COMPARATIVE STUDIES OF ULTRASONOGRAPHY IN ORTHOPAEDICS

by

T. UFUK EREN

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ABSTRACT

In this study ultrasonographic images of different musculosceletal parts of human body have been examined to see whether they can be used for orthopaedic applications. In some of the examinations, comparisons of the ultrasonographic images with X-Ray films have also been performed. Due to the wide difference between the characteristic impedances of soft tissue and bone, it is very difficult to obtain a clear bone image; only an echogen band and behind it an acoustic shadow can be obtained with ultrasonography.

As the results of the 47 examinations on the patients which have been performed in the Orthopaedics and Traumatology, and Radiology Departments of the Istanbul Medical Faculty with the help of the high frequency transducers, some results are obtained. Ultrasonography may reveal components of cartilage which may be obscure in some X-Ray films. Moreover, it can be used to study bone metastasis. Being a safe technique, ultrasonography may be used in "real-time" mode on moving joint parts like shoulder, hip, knee, wrist, ankle and elbow to obtain valuable diagnostic information.

It is shown that ultrasound may be used as an adjunct to radiography in the diagnosis of lesions of bone. The impermeability of bone tissue to ultrasound may be used to analyze the effects of bony lesions on adjacent soft tissues. This approach could make it possible to diagnose bony destruction, inflammation, and new bone formation. It is demonstrated that, in the diagnosis of these kind of pathological changed bone-related parts, ultrasound is a excellent adjunct modality to radiography.

Keywords: Musculoskeletal, ultrasonography, X-Ray

ÖZET

Bu çalışmada kas-iskelet sisteminin farklı bölgeleri ultrason görüntüleri ile incelenerek ortopedik uygulamalardaki avantajları ve konvansiyonel radyografi ile karşılaştırması yapılmıştır. Yumuşak doku ve kemik arasındaki karakteristik empedans farkının büyük olması, ultrasonografi ile iyi bir kemik görüntüsü alınmasını zorlaştırmaktadır. Yalnızca ekojen bir şerit ve bunun arkasında ise akustik bir gölge elde edilmektedir.

İstanbul Üniversitesi İstanbul Tıp Fakültesi Ortopedi ve Travmatoloji ve ayrıca Radyodiagnostik Ana Bilim Dallarında 47 hasta üzerinde yapılan incelemeler sonucunda, kullanılan yüksek frekans transdüzerler yardımıyla birtakım sonuçlara varılmıştır.

Ultrasonografi, röntgen filmlerinde anlaşılamayan kıkırdak komponentlerini gösterebilmektedir. Ayrıca kemik metastazları çalışmalarında kullanılabilmektedir. Ultrasonografi, teşhise yönelik değerli bilgiler elde edilebilmesi amacıyla omuz, kalça, diz, dirsek, el ve ayak bileği gibi hareketli bölümlerde gerçek zaman modunda çalışılmasına imkan tanımaktadır.

Kemik dokusunun ultrason tarafından nüfuz edilemez özelliği kemiksi patolojik yapıların komşu yumuşak dokulara olan etkisinin analizinde kullanılabileceği gösterilmiştir. Bu yaklaşım sayesinde kemikteki tahribatlar, iltihaplanmalar ve yeni kemik dokusu yapılanmalarının teşhisi mümkün olabilmektedir. Ultrasonun kemiğe ait patolojik değişim gösteren bu bölgelerin teşhisinde radyografiye yardımcı bir modalite olarak kullanılabileceği gösterilmeye çalışılmıştır.

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A	Amplitude [dB]
c	Phase velocity [m/s]
E	Factor related to the elastic properties of the material [g/s x cm^2)
f	Frequency [Hz]
K	Compressibility coefficient
p	Density [g/cm^3]
R	Reflection coefficient
v	Velocity [m/s]
Z	Acoustic impedance [kg/m^2xs= sx N/m^3=sx Pa/m]
λ	Wavelength [m]
α	Attenuation coefficient
Q	ROI-Activity quotient (Region of Interest)
ϕ	Angle of incidence

I. INTRODUCTION

1.1 Background and Objectives

To the human observer, the internal structures and functions of the human body are not generally visible. However, images can be created by various technologies, through which the medical professionals can look into the body to diagnose abnormal conditions and guide therapeutic procedures. The medical image is a window to the body. No image window reveals everything. Different medical-imaging methods reveal different characteristics of the human body. With each method, the range of image quality and structural visibility can be considerable, depending on characteristic of the imaging equipment, skill of the operator, and compromises with factors such as patient radiation exposures and imaging time.

Sound is a physical phenomenon, that transfers energy from one point to another. In this respect, it is similar to X-ray. It differs from X-rays, however, such a way in that sound can pass only through matter and not through vacuum. This is because sound waves are actually vibrations passing through a material. If there is no material, nothing can vibrate and sound cannot exist. Ultrasound is used as a diagnostic tool because it can be focused into relatively small areas as well-defined beams, that can probe the human body.

Most ultrasound images used for medical diagnostic purposes are formed by reflections, or echoes, from structural interfaces within the body. Refrected pulses, or echoes, are detected by the transducers, which convert them into electrical pulses that being amplified and displayed in an appropriate image format.

Vast areas of investigation have been opened as a result of the development of ultrasound as an imaging tool. In the past 15 years, there have been dramatic advances in imaging in the form of computerized tomography and magnetic resonance. These have developed, however, is highly expensive procedures with fixed facilities. By contrast, ultrasound provides economic, noninvasive imaging of tissues in static or dynamic states, and is serial studies where indicated. Its capacity to be easily transported adds to its value. It gives access to direct visual controls of the movements as a real-time diagnosis. It is reliable and equally good with other methods, even partly superior.

One of the disadvantage of this method is the high grade in subjectivity

which lies on the gain and the assesment of the image. Another is that the exact reproduceability of a certain section is only a limited possibility.

Ultrasonography is commoly used to image the soft tissues. It is possible to get good images from the soft tissue parts by ultrasonography. One of the aims of this study is to image the bony parts of the human body and to see how far can be ultrasonography used in Orthopaedics. And also, to find out the positive and the negative values against X-Ray imaging and the other diagnostic modalities was another aim of this thesis.

In the past, the use of ultrasound to evaluate the musculoskeletal system has been limited by the technology. Now it is only limited by the ingenuity and perseverance of the individual performing the scan. With the advent of the newer, high-resolution transducers, anything goes. Many clinical problems or questions can now be answered or investigated by ultrasonography. Not only does this technique allow high resolution of the soft tissues, but it also permits dynamic assesment.

1.2 Outline of the Thesis

Chapter I introduces the subject and gives a brief description about ultrasonography in diagnostic medicine. Chapter II presents a summary of physiological information on bone. The structure and composition of the bone are mentioned in this chapter. Also, ultrasound and its fundamental principles are mentioned. Physical basis in orthopaedic imaging by the ultrasound is presented in chapter III. Physical basis and artifacts in ultrasound imaging are described here. Details about instrumentation and examination technique are given in chapter IV. Subject profile can be found in this chapter, too. Chapter V is devoted to experimental results and discussion, and Chapter VI brings the thesis to a conclusion.

II. PHYSIOLOGICAL BACKGROUND

Bone and ligaments, which are the major subjects in orthopaedy and ultrasound were the components which are mainly used in the work. Bone has got a complex structure. It is made of minerals, water, and extracellular collagenous matrix.

Ultrasound are longitudinal waves. Frequency, velocity, wavelength, amplitude, intensity and attenuation of ultrasound must be explained in order to understand ultrasound better. In this chapter, bone ligament and ultrasound are described with their properties. So, the relation between bone and ultrasound in imaging can be understood better.

2.1. Bone Structure

Bone is described as a connective tissue. A tissue is an aggregation of similarly specialized cells united in the performance of a particular function. Connective tissue is the tissue, which binds together and is the support of the various structures of the body. Bone is a specialized connective tissue with a calcified collagenous intercellular substance for skeletal support of the body. It is either spongy (cancellous) or compact in structure. Spongy bone consists of intercrossing and connecting bars of varying shapes and thickness, between which spaces are filled with bone marrow. Compact bone is a continous hard mass, whose spaces are microcscopic in size. Both types exist in almost every bone. Bone is a composite material with several distinct solid and fluid phases [1]. Bone is unique among the connective tissue because it is relatively hard.

At the macroscopic level there are two major forms of bone tissue: compact, or cortical bone and cancellous or trabecular bone. The location of these bone types in a femur is illustrated in Fig. 2.1. Cortical or compact bone is a dense material with a specific gravity of about two [1]. The external surface Periosteum is a modified connective tissue, which covers the bone. The inferior surface is called the endosteal surface. It has a roughened texture which resembles cancellous bone. Endosteum lines the

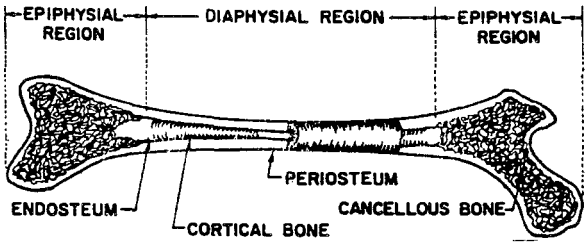


Fig. 2.1 Longitudinal section of the femur, illustrating cancellous and cortical bone [1].

marrow spaces.

Cancellous bone is also called trabecular bone because it is composed of short struts of bone material called trabeculae. The connected trabeculae give cancellous bone a spongy appearance, and is often called spongy bone.

Cancellous bone has a vast surface area. This is illustrated by human pelvis, which has an average volume of 40 cm^3 and an average periosteal surface of 80 cm^2, but the average surface of its trabecular bone is 1600 cm^2 [1].

The cortex of a bone is composed of compact bone, while the medulla contains cancelllous, or spongy bone. Spongy bone is made up of a loose network of trabeculae of bone which are interconnected but generally arranged along lines of maximum stress or tension. The trabeculae are made up of a varying number of adjoining bone plates. Osteocytes within the lacunae communicate with each other by canalicules.

From a microscopic viewpoint, there are three types of cortical bone: women, laminar and haversian (see Fig. 2.2). Woven bone is found typically in both cortical and cancellous bone of young, growing animals and in adults after some bone injury. However, during normal maturation it is gradually replaced by laminar bone so that, in a human being, for example, there is normally no women bone present after the age of 14 to 16 years. An additional distinguishing feature of woven is the lack of a relationship of mineral to collagen. In laminar and haversian bone these elements are closely related, and it seems virtually impossible for laminar bone to become hypermineralized. However, the mineral density of women bone varies enormously; the mineral appears to be weakly related to the organic matrix, mineralization occurs in a haphazard fashion, and hypermineralization is often observed [1].

Haversien bone is organized to accommodate small arteries, arterioles, capillaries, and venules of the microcirculating system. Haversian bone is never formed as a primary event, but forms as the result of the vascular invasion of bone.

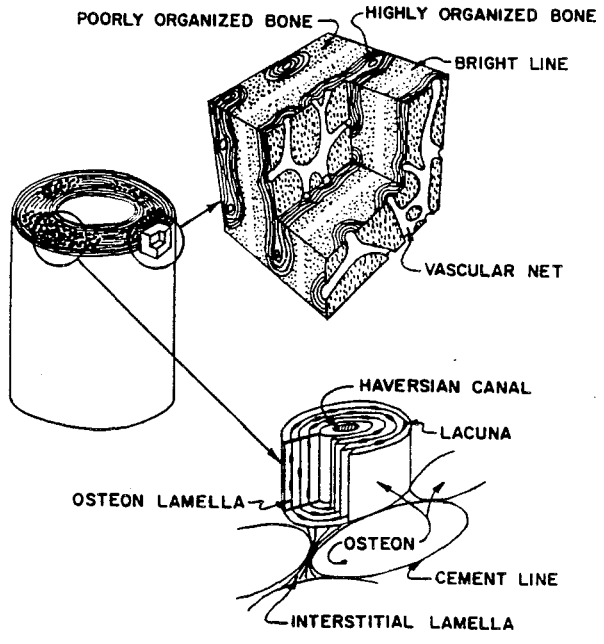


Fig. 2.2 Typical bone structure in the diaphysis of the femur. Two types of cortical bone are illustrated: plexiform and haversian [1]

The osteons of haversian bone and the laminae of laminar bone are basically just different geometric configurations of the same material (see Fig. 2.3). In both geometric configurations no point in tissue is more than 100 μm away from the body supply [1]. The interfaces between the laminae in both haversian and laminar bone contain an array of roughly ellipsoidally shaped cavities called lacunae, which contain bone cells, and from which extend numoreus fine canals called the canaliculi. All lacunae are connected by a tremendeous number of minute canals (canalicules), which penetrate the hard substance, branch abundantly and anastomose. Obteoblast (bone-forming cells) and osteoclasts (bone-absorbing cells) line the surface of bone. The thin layer between adjacent osteons is called the cement line, and the threedimensional region between osteons is filled with irregular pieces of lamellar bone. The canaliculi do not cross the cement lines, nor do they cross the bright lines between laminae in laminar bone.

Both haversian and laminar bone exist simultaneosly in the long bones of humans and many animals, including cattle. In the very young the long bones are composed of woven bone with a few osteons, called primary osteons. With maturation the woven bone is converted to laminar bone, and, at maturity, there is a partial conversion to haversian bone. The conversion from laminar to haversian bone is somewhat of a biological enigma. Haversian bone is known to have a less efficient local circulation

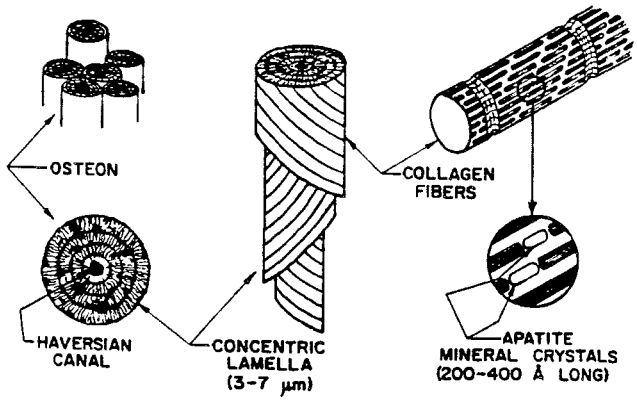


Fig. 2.3 Detailed structure of an osteon [1].

system [2] and to have less mechanical strength than laminar bone, yet the percentage of haversian bone generally increases with age.

Compact bone consists of lamellae which are regularly arrenged about branching and anastomosing canals through which nutrient vessels pass. These haversian canals communicate with the outer surface of the bone or the medullary cavity through canals of Volkmann.

The typical haversian system is the basic structure of compact bone. It consists of lamellae concentrically arranged about the haversian canal. Most haversian systems are directed in the long axis of the bone. Therefore, in cross section the canals appear as small rounded openings, and the lamellae as circles; in longitudinal section the canals appear as long slits. Large number of canalicules pass radially from the canal to the lacunae and intercommunicate with each other. Their function is supposedly for diffusion of nutrient fluids. Compact bone is made up of large numbers of haversian system between which are interstitial or ground lamellae. These latter are the remains of haversian systems, which are only partly destroyed. On the outer and internal aspects of the compact bone are lamellae, which are arranged circumferentially in relation to the main bone. These are the basic or circumferential lamellae. These are penetrated by the canals of Volkmann through which nutrient vessels enter the bone to reach the vessels in the haversian canals. They contain large vessels and are not surrounded by concentrially arrenged plates. Sharpey's fibers are thick bundles of collagenous fibers, which pass from the periosteum into the basic external circumferential lamellae. They fix the periosteum firmly to the surface of the bone, particularly where tendons and muscles attach, where large blood vessels and nerves enter the bone, and at the epiphyses of long bones.

