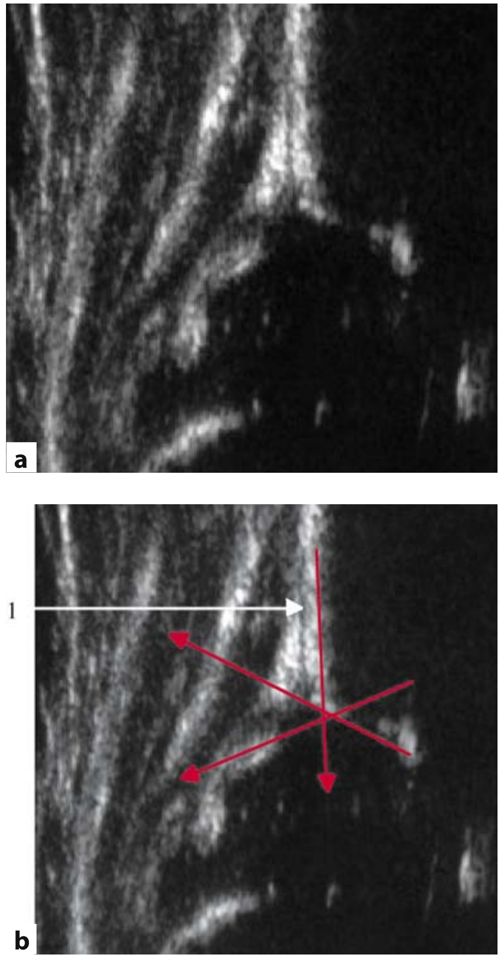


Fig. 15.9. **a** Five weeks, right hip. Go step by step. Start with the anatomical identification. Do the usability check (lower limb, plane, labrum). Look for tilting error. Description: the bony covering is good, the bony rim is blunt and the cartilage covers the femoral head. Type I. **b** *1*, Contact point (border) between the proximal part of the perichondrium and the os ilium. Measurement: alpha: 60°, beta: 70°, final type: Ib

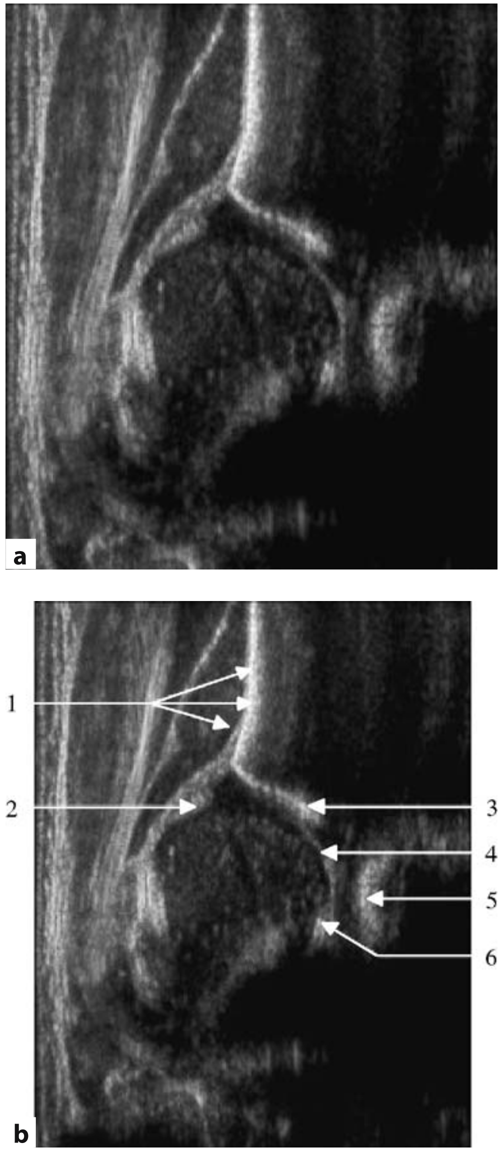


Fig. 15.10. a Two days, left hip. The plane is posterior, so you cannot use this sonogram. **b** *1*, Os ilium with concavity of the fossa glutealis (posterior plane); *2*, labrum; *3*, lower limb; *4*, ligamentum teres; *5*, os ischii; *6*, transverse ligament

