Musculoskeletal Ultrasonography in Rheumatic Diseases

Yasser El Miedany
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To my inspiring mom and dad for passing on the love of reading and the eagerness for learning

To my family for their love, care, and encouragement

Foreword

There are many challenges to providing a high quality musculoskeletal diagnostic and treatment service. Much of our diagnostic approach has relied traditionally on the skills of history and examination. These remain important, but are open to subjective interpretation. The same is true of assessing response to interventions, some of which are extremely expensive, and we need to justify their use with reliable methods of demonstrating improvement in the patient. We are working in health care systems where value (better outcomes at lower costs) is an increasingly important consideration.

Against this background, ultrasound has increasingly become a part of the armory of the musculoskeletal practitioner. It helps us

- in diagnosis, treatment, and assessing response to interventions;
- to make musculoskeletal disease management more selective and objective, and improves the chances of the patient getting the right treatment from the right person and at the right time;
- to enhance our expertise and differentiate ourselves from other musculoskeletal practitioners.

In summary, ultrasound helps musculoskeletal practitioners to improve value in health care, and possessing the skill of using this modality places the practitioner in a stronger position when it comes to the commissioning of high quality musculoskeletal services. All musculoskeletal practitioners should have the opportunity to train in developing expertise in this area.

Some people in musculoskeletal practice talk well about their service, but do not always deliver. Yasser El Miedany does not fit into this category. I have always been impressed by his ability to take great ideas and translate them into living practice in high quality services that we can all learn from. It comes as no surprise, therefore, that he has managed to assemble an international collection of ultrasound experts, encyclopedically covering all areas of musculoskeletal disease and practice. There is much we can all learn from the contents of these chapters. I commend this book to all musculoskeletal practitioners.

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Preface

The use of musculoskeletal ultrasonography in rheumatology clinical practice has expanded swiftly over the past decade as an outcome of the technological developments and implementation of the window of opportunity concept in most of the inflammatory musculoskeletal conditions. Ultrasound booked its place as the “rheumatologist’s stethoscope” as it enabled the treating health care professional to diagnose, prognosticate, monitor disease activity as well as response to management. In contrast with other imaging modalities such as X-ray and magnetic resonance, ultrasound has clear advantages, namely good tolerability, no radioactivity, ability to scan both joints and soft tissue at one sitting and its dynamic facility, which enables direct correlation between clinical and imaging outcomes. In spite of some concerns regarding standardization, the use of ultrasound in rheumatology is expected to grow further as prices of the machine fall and the opportunity to practice improves. This book will go beyond the traditional specific joint ultrasonography, which has already been discussed thoroughly in previous publications, to focus on ultrasonographic changes in different musculoskeletal disorders. The main purpose of this book is to serve as a guide for any physician who wishes to perform clinical musculoskeletal ultrasound regardless of experience. The aim is provide a practical approach to dealing with patients suffering from different rheumatic diseases in standard practice. It is therefore suitable to a wide range of audience from the novice embarking on providing a musculoskeletal ultrasonography service, to the experienced who wishes to develop their sonographic scanning skills.

The main theme of this book is to deliver a very practical and reader-friendly guide. On one hand it describes a “how to do it” approach, whereas in the meantime it delivers the evidence and advanced knowledge base of the relevant pathological sonographic appearances of the various musculoskeletal tissues. The illustrations and figures were meticulously selected to give the reader a clear guide towards implementation in real life practice. Focusing on the major values of ultrasound in rheumatologic diseases, this book with its 14 chapters is expected to fill an important void in the current literature. It represents what can be considered to be the best current thinking on role of ultrasonography in the assessment of pathology, diagnosis, and treatment of different rheumatic diseases. Therefore, this book can serve as both excellent introductory and a very good reference resource for future reading.

This work has been the outcome of cooperative effort of a large international group of leaders in musculoskeletal ultrasonography. They have done a superb job to produce authoritative chapters including vast amounts of scientific and clinical data to create state-of-the-art descriptions of sonographic changes encompassed by different rheumatic diseases. Special thanks to Dr. Chris Deighton who wrote the book's foreword and Dr. Adham Khalil for his support throughout the whole project which helped to make this book complete.

Personally, I feel privileged to have compiled this work and am enthusiastic about all that it offers our readers. I hope you too will find this edition a uniquely valuable educational resource.