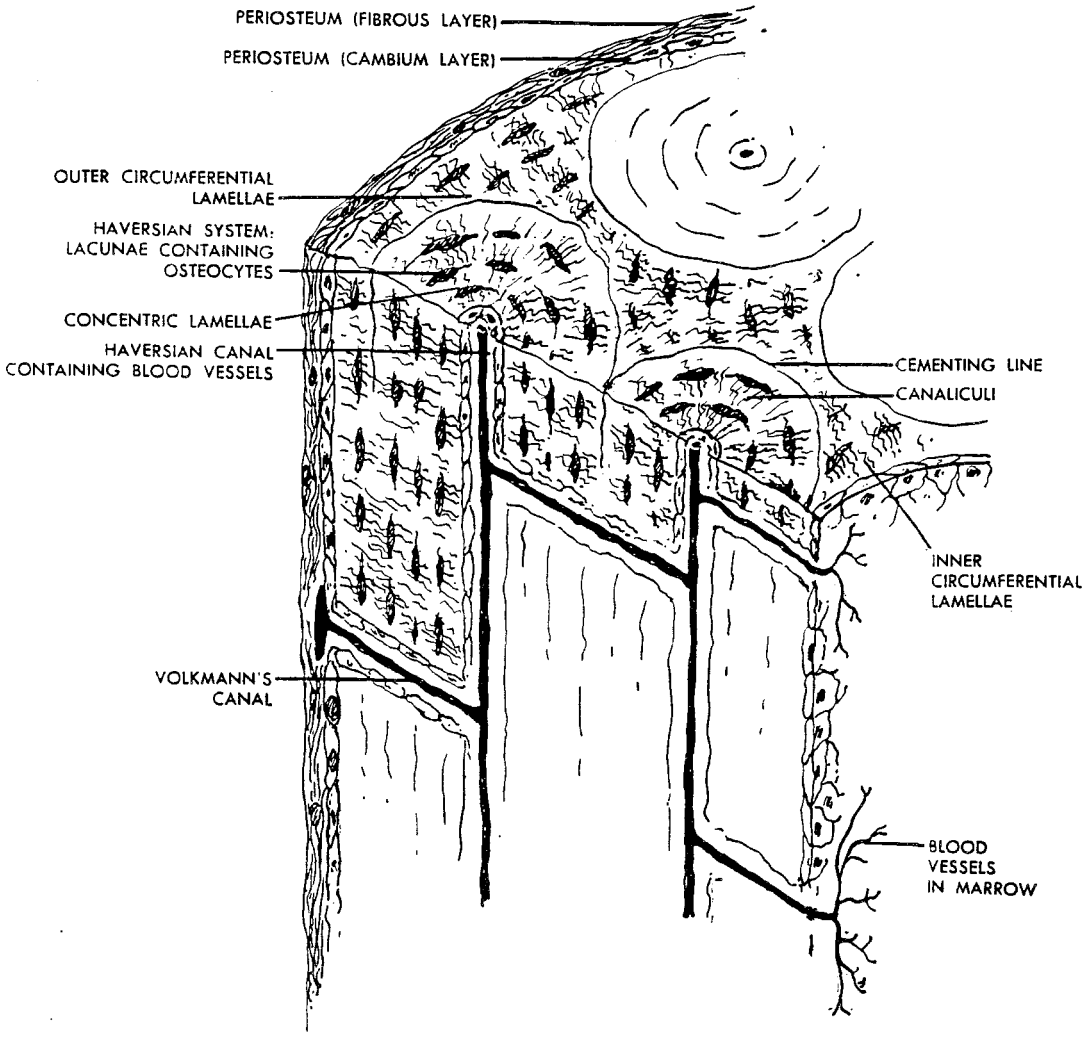


Fig. 2.4 Diagrammatic representation of a cross section and longitudinal section of the cortex of a long bone. Note the haversian systems running longitudinally. Volkmann's canals constitute connecting channels between periostel and haversian and bone marrow blood vessels [2].

The periosteum consists of dense connective tissues containing blood vessels. Its deepest startum, the cambium layer, is more loosely arranged and contains spindle-shaped cells and a network of thin elastic fibers. In the adult the periosteum is not osteogenic until necessity arises, as after a fracture, whereupon osteoblast appears in the cambium layer.

2.2 Bone Composition

The composition of bone tissue is, very roughly, equal thirds by

Fig. 2.5 Cortex of long bone, showing appearance of haversian canals in longitudinal section (A) and in cross section (B) [2].

volume of minerals, water, and the extracellular collagenous matrix. The hard interstitial substance is compased of water, the organic framework and inorganic salts. The mineral salts consists mostly of submicroscopic crystals of hydroxyapatite [Ca3 (PO 4) 2] 3Ca (OH) 2 or the closely related hydrated tricalcium phosphate [1].

The bone salt composes 65 per cent of the adult dry bone. This is reduced to 30 to 35 per cent in rickets and osteomalacia. The organic constituent of bone is the bone collagen or ossein. When boiled, gelatin results. A weak acid, such as glycerine, will remove the inorganic salts and leave the original structure grossly and microscopically.

In order to be more precise about bone composition, one must specify, species age sex, the species of bone in question, the type of bone tissue (cencellous or cortical), and whether or not bone disease is present. Details of some age and species differences are given by Jowsey [1]. Table 2.1 presents data on the specific gravity, water fraction, mineral fraction, and organic fraction of cortical bone for 16 different vertebrates, including humans. These data are taken from a paper by Blitz and Pellegrino [1], who give a detailed chemical assay of the bone for each of the 16 vertebrates. They assayed the percentages of calcium, phosphorus,

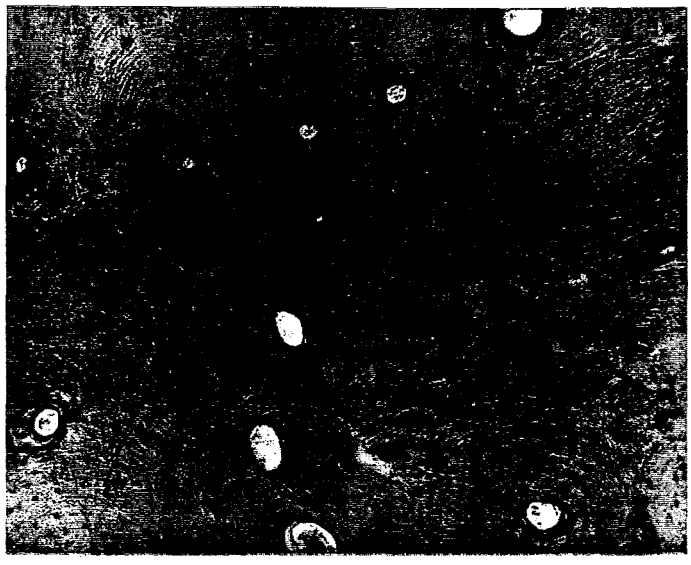


Fig. 2.6. Cross section of cortex of a long bone. The haversian systems are well displayed [2].

magnesium, sodium, carbondioxide, OH-proline, hexosamine, ciltrate, and lactate. Results of the hydrated bone assays for both cortical and trabecular bone for four species were reported by Gong, Arnold, and Chon [1]. Some of their data are summarized in Table 2.2 Comparison of the data given in Table 2.2 for trabecular bone with that given for that cortical bone shows that the water fraction is greater and the ash fraction is less for trabecular bone. The organic fraction for the two bone types is fairly close.

Table 2.1. Results of hydrated bone assays for 16 species using cortical bone from the tibia [1].

Species*	Specific gravity	Water content, vol %	Mineral ash, vol %	Organic $+CO_2$, vol %
Fish (2)	1.80	39.6	29.5	36.9
Turtle (6)	1.81	37.0	29.2	40.1
Frog (4)	1.93	35.2	34.5	38.5
Polar bear (1)	1.92	33.0	36.2	40.1
Human being (15)	1.94	15.5	39.9	41.8
Elephant (1)	2.00	20.0	41.4	41.5
Monkey (3)	2.09	23.0	42.6	41.1
Cat (1)	2.05	23.6	42.2	40.5
Horse (3)	2.02	25.0	41.0	40.5
Chicken (4)	2.04	24.5	41.7	38.7
Dog (10)	1.94	28.0	38.7	35.5
Goose (2)	2.04	23.0	42.7	37.6
Cow (5)	2.05	26.2	42.6	36.2
Guinea pig (2)	2.10	25.0	43.5	37.0
Rabbit (2)	2.12	24.5	45.0	37.2
Rat (12)	2.24	20.2	49.9	38.3

* The number of adults of each specifes sampled are indicated in parantheses after the common species name.

Table 2.2 Results of hydrated bone assays of cortical and trabecular bone for four species using cortical bone from the tibia or femur and trabecular bone from the vertebrae [1]

Species	Specific gravity*	Water fraction, vol %	Ash fraction, vol %	Organic fraction, vol %	Volatile inorganic fraction, vol %
			Trabecular bone		
Human being	1.92	27	33.9	34.9	4.2
Monkey	1.89	27.1	32.9	36.1	4.0
Cow	1.93	28.1	33.5	34.2	4.2
Dog	1.91	28.8	32.6	34.5	4.2
			Cortical bone		
Human being	1.99	23.9	37.7	33.8	4.6
Monkey	2.04	23.7	38.2	33.7	4.7
Cow	2.00	25.2	36.6	33.6	4.6
Dog	2.00	22.3	36.8	36.3	4.6

* This is the specific gravity of the trabeculae.

2.3 Introduction to Ultrasound

The use ultrasound in the modern-day medical clinic has found a solid niche among the various methods for imaging body. The reasons for this popularity are many, but they perhaps chiefly derive from the ease and safety associated with its use. Ultrasound is defined as acoustic waves with frequencies above those which can be detected by the ear, from about 20 kHz to several hundred MHz [3]. Medical instrumentation typically uses only the portion of the ultrasound spectrum from 1 MHz to 10 MHz due to the combined needs of good resolution (small wavelength) and good penetrating ability (not too high a frequency). The waves are generated by small acoustic transducers, usually hand-held, that are electrically driven and placed on the surface of the skin. The waves propagate into the tissues of the body; where a portion is reflected from the myriad of interfaces between tissue types of different acoustic properties. Some of these interfaces are abrupt, representing major organ boundries, and some are more gradual.

2.4 Fundamental Principles Of Ultrasound

Sound waves and x-ray photons both are forms of energy transmission. However, that is where the similarity between the two ends. Their interactions with matter are quite dissimilar. The ways in which these two forms of energy interact with matter determines how they can be used in medical imaging. Unlike radiography, ultrasound imaging most commonly utilizes energy reflected back to the source to produce an image. This is referred to as pulse-echo imaging.

X-rays are best transmitted through a vacuum, but sound required matter for its transmission. The speed at which x-ray photons travel is constant. However, the speed of sound varies with the type of matter through which it passes. Table 2-3 lists the speed of sound through a variety of substances. The factors that determine the speed of sound through a substance are density and compressibility. Materials with the greatest density and least compressibility will transmit sound at the highest velocity.

Sound is reflected at interfaces between materials. Two factors influence reflectivity; the acoustic impedance of the two materials and the angle of incidence of the sound beam. Acoustic impedance is the product of a material's density and the speed of sound within that substance. Reflectivity is greatest at interfaces between materials with dissimilar acoustic impedance, as defined by the following equation:

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2 \times 100 \quad [4]$$

where R ist the precentage of sound beam reflected, and Z_1 and Z_2 are the acoustic impedances, assuming an angle of incidence of 90 degrees.

The data in Table 2-4 indicate that interfaces between soft tissue and air should be highly refrective.

With this in mind, it is clear why a coupling gel must be used to assure contact between the ultrasound transducer and the patient's skin. The previous equation tells us that 99.9 per cent of a sound beam is reflected at any tissue-air interface. In areas of poor with the skin, where an air gap exists, essentially no energy is available for imaging [4]

Table 2.3 Speed of Sound Through Various Substances [4]

Transitting Substance	Speed of Sound (m/sec)
Air	331
Fat	1.450
Water	1.540
Liver	1.549
Blood	1.570
Muscle	1.585
Cortical bone	4.080

Reflection of a sound beam varies greatly with the angle of incidence. The least reflection occurs with the sound beam perpendicular to the reflecting interface; in other words, an angle of incidence of 90 degress. As the angle of incidence is decreased, the percentage of the sound beam reflected increases. Beyond a certain angle the entire sound beam is reflected. In addition, the direction of the reflected beam is determined by the angle of incidence (Fig 2.7). This is important to keep in mind when imaging an object with a curved surface, such as the femoral condyles or the diaphysis of a long bone. As the angle of incidence is decreased, the beam will be reflected away from the transducer and not contribute to the image (Fig. 2.8). Therefore, the optimal scanning pattern for a curved surface is an arc that keeps the beam perpendicular to the surface of the object to be imaged (Fig 2.9).

Spatial localization will also be impaired when the angle of incidence is less than 90 degrees. This phenomenon is known as refraction. Refraction is a change in direction of a sound beam occurring at an interface between two dissimilar materials when the beam is not perpendicular to the interface. A change in wavelength of the sound beam occurs in

Table 2.4 Acoustic Impedance of Various Materials [5]

Material	Acoustic Impedance (gm/cm^2 sec x 10^{-5})
Air	0.0004
Fat	1.38
Water	1.54
Blood	1.61
Muscle	1.70
Cortical bone	7.8

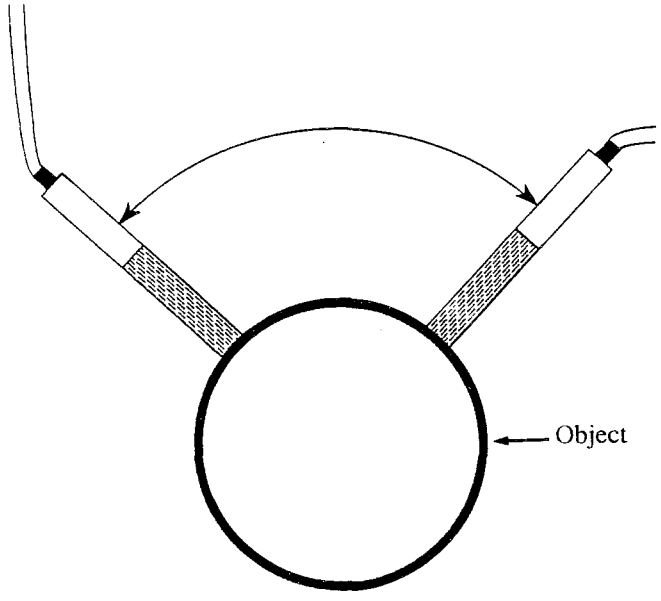


Fig 2.9 Optimal imaging of a curved object [5]

accommodation to the different speed of sound in the new material. This acts to "bend" the beam. The magnitude of the change in direction of the sound beam is proportional to the difference of the speed of sound within the two materials and inversely proportional to the angle of incidence. In most circumstances, the error introduced by refraction is not significant. However, under certain conditions, the true location of an object will differ significantly from its imaged position.