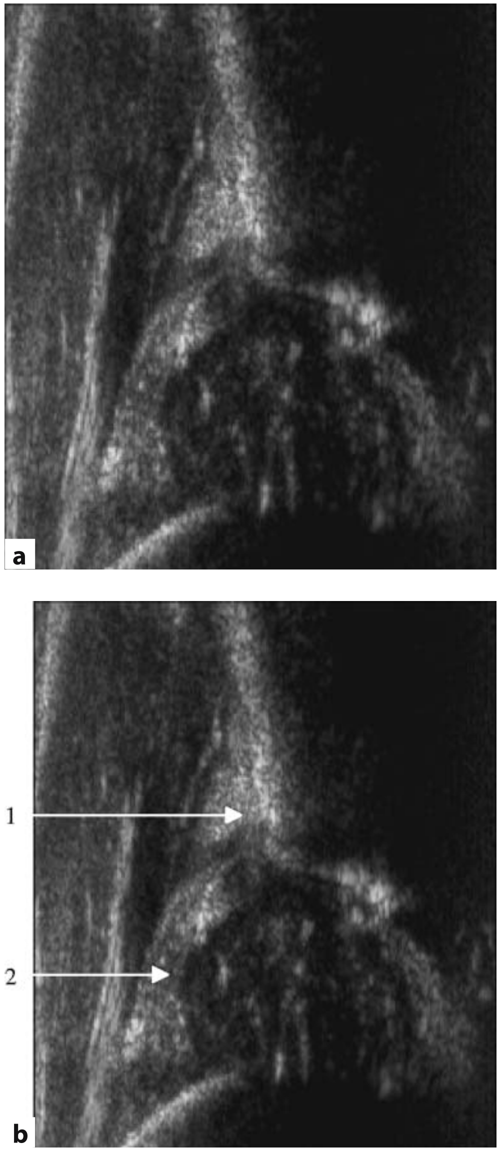


Fig. 15.11. a Three months, left hip. This sonogram is not usable – tilting error! **b** *1*, Blurred perichondrium;*2*, because of ventral–dorsal tilting of the transducer, the joint capsule becomes blurred

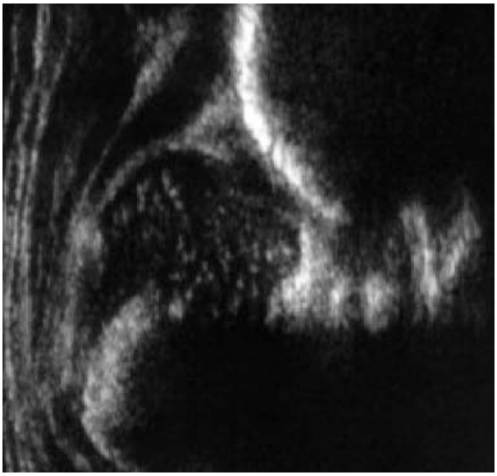


Fig. 15.12. Four days, left hip. The bony roof is poor, the bony rim is flat and the cartilage is pressed upwards without structural alteration – type IIIa

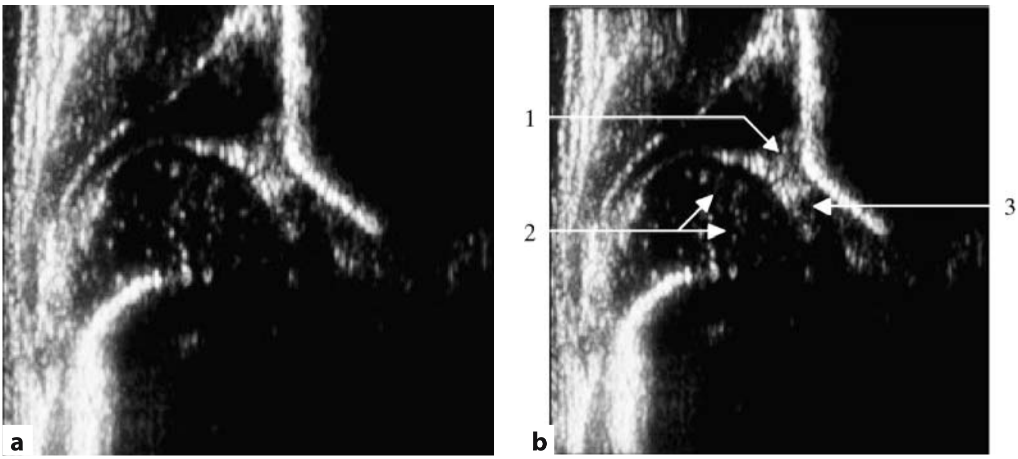


Fig. 15.13. a One week, left hip. The hip is decentred and the cartilage is pressed downwards – type IV. **b** *1*, Perichondrium; *2*, femoral head; *3*, cartilage (pressed downwards)

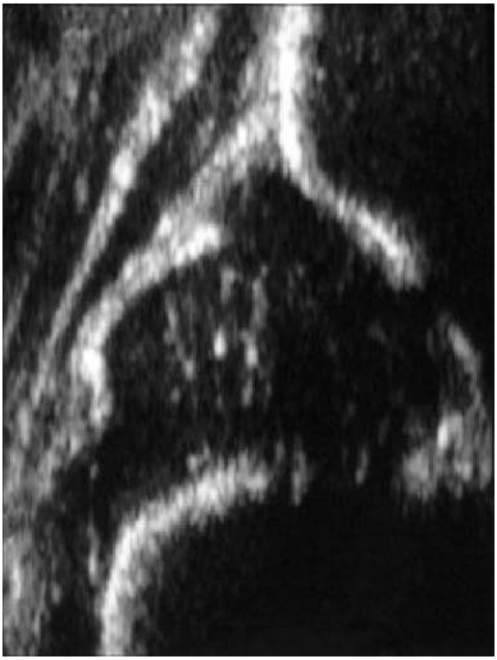


Fig. 15.14. Five weeks, left hip. The bony roof is deficient, the bony rim is round to flat, but the cartilage is covering the femoral head. The hip is centred – type II. Type IIa(+/-) and type IIc can only be differentiated by exact angle measurement

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