As a sound beam passes through a material, a portion of its energy is absorbed by frictional forces. The energy is converted to heat and no longer contributes to the imaging process. Viscosity, relaxation time, and temperature of the material, along with the frequency of the the sound beam all effect absorption. Of these factors, the one that can be modified in the clinical setting is the frequency of the transducer. The degree of absorption to frequency. If the frequency of the sound beam is doubled, absorption will double. This becomes important in selecting a transducer, because spatial resolution is also proportional to frequency. The best transducer for a specific examination is one having the highest frequency that can penetrate to the desired depth within the soft tissues being examined. This will result in images with the greatest possible spatial resolution [5].

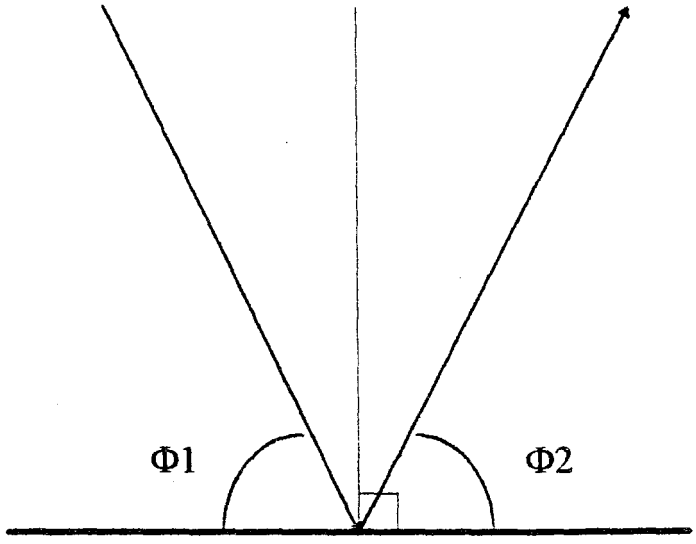


Fig. 2.7 Reflection of sound and angle of incidence ϕ ($\phi 1 = \phi 2$). [5]

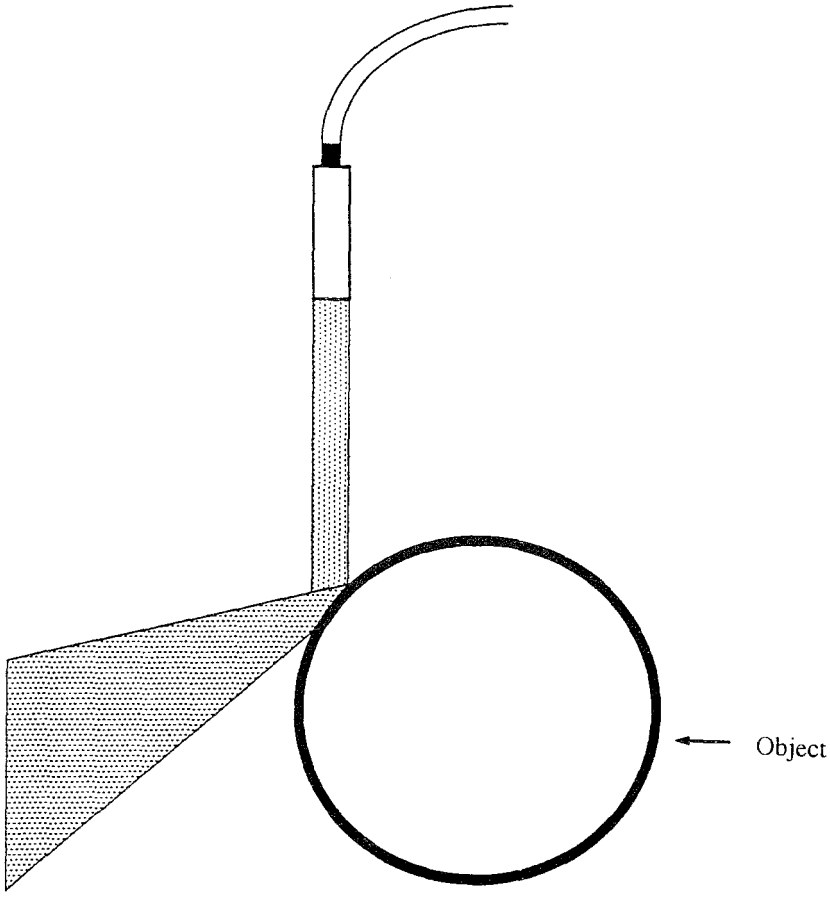


Fig. 2.8 İmproper imaging of a curved object [5]

2.5 Equipment

Four types of ultrasound transducers are currently available: (1) sector scanners, (2) annular arrays, (3) radial arrays, and (4) linear arrays. The basic principles governing their function are identical for the four types. They differ only in how some of the components are arranged (Fig 2.10) Annular arrays are the least familiar, because they are used predominantly in cardiac and ophthalmalogical examinations.

The heart of an ultrasound transducer is a piezoelectric crystal. These crystals, discovered by Pierre and Jacques Curie in 1880, have unique physical and electrical properties. When a voltage pulse is applied to a piezoelectric crystal, it vibrates and can produce sound at a specific resonant frequency. In addition, if a mechanical force is applied to a piezoelectric crystal, an electrical potential will result. These properties make piezoelectric crystals ideal for ultrasound transducers because the same element serves as both transmitter and receiver of the ultrasound beam. The original materials described by the Curies were quartz and Bochelle salts, but these have been replaced in modern medical imaging equipment by lead zirconate titanate [5].

How these crystals are incorporated into an imaging transducer is demonstrated schematically in Figures 2-10, A through D. Two opposing sides of the crystal are plated with a metallic conductor, usually gold, to serve as electrical contacts. Electrical leads attached to the plated surfaces deliver the electrical pulses to the crystal and conduct the potential generated by the crystal when it detects the reflected sound beam. The crystal surface facing the patient may be in contact with an acoustic lens that helps to focus the sound beam. These lenses are usually formed of polystyrene and use the principle of refraction to focus the sound beam. This unit is separated from the patient by an insulating layer that serves to protect the patient from possible electrical shock and protects the crystal from contamination. The other side of the piezoelectric crystal is in contact with a backing block that dampens the vibration of the crystal and absorbs sound moving away from the patient. This assembly is protected from noise by a layer of acoustic insulating material and enclosed within a plastic housing.

Operating characteristics of a transducer are described by its resonant frequency and the Q factor. Two properties of a transducer are described by the Q factor: the purity of sound produced and the "ring down" time.

Ring down time refers to the time required for the crystal to stop vibrating. Piezoelectric crystals with a high Q factor produce pure sound but have a long ring down time. Likewise, crystals with a low Q factor produce a sound beam containing a relatively wide variety of frequencies but have a short ring down time. Crystals with a relatively low Q factor are most desirable fo use in medical imaging because they are sensitive to a wider frequency range of sound returning to the transducer, and the short ring down time deduces interference with the returning signal. Careful selection of the backing block utilized in the transducer can enhance the operating characteristics by further reducing the ring down time [5].

The sound beam emitted by the transducer has a shape that changes with distance from the transducer (Fig 2.11). In the near field, the borders of the sound beam are almost parallel, referred to as the Fresnel zone. At a certain distance from the transducer; the beam diverges, referred to as the Fraunhofer zone. The point of transition varies with the frequency and width of the sound beam. As the frequency and width of the beam increase, the Fresnel zone (parallel borders) becomes longer. Side, lobes are also present, extending laterally from the main beam. These side lobes are usually less than one per cent of the intensicity of the main beam and thus very rarely clinically significant. When they do contribute to an image, they have the same effect as beam width artifact. Acoustic lenses and firing sequence of an array of crystals can be used to modificy the shape of the ultrasound beam.

2. 6 Imaging

Ultrasound images are composed of a matrix of picture elements. Gray scale images are produced by the display of echos returning to the transducer as picture elements (pixels) varying in brightness in proportion to the intensity of the echo. The location of the echo to be displayed is determined by the location on the transducer receiving the echo and the time of flight. Time of flight is the time elapsed between initiation of the sound pulse and its return to the transducer.

In ultrasound imaging we speak of two types of resolution: axial and horizontal. Axial resolution is the ability to distinguish two objects as being separate when they lie directly over each other; that is, aligned

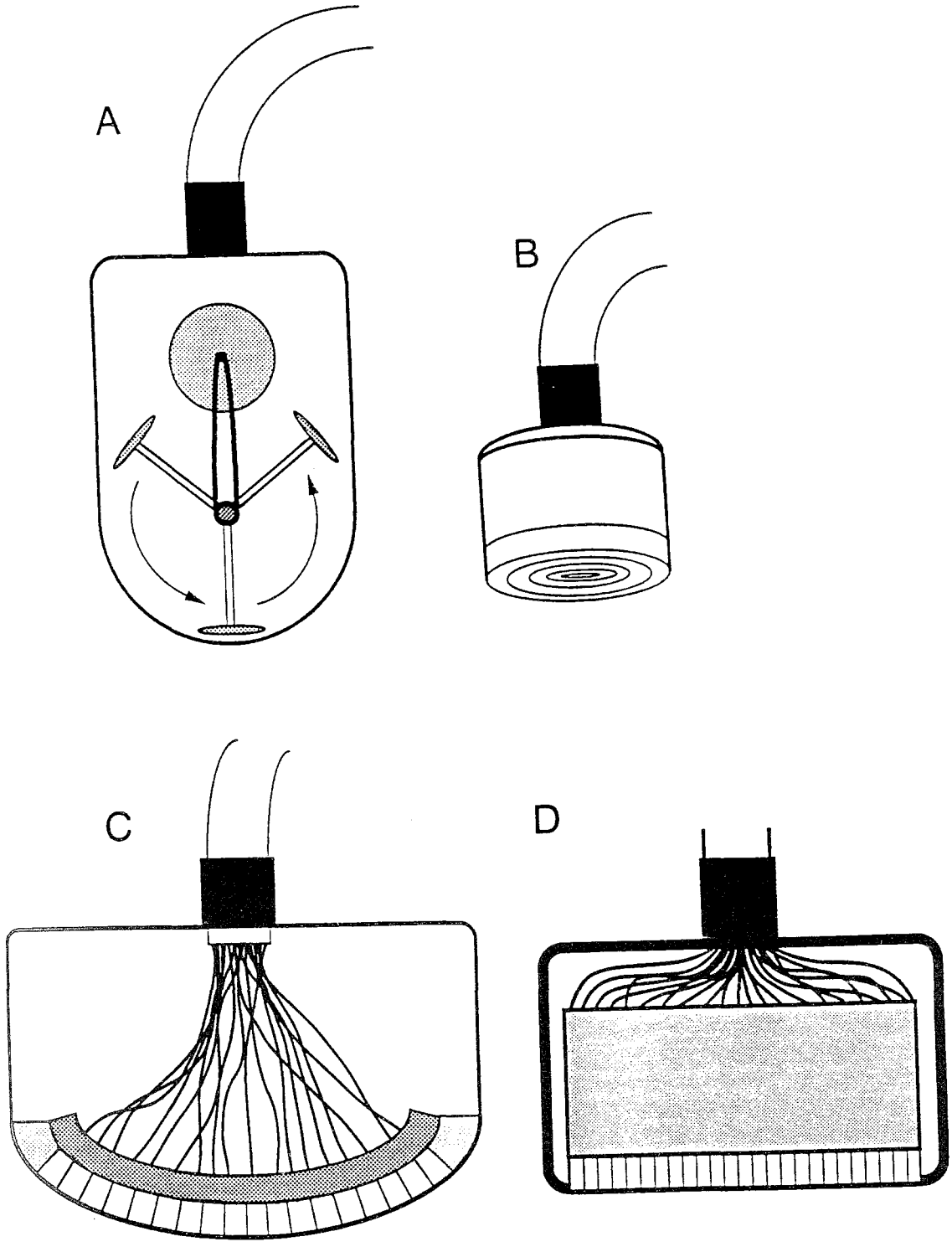


Fig 2.10 A. sector scanning transducer, B. annular array transducer, C. radial array transducer, D. linear array transducer [5]

sequentially along the length of the beam. Frequency of the transducer and Q factor determine axial resolution. A higher-frequency transducer will provide greater axial resolution. Since Q factor of the transducer is determined by the manufacturer, selection of transducer frequency is the

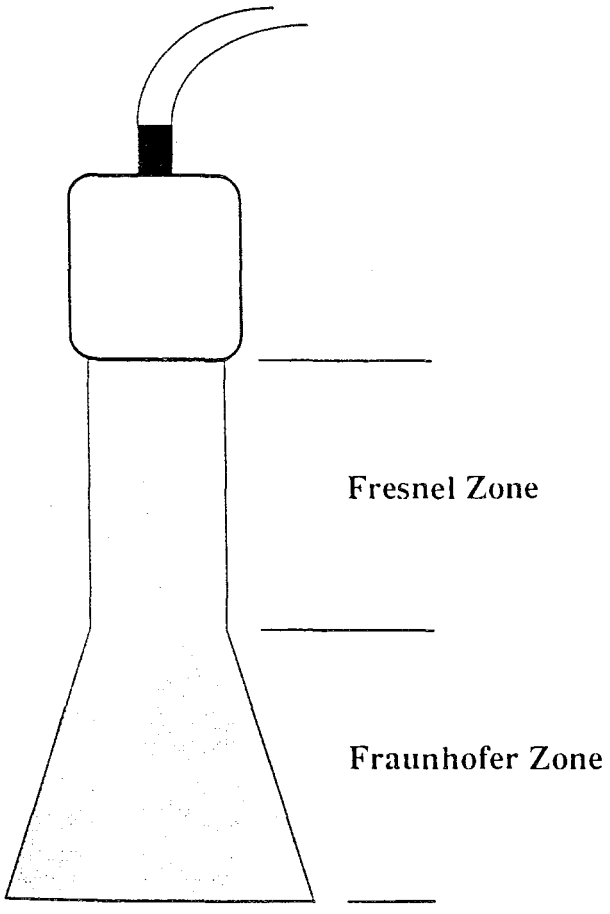


Fig. 2.11 Fresnel and Fraunhofer zones a sound beam. [5]

only control the examiner has over axial resolution.

Horizontal resolution is the ability to distinguish two objects as separate when they are located side by side at the same distance from in horizontal resolution. Factors determining beam width relate to focusing of the ultrasound beam, principally whether imaging is performed in the Fresnel or Fraunhofer zones. The examiner has little control over beam width, and therefore horizontal resolution, because it is largely a function of transducer desing. Therefore, careful attention should be paid to transducer specifications when an ultrasound machine is purchased.

Divergence of the sound beam, absorption, and scattering all play a role in attenuation of the ultrasound beam within the body. A sound beam undergoes an exponential decrease in intensity as it passes through tissue. If it is uncorrected, this would result in images that are markedly decreased in diagnostic information with increasing distance from the transducer. Correction for attenuation is made by amplifying echos returning to the transducer using an exponential function based on the

time of flight. This type of correction is called time gain compensation. The examiner may modify the correction function using controls on the ultrasound unit to optimize the information displayed.

III. PHYSICAL BASIS IN ORTHOPAEDIC IMAGING BY THE ULTRASOUND

3.1. Physical Basis of Imaging in Orthopaedics

The origin of the ultrasound is based on differences between impedances. This is the reason of the different wave speeds in the neighbour medias. Only one per cent difference of the wave speed gives a realizable reflection. Tissues, in which the ultrasound wave speeds and the acoustical behaviours are same, are not discriminateable. They are acoustical homogenous tissues [6].

The reasons for the signals changes are different physical phenomen in the boundaries (like reflection, refraction, bending, absorption, scattering). Differentation is very difficult for the small areas, which are between anatomical boundries. The interpretation of a single image point is not possible. Here are some of the physical legalities, which are important in the development an ultrasonographic image [7].

Reflection: The velocity of the wave varies on the boundries of two different media. One part of the ultrasound wave energy, which will be used as an information will be backscattered.

Refraction: Because of the acoustical differences, the ultrasound waves are refracting, when they pass from one media to other. The refraction of the ultrasound waves can be calculated from their expansion speed.

Bending: The ultrasound waves scatter in a level in the hemogenous medium. But, if there is an obstacle in the medium, the ultrasound waves will be bended. The bending effect depends on wavelength and frequency. The increasement in the frequency causes less bending effect.

Scattering: All the surface of the boundries are much or less rough and this cause to scatter the ultrasound waves. It is obvious to have the scattering effect on all boundries because there are not any physical surface which is exactly smooth. This cause to loss of the energy that

ultrasound waves have. This effect depents on frequency. Increasement in the frequency means increasement in scattering effect.

Absorption: By the entering of the ultrasound waves in to the tissue, some part of their energy will be absorbed and converted to heat. It is necessary to obtain the ultrasound reflections from the deep tissue layers by a depth compansation controller and running time dependent amplifier for having a symetrical image from the whole penetration depth. So, by this method the loss of the energy will be compensated. And it gives an uniform image too.

Amplification of the ultrasound: Ultrasound waves are not absorbed and reflected by the liquids. Because of this, the energy loss is very less in these sections. So, they can be compared with the neighbouring regions. This brings the concept of amplification. The ultrasound amplification is a characteristic concept for cyst and inflamations.

The Depth compensation: The echoes which come from the deep body layers must be amplified in order to have same intensity with the echoes which are reflected from surface. And also the image should be homogenous. Proportionally, this is only possible to lift up echous which reflected from deep tissue layers.

Focusing: The ultrasound waves can be focused through a certain zone by so-called 'acoustic lens'. The best image can be obtained when a structure lies at the end of the near-field of the ultrasound focus axis.

The summation of many physical features like above, leads to develop the image point.

3.2. Artifacts in Orthopaedic Ultrasound Imaging

All imaging modalities are subjects to artifacts that are unique to that system. In radiography systems, artifacts degrade images and reduce their diagnostic value. Sonographic imaging differs in that some artifacts may facilitate making the corret diagnosis. Artifacts in ultrasound can be

categorized in three ways. There are the good, the bad, and the ugly. Therefore, it is especially important to be aware of the various types of artifacts and the circumstances in which they may be encountered.

3.2.1. The Good Artifacts

Shadowing

At highly reflective interfaces almost all of the energy of a sound beam incident on that interface will be reflected. A minimal amount of energy will pass deep to this is a signal void deep to the hyperreflective object. On sonographic images this signal void appears similar to the shadow cast by a building on a sunny day.

In clinical imaging, shadowing is seen at interfaces of materials that differ significantly in acoustic impedance. Classic examples of materials that produce shadowing in vivo are bone, air, calcifications, and biliar and renal calculi. "Dirty shadowing" is a characteristic exhibited by gas within the soft tissues.

Refractile shadowing or critical angle shadowing is observed when objects with highly curved surfaces, such as the diaphysis of a long bone, are imaged. However, the interface need not be as highly reflective as a soft tissue-bone interface.

Due to both refraction and refraction, essentially none of the incident sound beam returns to the transducer from that region. The results is an acoustic shadow [5].

Enhanced Through-Transmission

The intensity of echos returring to the transducer decreases exponentially with increasing depth in the tissues being examined. Superficial echos may be 10^6 times greater in amplitude than those from the deeper tissues [5]. If the discrepancy is uncorrected, the result would

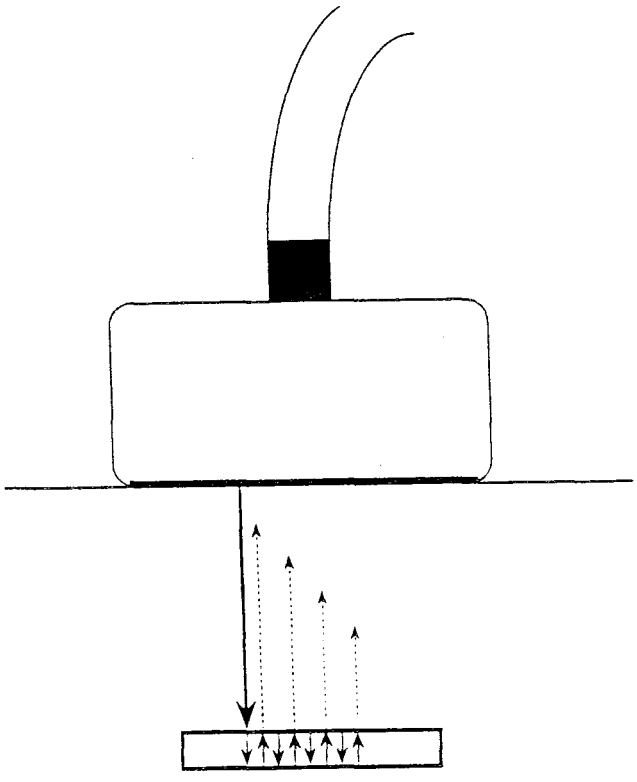


Fig. 3.1 Schematic representation of reverberation in a comet- tail artifact [5].

be a rapid decline in image definition with increasing depth. Time gain compensation is the primary means of correction for this in the image to be displayed.

When a structure that does not attenuate the sound beam as much as surrounding tissues is encountered, more sound is available to image the structures at deeper levels. Therefore, echos returning to the transducer have greater amplitude. These echos are further amplified by the time gain compensation. The result is a false impression of increased echogenity of the deeper structures. Enhanced through-transmission is most commonly seen deep to anechoic structures, usually simple fluid.

Comet Tail Artifact

Metal and glass will produce characteristic bands of increased echogenicity deep to the object. These bands cross tissue boundaries, including those tissues that produce shadowing. The intensity of these ec hogenic bands decreases with distance from the object, giving the appearance of the tail of a comet [5].

This artifact has been shown to be the result of reverberation occurring within the metallic or glass object. Figure 3.1 demonstrates diagrammatically how the sound beam is repeatedly reflected between

the highly refrective anterior and posterior surfaces of the object. The periodicity of the bands within the comet tail is equal to the thickness of the object [8].

3.2.2. The Bad Artifacts

Refraction

Artifact results from refraction is the depiction of real structures in a false location. Refraction occurs at interfaces between substances that transmit sound at different velocities, such as fat (1.450 m/sec) and muscle (1.585 m/sec) [5]. The sound beam is "bent" at these interfaces in proportion to the difference in velocity of sound transmission within the two materials and the angle of incidence of the sound beam. Bending of the sound beam results in the depiction of structures deep to the interface in an incorrect location (Fig. 3.2). Since we cannot control the speed of sound in various tissues, refraction artifact must be minimized by having the angle of incidence as close to 90 degrees as possible. The example in Figure 3.2 demonstrates schematically what can occur when one is

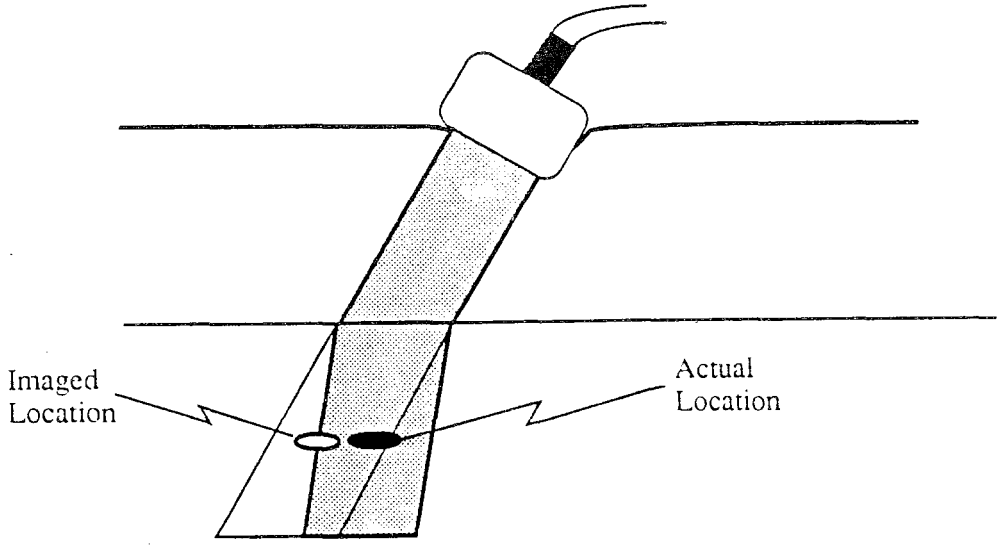


Fig.3.2. Refraction artifact resulting in a real lesion depicted in an incorrect location. [5]

scanning obliquely. A lesion is identified but depicted in an incorrect location.

Anisotropic Reflectors

An anisotropic substance is one that displays different properties depending on the direction of measurement. Musculoskeletal ultrasound involves imaging of strongly anisotropic reflectors, such as tendons. Muscle demonstrates anisotropy, but it is much less pronounced than tendon [5].

Examination of tendons should always be performed with the sound beam perpendicular to their surface during real-time examination, this is not as difficult as it may appear.

Speed of Sound Artifact

Ultrasound equipment determines the distance of an object from the trasducer by measuring the time elapsed between the origination of the sound pulse and its return to the trasducer. This is referred to as the time of flight. In calculatign distance, the machine assumes a constant speed of sound. Although the speed of sound within human tissues does not vary greatly, it may still produce a significant artifact.

This type of artifact may also be encountered at muscle-fat interfaces in the extremities of obese patients [5].

Beam Width Artifact

An ultrasound beam has a width that varies according to the design characteristics of the transducer. Therefore, like other cross-sectional imaging modelities, ultrasound images a volume of tissue. When an object is smaller than the width of the ultrasound beam, echos depicted at that location are a combination of those from the object and the surrounding tissues. This volume averaging, as it is called in computed tomography and magnetic resonance imaging (MRI), can give the appearance of echos within simple cysts, as well as eliminating shadowing deep to small calcifications. Normally, this does not interfere with the diagnosis. However, in musculoskeletal ultrasound, we are often dealing with very small structures, so this artifact is seen much more frequently than in abdominal imaging. The examiner must always remember that a highly echogenic focus may be a calcification despite the lack of acoustic shadowing [5].

3.3.3. The Ugly Artifacts

Motion Artifact

Patients motion can regrade ultrasound images as weel as radiographs. The displayed image on an ultrasound machine is an average of several data acquisitions. When movement occurs, the image is blurred, sometimes severely limiting the diagnostic value. State of the art machines provide cine loop functions that can help in some cases. On other machines, the degree of persistence (i.e. the number of acquistions averaged) can be reduced [5].

Electrical Noise

Ultrasound machines are generally well insulated from electronic noise. However, some circumstances may arise where electromagnetic interference from high-voltage transformers or other equipment degrades images.

Frame Buffer Drop Out

All modern ultrasound machines use digital image processing. The displayed image is stored in a matrix of computer memory. When a memory chip fails, a number of pixels that compose the image will be missing.

IV - INSTRUMENTATION AND METHODS

4.1. Practical Considerations

The physical characteristics of ultrasound is described in the previous chapters. It must be pointed out that sonography of the musculoskeletal system can easily be accomplished with standard equipment that is commonly available in any department of radiology. This equipment usually includes a set of linear transducers of high frequency in the 5, 7.5, and 10 MHz range for the evaluation of relatively superficial structures. The use of a stand-off pad is also recommended because some important anatomy, such as tendons and subcutaneous fat planes, are situated immediately under the skin.

The examination is well tolerated by the patient because it is quick and requires no preparation.

Because of technical limitations due to a small field of view, the exploration must be restricted to a limited anatomic area. A whole extremity cannot be explored satisfactorily. It is necessary to rely on clinical findings and plain films of the extremity to decide on the area of interest to be examined. Clinical conditions of the extremities that may benefit by being studied with ultrsonograph include soft tissue masses, localized pain, and swollen joint.

The standard protocol for musculoskeletal ultrasonograph includes a bilateral study of the extremities for purposes of comparison with the normal side or of differential features between the two sides. Longitudinal and transverse scanning of the area is performed. A complementary dynamic study is performed when dealing with muscles and tendons.

Specific artifacts and pitfalls to avoid are treated in detail for each application of the technique. The examination of a given anatomic region can usually be performed within 20 minutes.

4.2. Examination Technique

A 5 and 7.5 MHz linear array transducers are used for the examinations

due to their utilities for both superficial and deep foreign bodies. One of the ultrasound device was from a Japanese company which is called HITACHI and the model was EUB. This device was mainly used because it was located in Orthopaedy and Traumatology Department which has a high orthopaedic patients throughput. The second ultrasound device was from a German company which is called SIEMENS. The model was Sonoline SI-400. This ultrasound device was located in Radiology department of the University. Both have a black and white monitors with a 256 gray tone, 32 transmit and receive channels, and they are capable to work with linear, convex and sector transducers.

Examination of the superficial subcutaneous tissues requires a standoff pad. If a gel pad is unavailable or cannot be used because of a sterile field, a bag of IV fluid with the air removed will serve adequately. This will eliminate near-field artifiacts and help to bring the object into the optimal focal zone of the transducer.

Once the foreign body is identified, its relationship to adjacent structures must be carefully documented. Defining its position relative to neighbouring anatomical landmarks will make the surgeons job much easier. In addition, location of nearby vessels, nerves and synovial membrane must be established allowing the surgeon to select the most desirable approach. These structures have a characteristic sonographic appearance. The distance separating the foreing body and these vital structures can be easily meusared using the postprocessing features available on state of the art ultrasound equipment. Occasionally, foreing bodies can penetrate tendons, facia, or muscle. In these cases real-time sonography can provide a dynamic study, which better defines the structures involved and the location of the foreign body through a range of motion.

4.3 Subject Profile

All the examinations have been performed in the Orthopaedics and Traumatology department and Radiology department of the Istanbul Medical Faculty. Some additional examinations have also been performed in the International Hospital-Istanbul.

The main orthopaedic parts which were examined in different patients were Hip, Shoulder, Lower Extremities, Hand and Wrist, Knee, Elbow and Costa. Total 47 different patients were examined. The list of the patients with their sex, age, examined part and the transducer frequency which are used during the examinations can be found in the Table 4.1

Table 4.1. Patients and Examinations

No	Sex	Age (year)	Part of the Body Examined	Transducer's Frequency [MHz]
1	M	26	Lower extr. (Ankle)	5 and 7.5
2	M	63	Lower extr. (Femur)	7.5
3	F	4.5 months	Lower extr. (Tibia)	5 and 7.5
4	F	10	Lower extr. (Ankle)	7.5
5	F	36	Le. (Achille tendon)	7.5
6	M	17	Lower extr.(Femur)	5
7	M	13	Lower extr. (Tibia)	5 and 7.5
8	F	10	Lower extr. (Tibia)	5 and 7.5
9	F	22	Lower extr. (Tibia)	5 and 7.5
10	M	26	Shoulder	7.5
11	F	73	Shoulder	5
12	F	46	Shoulder	5
13	M	47	Shoulder	5
14	F	60	Shoulder	5
15	F	55	Shoulder	5
16	M	50	Shoulder	5
17	M	31	Shoulder	5
18	F	61	Shoulder	5
19	M	39	Shoulder	5
20	F	21	Wrist	7.5
21	F	17	Wrist	7.5
22	M	31	Hand	7.5
23	M	14	Elbow	7.5
24	F	8	Hip	5
25	F	8	Hip	5
26	M	2.5	Hip	5
27	M	5	Hip	5
28	M	10	Hip	5 and 7.5
29	F	7	Hip	5
30	M	1	Hip	5
31	M	5	Hip	5
32	F	6	Hip	5
33	F	11	Hip	5
34	F	7	Hip	5
35	F	3months	Hip	5
36	M	1 months	Hip	5
37	M	10 months	Hip	5
38	F	3months	Hip	5 and 7.5
39	F	10 months	Hip	5
40	F	6months	Hip	5
41	F	6months	Hip	5
42	F	4months	Hip	5
43	M	17	Hip	5
44	F	6	Knee (Baker Cyste)	5 and 7.5
45	F	30	Knee	5 and 7.5
46	M	58	Knee	5
47	F	29	Costa	5 and 7.5

According to the number of patients, sex, age and parts of the body examined; there are some graphical illustrations below showing number of patients and their sex groups and parts of the body examined. (Fig. 4.1 and 4.2):

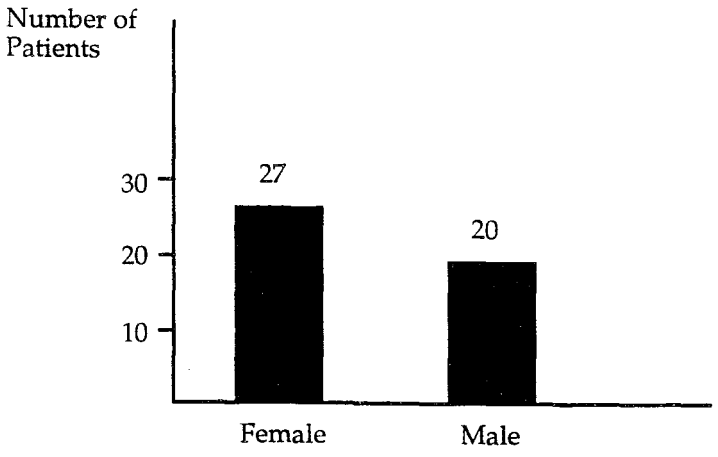


Fig.4. 1. Distribution of patients according to the sex groups

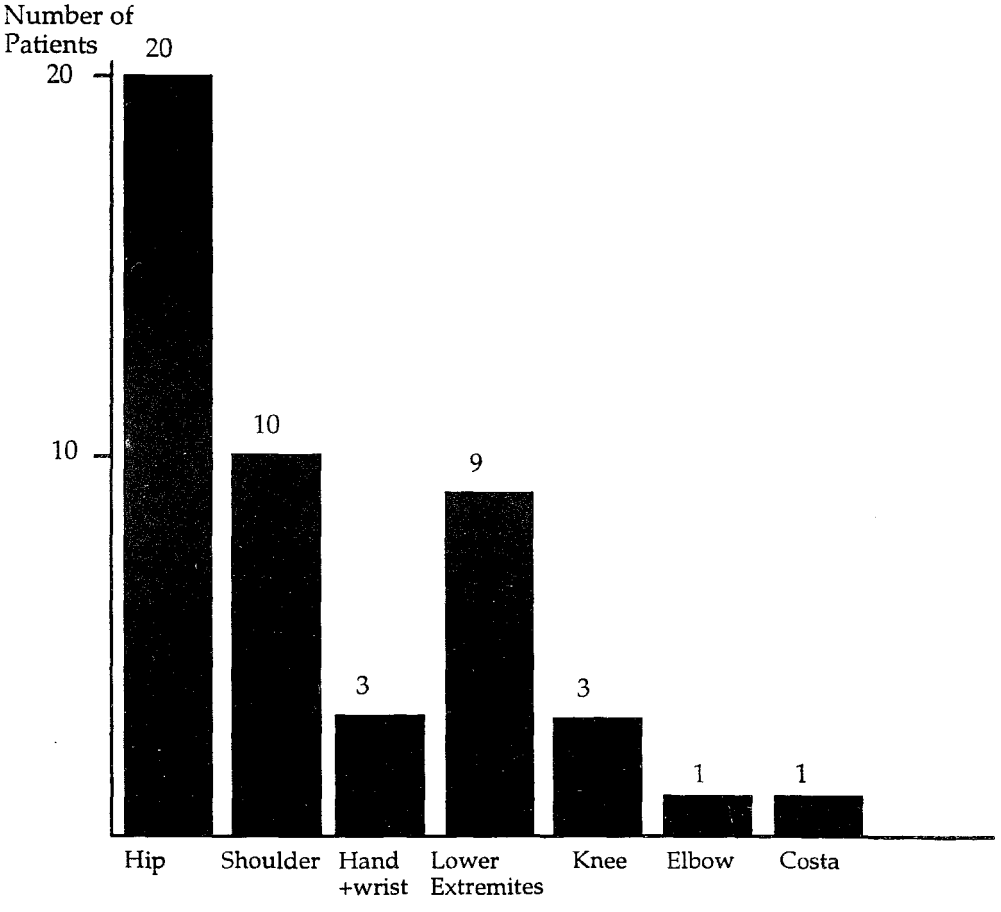


Fig. 4.2 Distribution of patients according to the part of the body examined.

V. EXPERIMENTAL RESULTS AND DISCUSSION

5.1. Introduction

Sonography's unique real-time capability, which permits examination during movement and allows guidance of biopsy needles, combined with the exquisite resolution of state-of-the-art high-frequency transducers and advances in color Doppler imaging makes sonography a powerful tool, in expert hands, for diagnosing abnormalities of the soft tissues, from the surface of the skin to the surface of the bones.

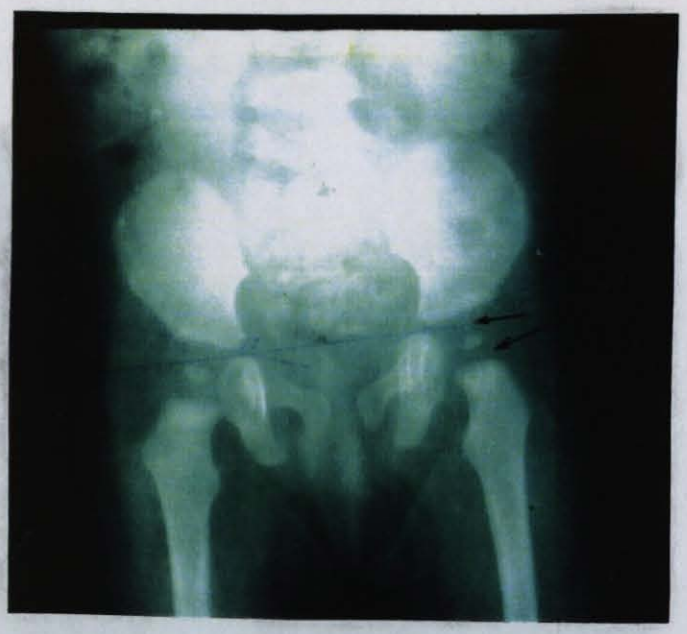
In the thesis work specific anatomic segments of the extremities like knee, hip, shoulder, lower extremities, hand and wrist, elbow and costa are covered. In the following part of this section the experimental results of each of these musculoskleletal anatomic segments can be found.

5.2. Experimental Results

5.2.1. Hip Examinations

Real-time sonography is presently used in the diagnosis and management of developmental dislocation and/or dysplasia of the hip in infants. Sonography offers several advantages over other imaging techniques, particularly in the first 6 months of life, when the femoral head and acetabulum are compased mainly of cartilage [9]. On sonograms, one is able to distinguish the cartilaginous components of the acetabulum and the femoral head from the other soft-tissue structures. This is not possible with conventional radiographs, which show only the bony parts of the pelvis and the femur. Realtime sonography also permits a multiplanar evaluation, which clearly determines femoral head position with respect to

a)



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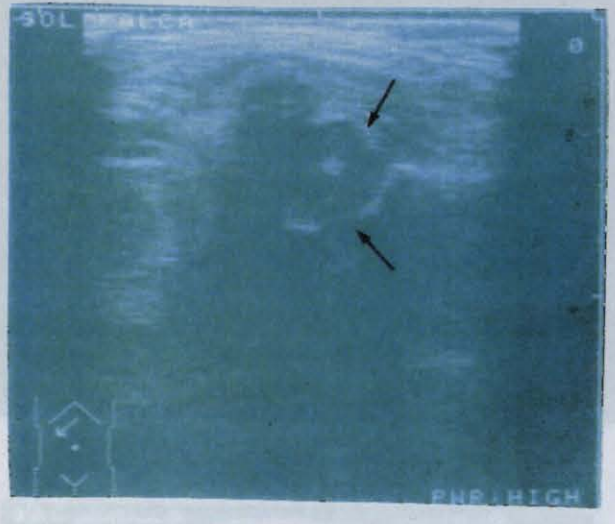

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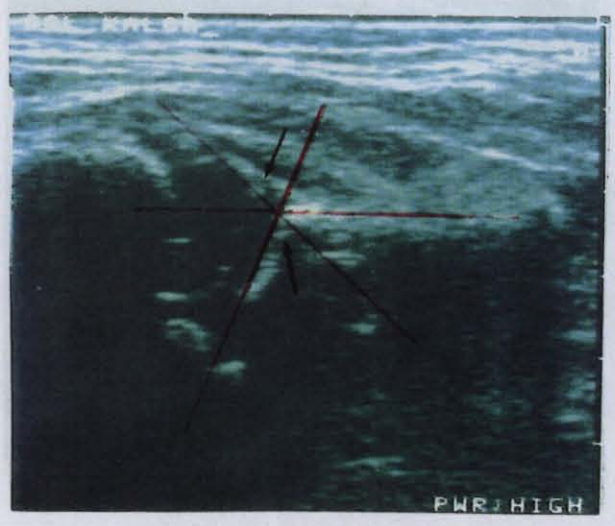


Fig 5.1 a) An X-Ray film (A-P neutral) and b, c) ultrasound images from two different positions (b: axial, c: longitudinal) of a 3 months old patients with congenital hip dysplasia. 5.0 MHz linear transducer is used in ultrasound examination.

a)

b)

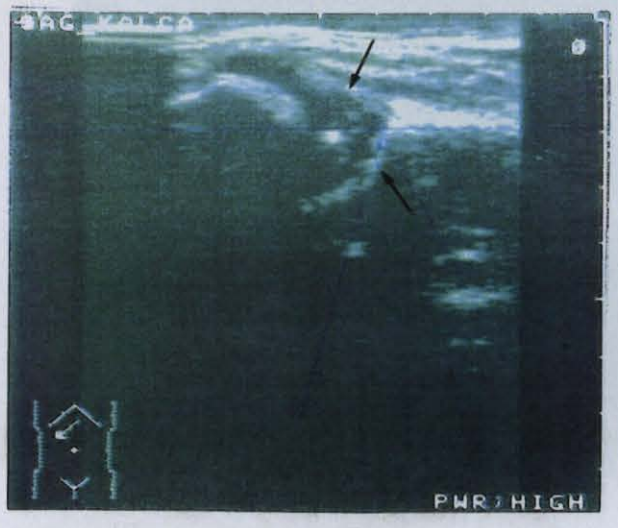
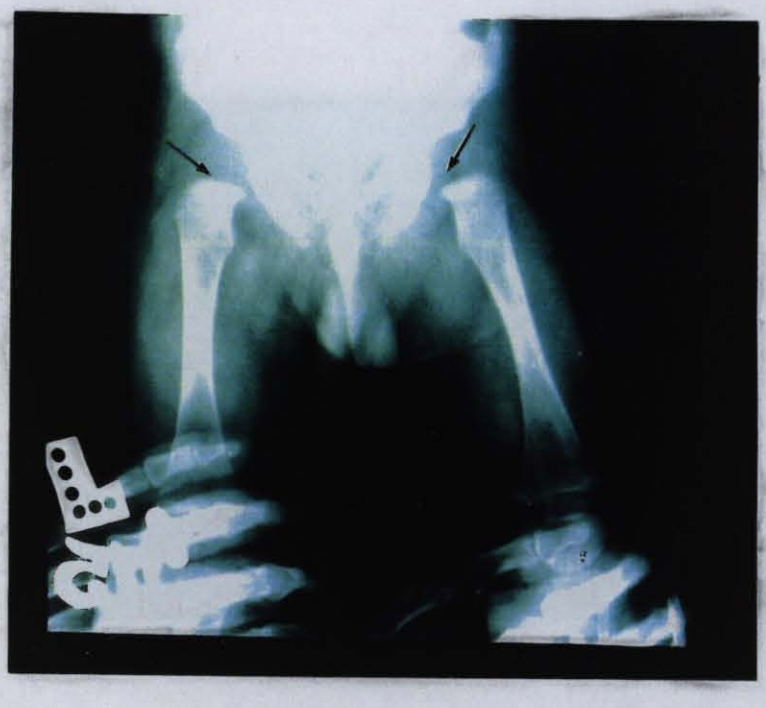


Fig 5.2. a) An X-Ray film (A-P Neutral) and b) ultrasound image of a congenital hip dysplasia. Ultrasound examination is done by a 5.0 MHz linear transducer. The patient is 10 months old.

a)



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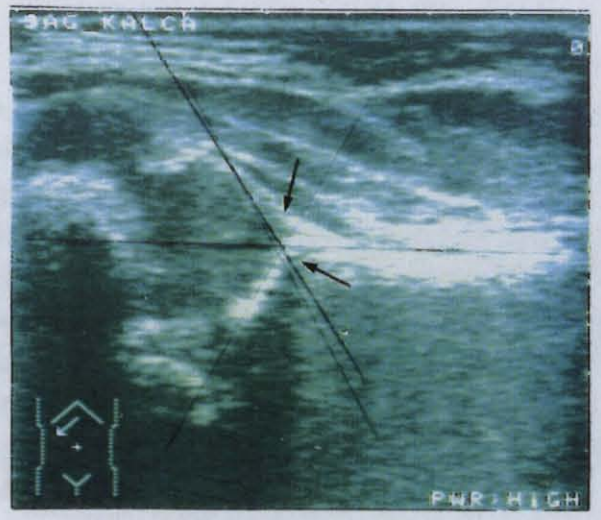


Fig. 5.3 One monthold patient with congenital hip dysplasia. a) X-Ray film, b) Ultrasound image of the patient. 5.0 MHz linear transducer is used.

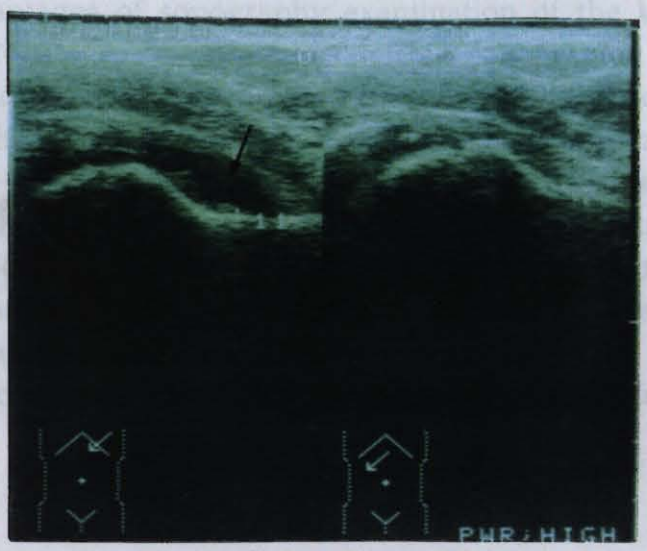


Fig. 5.4 A 17 years patients with an effusion on the left hip; septic arthritis. 5.0 MHz linear transducer is used.

the acetabulum (Figure 5.1). Hence, another limitation of the routine radiography, the compression of three dimensions into two, is eliminated. The ability to observe changes in hip position during movement is a further advantage of sonography (Figure 5.2 and Figure 5.3). Finally, by its ability to replace most radiographic studies, ultrasound evaluation can reduce the radiation exposure of the young infant. It is therefore easy to understand the wide acceptance of hip sonography throughout the world.

In older children, hip sonography is performed for a different purpose, the detection of joint effusion (Figure 5.4). Hip pain is a common presenting symptom in pediatric patients and can reflect a number of conditions, including those in which radiographic findings are absent or subtle early their cource. The presence of fluid in the hip joint is an important finding that may lead to diagnostic aspiration.

5.2.2 Knee Examinations

The advantages of sonography examination of the knee parallel the broader advantages of musculoskleletal sonography; the modality's dynamic and interactive nature and its ability to be performed in a rapid and cost-effective manner. In addition, the noninvasive nature of sonography avoids complications associated with arthroscopy. In general, in the evaluation of musculoskeletal pathology, radiographs of the symptomatic area are obtained first. Sonography is the imaging modality of choice for musculotendinous lesions, ligamentous tears (especially of the collateral ligaments), popliteal masses (Figure 5.5), swelling (Figure 5.6) localized knee pain, and evaluation of the synovium and bursae [12].

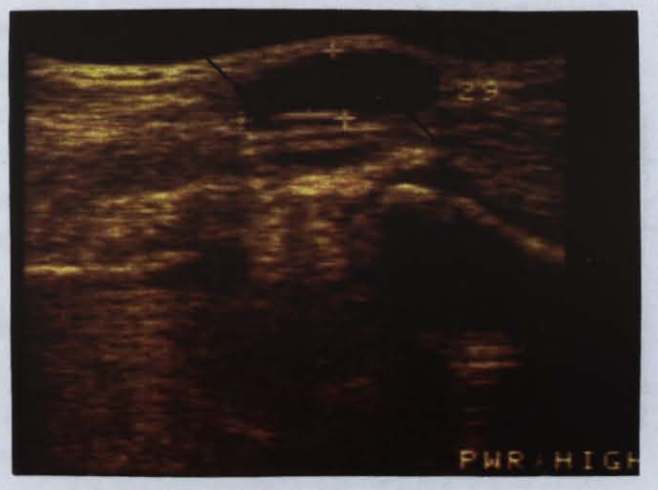


Fig. 5.5. Six years old patient with a Baker cyste in the popliteal region at the posterior part of the left knee. The examination is done by a 5.0 MHz linear transducer.

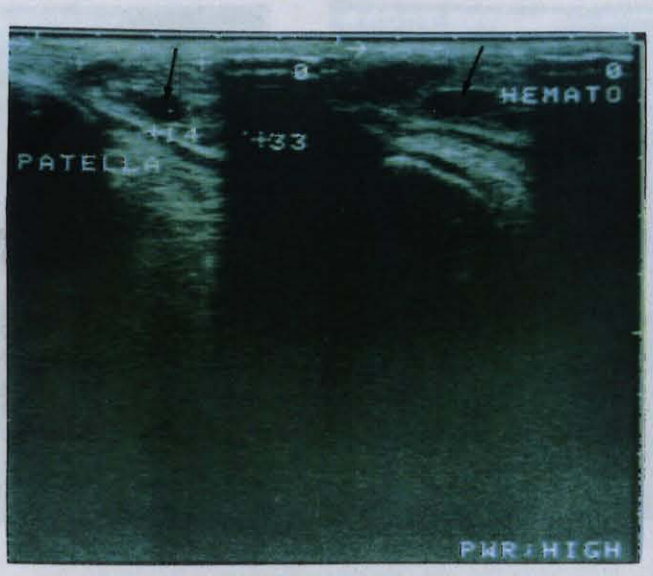


Figure 5.6 30 years patient with a chronic hematoma on the anterior part of the knee after a trauma. With the ultrasound examination an organized hematoma is imaged on the suprapatellar region (anterior part of the quadriceps tendons). 7.5 MHz linear transducer is used.

5.2.3 Shoulder Examinations

Shoulder pain and weakness on elevation of the arm are common clinical problems. In patients over 40 years of age, rotator cuff disease is a frequent etiology. Older and disused rotator cuffs and those of smokers fail more easily than other. In contrast, in healthy subjects under the age of 40, a major injury is required to disrupt the tendons of the rotator cuff, and the bone of the greater tuberosity may fracture before the cuff tears [13].

Contrast arthrography has served for many years as the primary radiologic examination used to investigate the integrity of the rotator cuff tendons. Although this technique is accurate for the diagnosis of full-thickness rotator cuff tears, it is less helpful in assessing the size of tears and in detecting partial-thickness tears [13]. Magnetic resonance imaging (MRI) has also gained wide acceptance as a technique for evaluation of the rotator cuff. This technique is accurate in the diagnosis of full-thickness tears, but recent reports have questioned whether MRI can reliably distinguish full- or partial-thickness cuff tears from degeneration of the cuff [12].

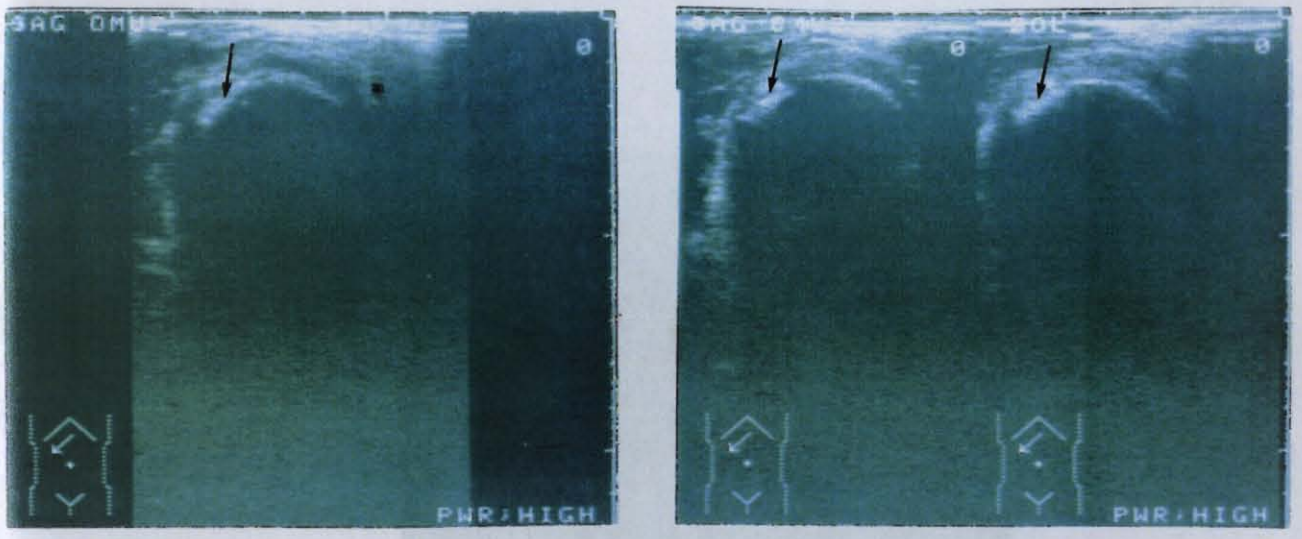


Fig. 5.7 31 years old patient with a calcified tendinities on the insertion of the supraspinatous tendon of the right shoulder. 5.0 MHz linear transducer is used.

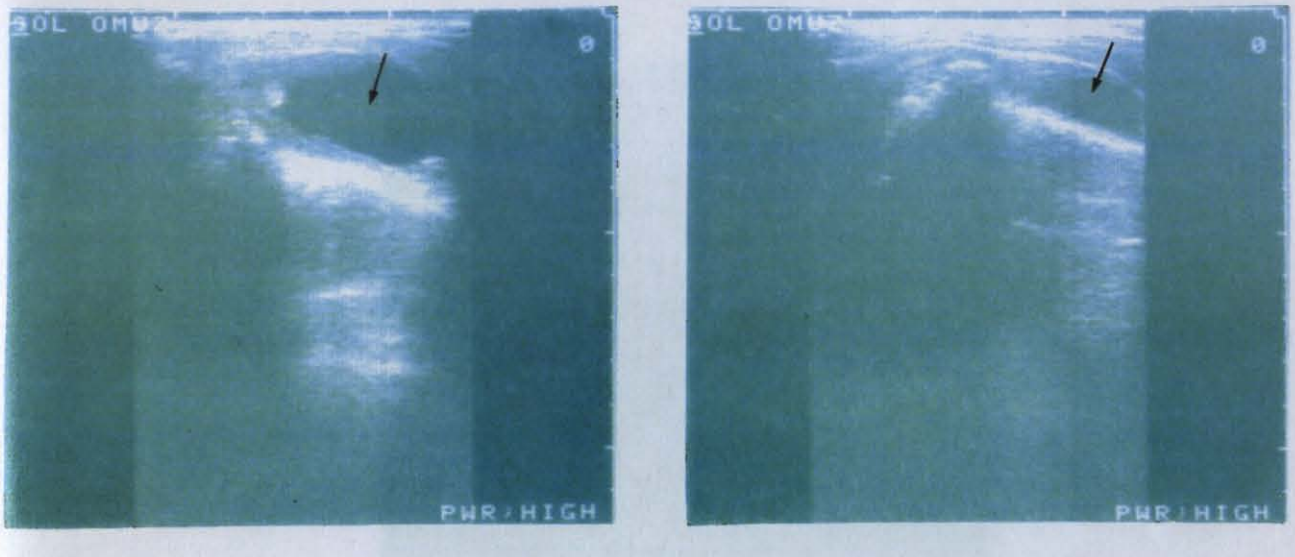


Fig. 5.8. 39 years old patient. Purpure and hematoma on the left supraspinatous muscle. The examination is done by a 5.0 MHz linear transducer

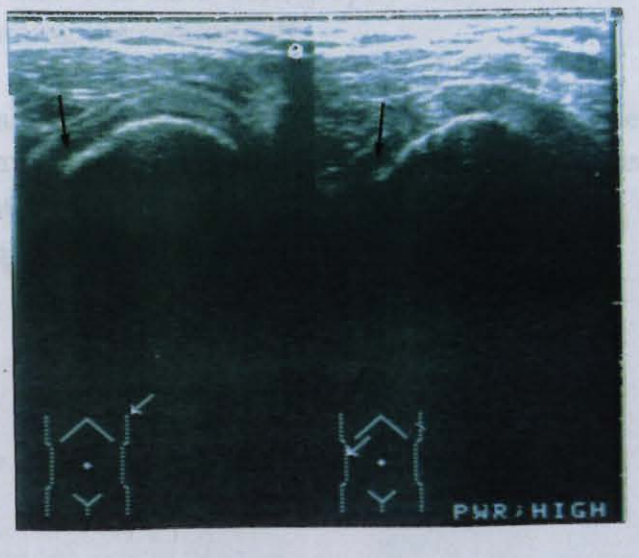


Fig. 5.9 Effusion on the subacramial Bursa. The patient is female and 50 years old. The examination is done by a 7.5 MHz linear transducer.

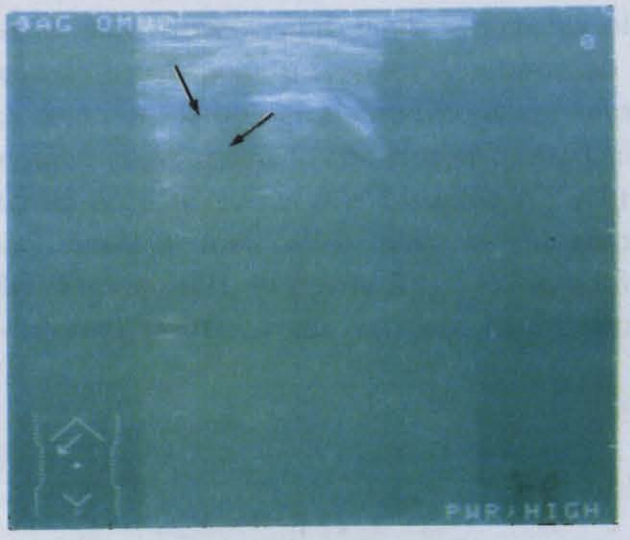


Fig. 5.10. 60 years old female patient with a complete rupture of the left supraspiratous,5.0 MHz linear transducer is used.

In 1983 the first technique of examination of the cuff tendons using real-time mechanical sector scanners has been described [9]. A number of more recent reports using high-resolution linear-array transducers have demonstrated that real-time sonography may serve as an alternative means of examining the rotator cuff.

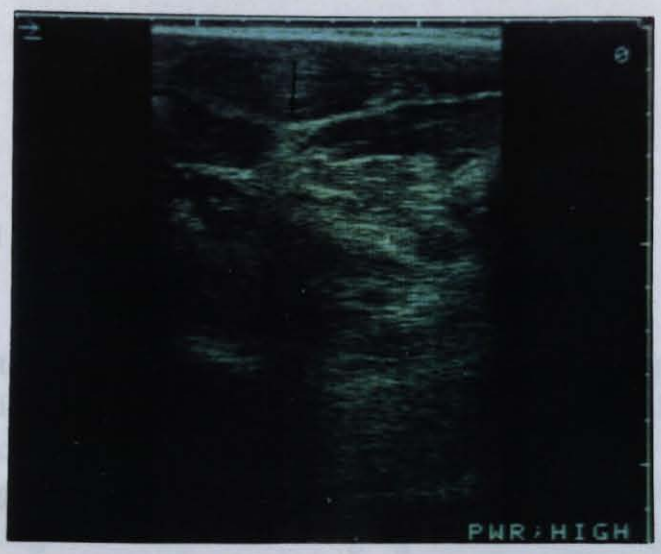
Figure 5.7 shows a patient with a calcified tendinities on the right shoulder. Examples of hematoma and effusion are imaged in Figure 5.8 and 5.9. Ultrasonography is an ultimate way to show rupture of the rotator cuff (Figure 5.10).

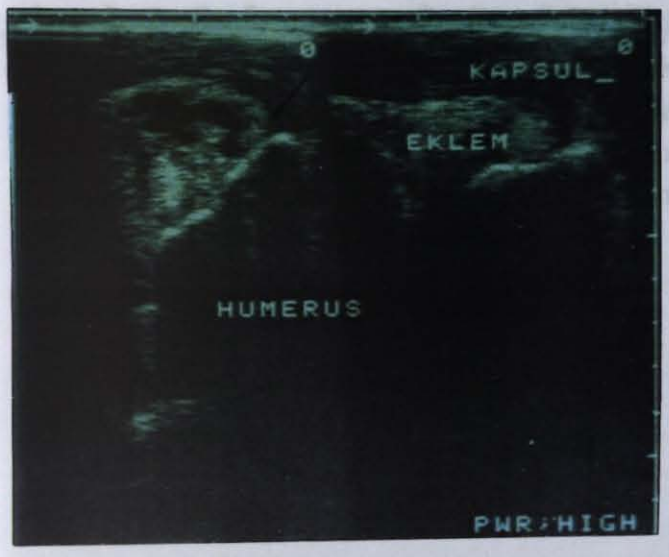
5.2.4. Elbow Examination

The elbow is a large synovial hinge joint that allows the proximal radius and ulna to articulate with the distal humerus. In proximity is the radioulnar joint, which enables pronation and supination of the hand. The proximal radius and ulna are attached by the annular ligament of the radius. The elbow and radioulnar joints share a common fibrous capsule and synovial cavity [9].

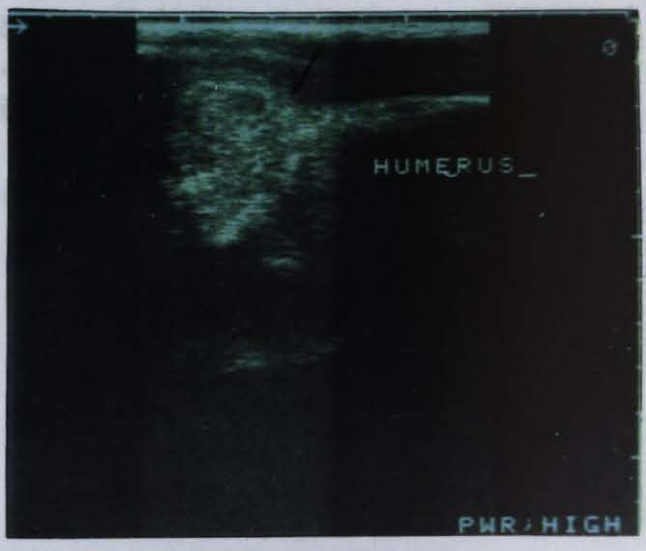
The soft tissues and fibrous and bony structures of the elbow are readily delineated by sonography. A standardized approach and familiarity with common pathological conditions are helpful for complete evaluation. Frequent comparison to the patient's opposite, normal elbow or an age-matched normal elbow aids in detecting subtle abnormalities [12]. By the way, another, method to diagnose the elbow dislocation is ultrasonography (Figure 5.11). In figure 5.11, X-Ray film and ultrasound images from different positions can be seen of an patient with elbow dislocation.

a)





c)



d)

Figure 5.11 14 years old patient with an elbow dislocation. The disintegration of the entirety of the elbow joint can be seen by the ultrasonography (5.0 MHz linear transducer) (a, b, c). The joint capsule is tightened. But no fluid or hematoma can be observed inside. The X-Ray film shows the elbow dislocation, too (d).

5.2.5 Hand and Wrist Examinations

In the past 20 years hand imaging has signigficantly improved. Special x-ray projections, such as dynamic, scaphoid, and carpal tunnel views have been developed; and new techniques, such as arthrography, xeroradiography, sonography, computed tomography (CT), and, ultimately, magnetic resonance imaging (MRI), have been introduced. These procedures are helpful in diagnosing not only bone lesions but also lesions in the soft tissues between the skin and the bone [12]. An advantage of sonography in particular is its ability to visualize fine structures, such as tendons, nerves, and vessels, and to elucidate the nature of any kind of soft-tissue swelling, such as a cyst or synovial enlargement (Figure 5.12).

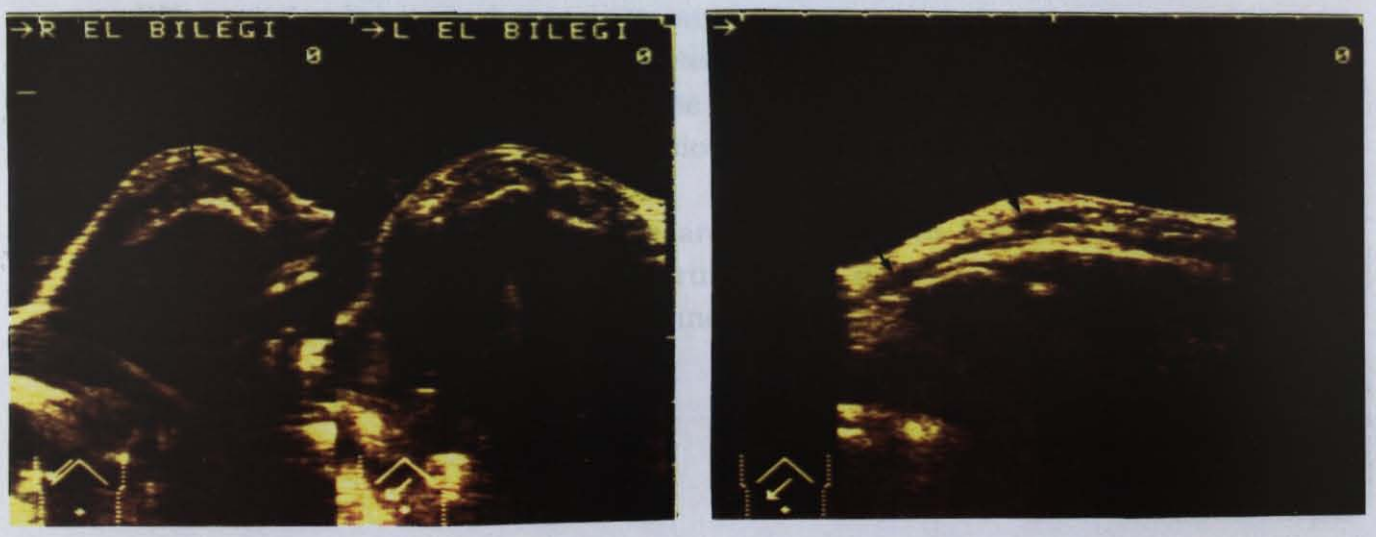


Fig. 5.12 A hyperechogen region between the navicular and lunatum on the right hand of a 17 years old female patient. The diagnosis is Tenosynovitis of Extensor polycus longus. The examination is done by a 7.5 MHz linear transducer.

5.2.6 Lower Extremities Examinations

Sonography can be used as a cost-effective method of evaluated muscle, tendons, ligaments, and synovium of joints and bursae. It is therefore an important adjunct to clinical examination and radiographic evaluation of patients with musculoskeletal disorders of the foot and ankle. The availability of ultrasound equipment throughout the world and its affordable price make this technology very accessible for patients with foot and ankle disease. The dynamic character of ultrasound examination is an additional advantage. Sonography has the potential to become a screening method that allows one to distinguish between significant and trivial soft-tissue injuries, not unlike the way radiography is used to exclude the possibilitiy of fractures.

On Figure 5.13 ultrasonography is used to show the callus formation between the resected tibia parts. Figure 5.14 is an example to show the callus formation, too. Another callus formation in femur is shown in Figure 5.15. These callus formations can not be understood with the X-Ray film easily (Figure 5.14 b). In X-Ray imaging the soft tissue-hard tissue differentiation is not good as in ultrasound.

Cystic lesions on the bones are detectable with ultrasonography, too. Figure 5.16 shows a cystic lesion on the left tibia proximal by X-Ray films and ultrasound images. The cystic lesion is detected with the ultrasound without any radiation.

Ruptures, especially in the ankle are detected with ultrasonography which can be seen in Figure 5.17. A rupture in tibiofibular bond of the right ankle is imaged with a 7.5 MHz linear transducer.

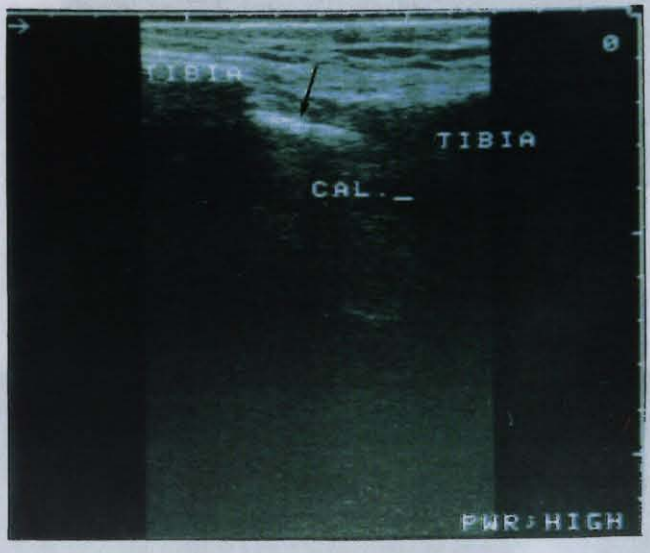
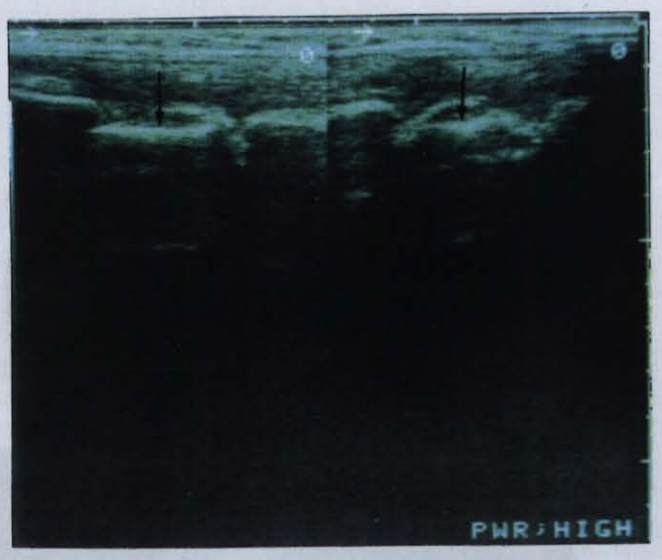


Fig. 5.13 A 22 years old patient with an application of bone extention after polio. As the result of this application the callus formation between the resected tibia parts can be seen by the ultrasound image. 5.0 MHz linear transducer is used.

a)



b)

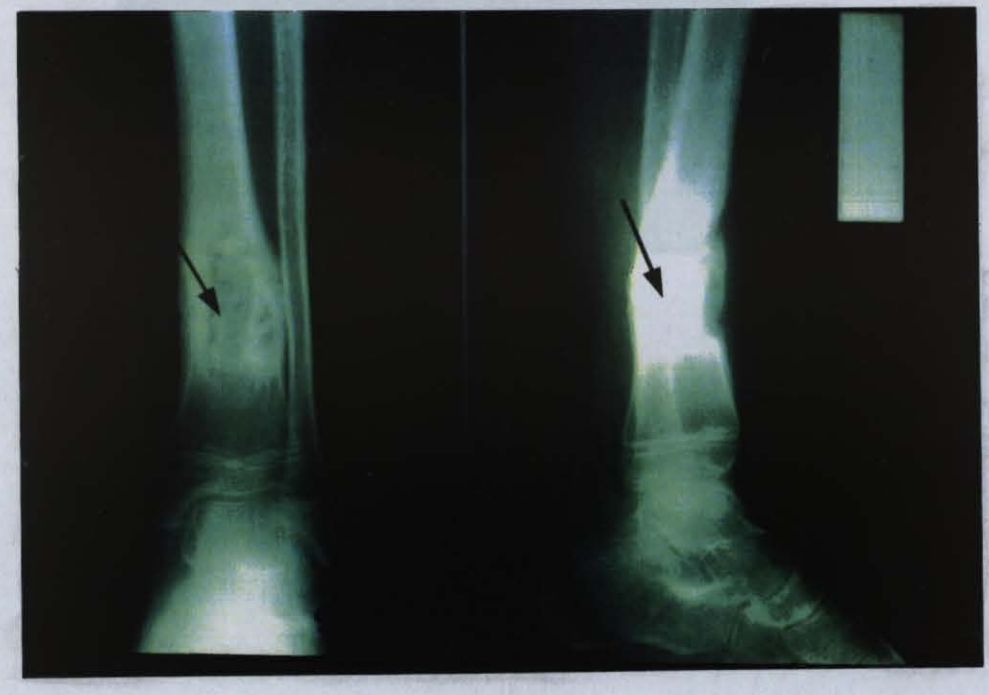


Fig 5.14 A tumor on the distal part of the left tibia. The patient is 14 years old. With a surgical operation the tumor is resected from the tibia. After this tumor resection osseos graft is plated. A new bone formation can be seen around the osseos graft with ultrasonography (a) and X-Ray film (b). No tumor or soft tissue masses are seen. No reaction is observed around, too. 5.0 MHz linear transducer is used.

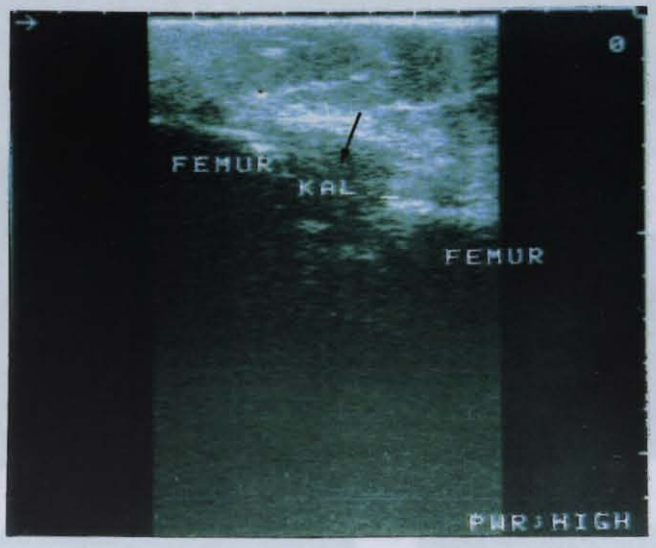


Fig. 5.15. A 14 years old patient with a tumor resection in femur. Ilizoroff application is done. Callus formation is observed by the ultrasonography. 5.0 MHz linear transducer is used.

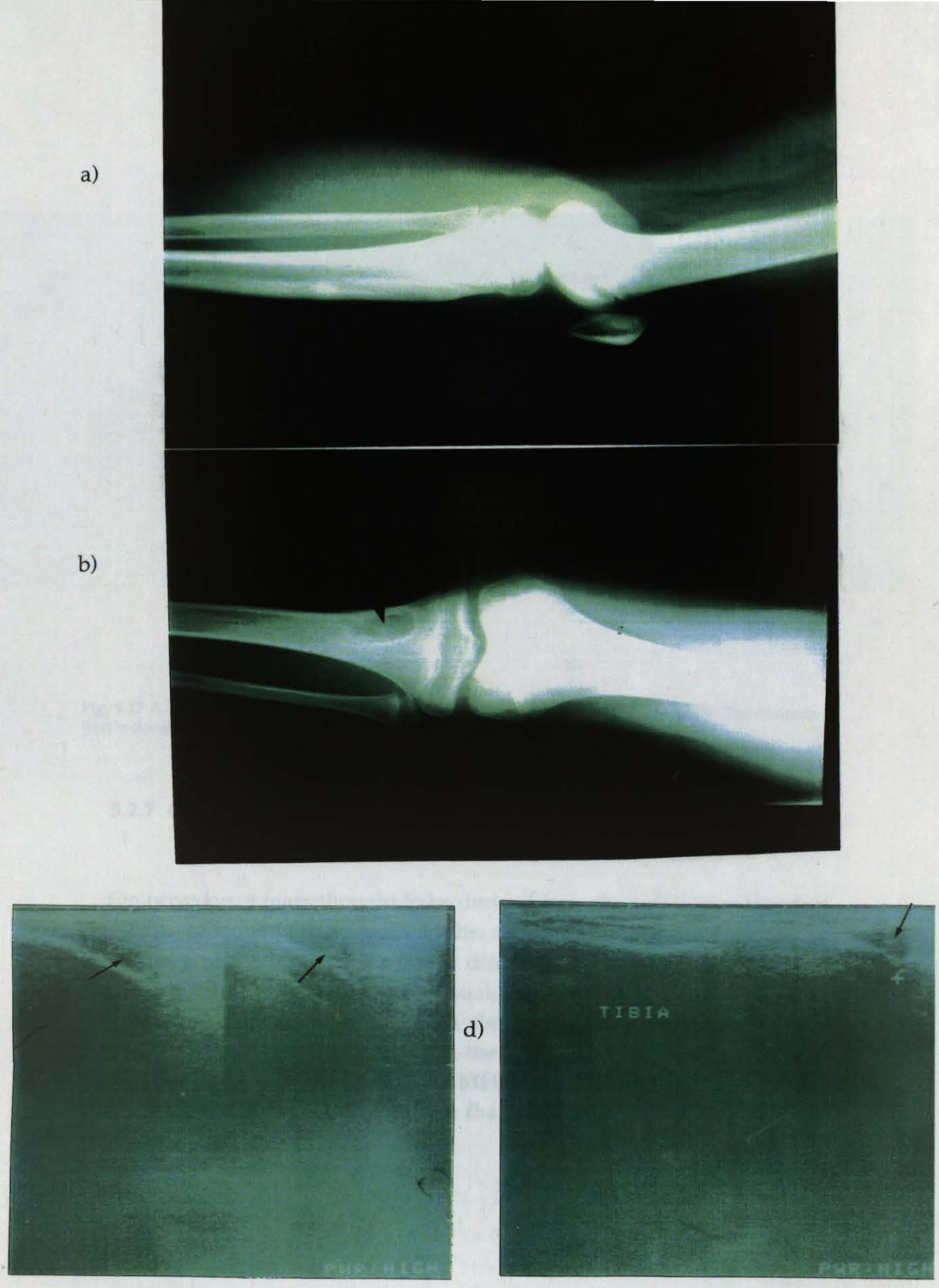


Fig 5.16. A 10 years old patient with a cystic lesion on the left tibia proximal. In the X-ray film it seems like a cyst (a,b). A bone-cortex entirety is seen with the ultrasonography (c, d). There is no soft tissue component accompaniment. Cystic lesion is not seen clearly. Probably diagnosis is a aneurisal bone cyst. The ultrasound examination is done by 5.0 MHz linear transducer.

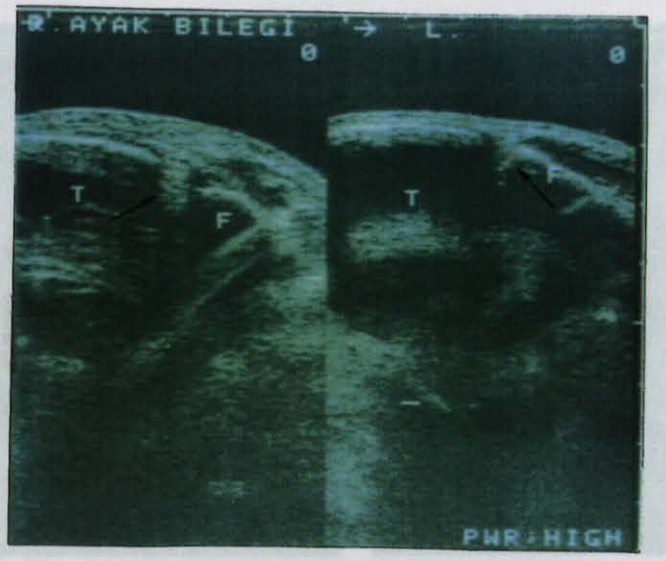


Fig. 5.17 A 10 years old patient with a rupture in tibio-fibular bond of the right ankle. The examination is done by a 7.5 MHz linear transducer

5.2.7 Costa Examinations

On occasion, a mass thought to be derived from the soft tissues is in fact due to an osseous pathology. In adults, any deformity or discontinuity of the surface of the bony cortex that is directly accessible to the ultrasound beam and sufficiently large can be visualized. Figure 5.18 shows a swelling problem on the second costa. With the X-Ray film of the patient this problem was not detected. But, with the ultrasound examinations, which have been done with the 5.0 and 7.5 MHz transducers, it can be observed that the second antero-costa is thicker than the others.

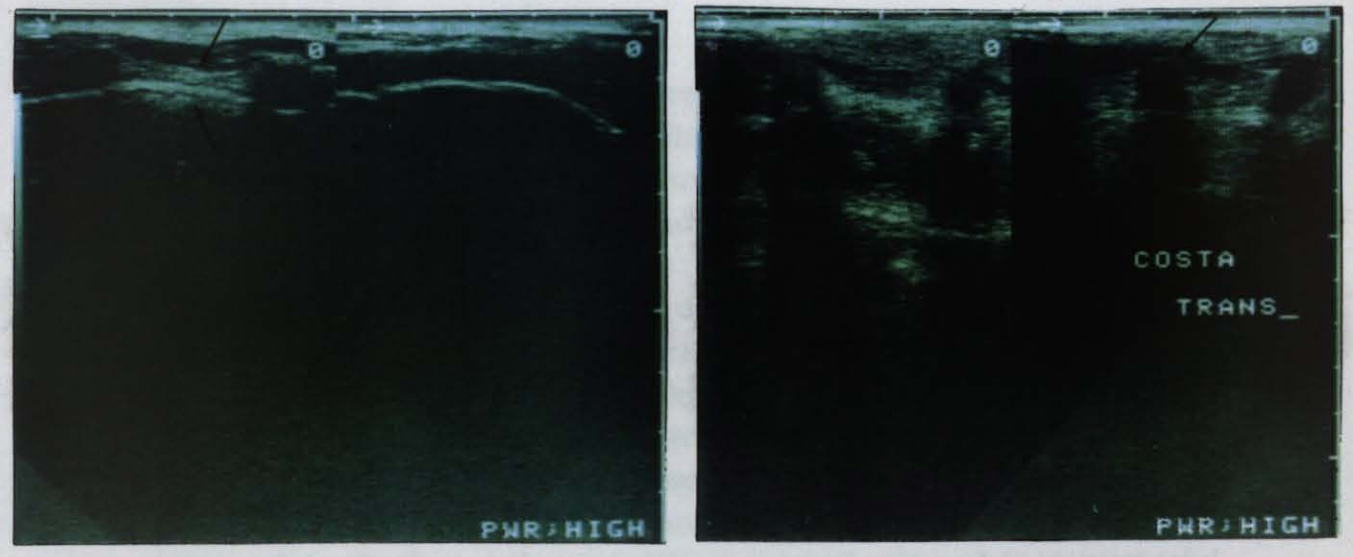


Figure 5.18. A 29 years old female patient with a swelling problem on the second costa. The X-ray is negative. With the ultrasound examination (5.0 MHz and 7.5 MHz linear transducers). It can be observed that the second antero-costa is thicker than the others. Cortex is smooth, no soft tissue masses observed.

5.3 Discussion

Ultrasonography has proved to be useful and efficient in the exploration of musculoskeletal pathology. During the initial investigation of lesions in the extremities, ultrasonography may be utilized as a relatively inexpensive technique following clinical examination and conventional radiographs. Ultrasonography may provide information that determines the need for other more costly investigations such as computed tomography (CT), magnetic resonance (MR) imaging, or more invasive procedures such as arthrography.

The bone-soft tissue interface is highly reflective, seen as a bright line with acoustic shadowing deep to the interface. The inability to image the medullary cavity of bone using pulse-echo ultrasound has led to the misconception that it is not well suited for the evaluation of bone. However, the high reflectivity of cortical bone and the tomographic nature of ultrasound imaging make it ideal for evaluation of bony contours.

Ultrasound offers great deal more than radiography in the detection and localization of foreign bodies. Since the ability to detect an object on sonographic images is primarily a function of the difference between the acoustic impedence of the object and the surrounding tissue objects that are radiolucent or radiopaque can be imaged quide easily.

However it is not practical to use ultrasound in all cases. The algorithm outlined in Figure 5.19 provides a rational cost-effective approach to the diagnosis and localization of foreign bodies. When clinical history indicates that the foreign body is radiolucent, ultrasound is the study of choice. Otherwise low-kilovoltage radiography should be the first step. If radiographs do not provide adequate information, ultrasound is then indicated for further evaluation. When surgical removal is unsuccessful following conventional radiography, real-time ultrasound guidance can be most helpful.

The availability of high-frequency linear-array transducers makes it feasible to image the internal architecture of musculoskeletal structures, permitting greater diagnostic accuracy in areas already explored and opening new areas for ultrasound evaluation. There can be more accurate measurements of cartilage thickness may be obtained, and the progress of healing muscle and tendon ruptures may be addressed.

At present, only a lack of willingness to explore this modalitiy limits its use in diagnosing musculoskeletal disorders. Real-time ultrasound is a dynamic study with interactive capabilities between the patient and the ultrasound examiner. The rapidity of the examination may be a real clinical advantage.

Even with its advantages ultrasonography in musculoskeletal disorders has not achieved broad acceptance by radiologists. Three main reasons may in part explain the limited level of interest in the method. The first relates to the physical limits of the modality, permitting exploration of only a narrow segment of an anatomic area at a time. The second reason is the long learning curve for the operator before he or she becomes proficient with the method. A third reason is that it must compete with the exquisite images produced by MR imaging.

Given these limitations, interest in ultrasonography for musculoskeletal pathology is nonetheless continuing to develop.

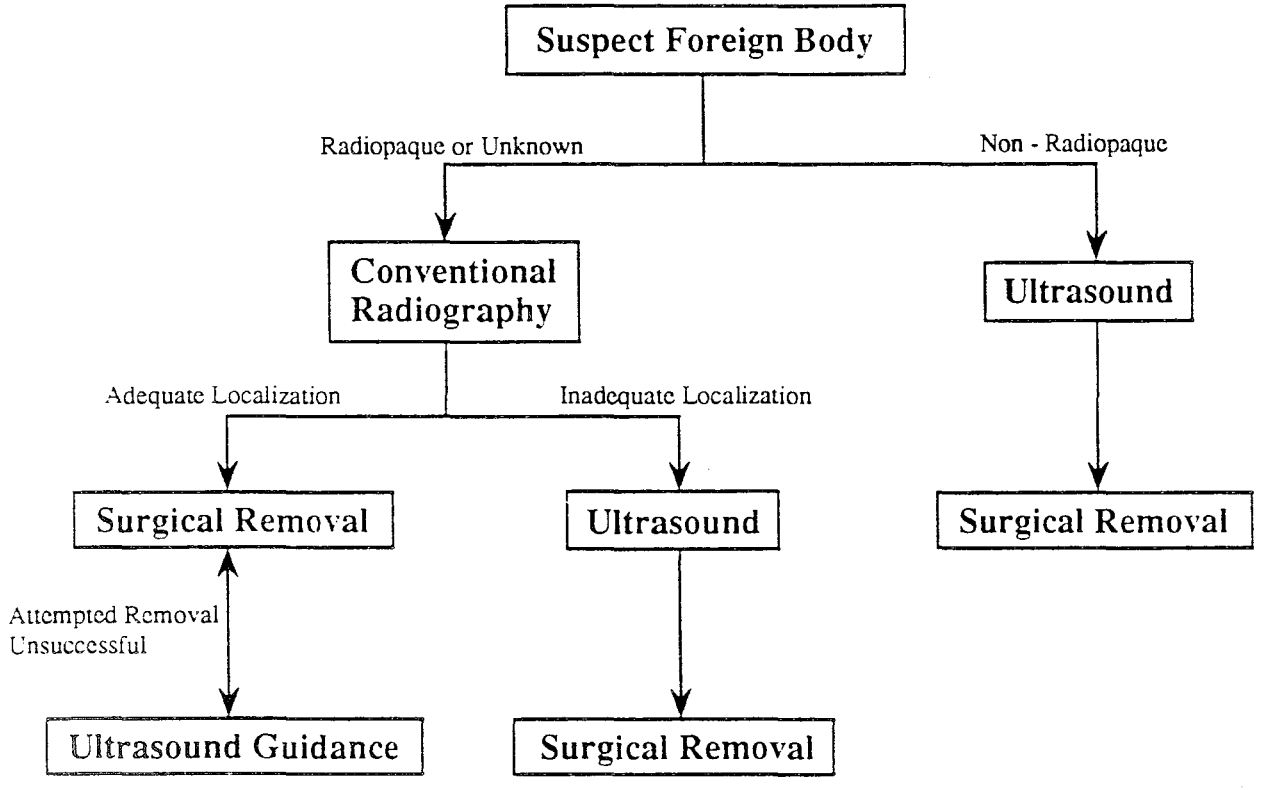


Fig. 5.19. Algorithm for evaluation of foreign bodies [10].

VI. CONCLUSIONS

Ultrasound is the ideal modality for the examination of soft tissues because of its multiplanar and real-time capabilities. Sonography yields anatomic information during active and passive mobilization that is unattainable with other modalities. Ultrasound examination of deep seated joints such as the hip and shoulder is especially valuable. Joint effusions, loose bodies, tendonitis, and tendon and muscle ruptures can all be demonstrated sonographyically. The noninvasive nature of the examination and lack of ionizing radiation make it very well accepted by patients, especially children. Dynamic studies of the joints and ligaments are very convenient and useful to give an additional diagnostic value. So, the functions and anatomical disorders during the movements (like partial rupture) can be imaged easily with the ultrasound. These are some of the main argumentation against X-Ray.

Ultrasound may be used as an adjunct to radiography in the diagnosis of lesions of bone. The impermeability of bone tissue to ultrasound may be used to analyze the effects of bony lesions on adjacent soft tissues. This approach could make it possible to diagnose, bony destruction, inflammation, and new bone formation.

Pathological changes in the bony contours are equally well recognized. Marginal erosions and synovial inclusions found in rheumatoid disease are more easily seen sonographyically than with conventional radiography.

Sonographic evaluation of bone in children is often more valuable than conventional radiography because cartilage is visualized on ultrasound images. Ossification of the growth cartilage can be detected sonographically well before it is evident on conventional radiography.

Ultrasound is ideal for the evaluation of congenital hip dysplasia. It provides both morphological and functional information about the developing acetabulum and femoral head. Furthermore, repeat ultrasound examinations performed to follow growth and maturation of the hip do not carry the risks associated with ionizing radiation.

The cystic structures in the soft tissue like the popliteal Baker cyst may be visualized on ultrasonograph as a lucent mass at the medial aspect of the popliteal fossa. We can also examing other soft tissue solid masses.

Normal tendons appear uniform in thickness and echogenicity. Tendinitis, tenosynovitis, tendon rupture, and dislocation are detectable. With tendinitis, there are regions of tendon thickening and decreased echogenicity. Muscle bundles appear hypoechoic on ultrasonograph,

whereas fibroadipose septas are echogenic. The normal regular architecture is interrupted in cases of muscle rupture, ischemia, infarction, and infection. Both compression ruptures, caused by blunt trauma, and distraction ruptures, are visualized.

Not only may ultrasonograph diagnose a muscle rupture, but it may also contribute to treatment and follow-up .

With recent advances in ultrasonograph technology, more detailed view of the surfaces of cortical bone and periosteum can be delineated. Ultrasound can demonstrate particular erosions more accurately than conventional radiography.

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