Kent, England, UK

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Chapter 1
Fundamentals of Musculoskeletal Ultrasound

Hatem El-Azizi MD, PhD and Carolina Botar Jid MD

Introduction

Ultrasonography is a safe, well-tolerated, low-cost imaging technique with no ionizing radiation and few technical limitations. High-frequency ultrasound has better spatial resolution than magnetic resonance imaging (MRI), and ultrasonography really excels in its ability to perform real-time dynamic studies and interventions. Sonography also allows easy comparison with the contralateral side, which can help in identifying subtle abnormalities [1].

Basic Physics

Wavelength is the length of one complete cycle; it is the distance between two identical adjacent points in consecutive waves. Wavelength is typically measured between two similar points, such as two adjacent crests or troughs in a waveform. Wavelengths are most accurately measured in sinusoidal waves, which have a smooth and repetitive oscillation. It is normally given the symbol λ (lambda) and has units of meters or millimeters (Fig. 1.1).

Frequency is the number of waves per second. It is measured in hertz (Hz), with 1 Hz being one complete cycle per second. The audible sound for human has

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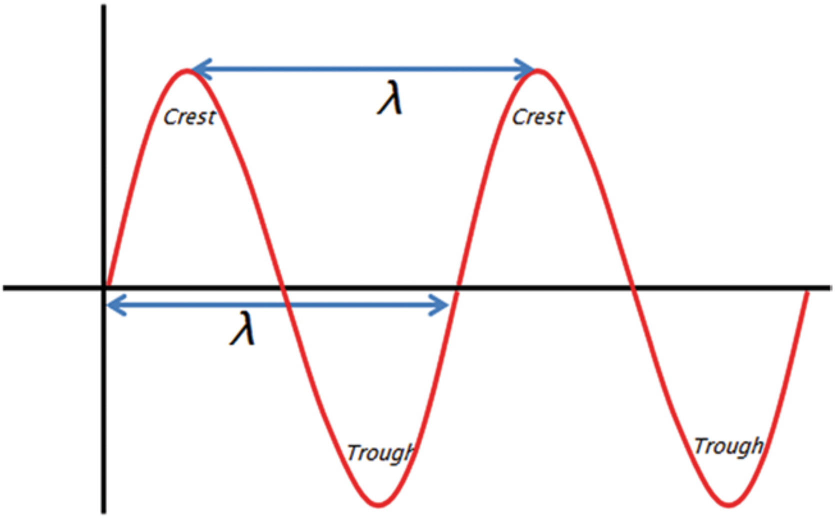


Fig. 1.1 Wavelength is the distance between two crests or any similar points in consecutive waves

the frequency of 20–20,000 Hz; any frequencies above this range are referred to as ultrasound. The frequencies used in diagnostic ultrasound typically ranges from 2 to 20 MHz (1 MHz = 1 million Hz). The frequency is inversely proportional to the wavelength; the higher the frequency, the shorter the wave length (Fig. 1.2). Higher frequency leads to a better resolution, while lower frequency provides better

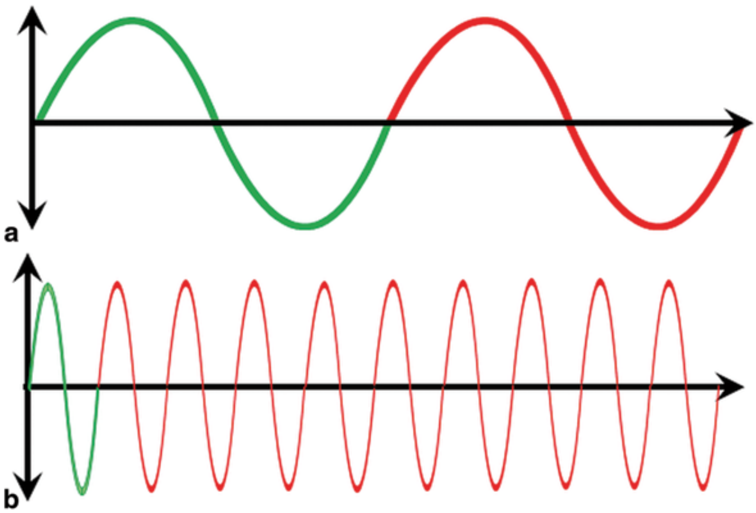


Fig. 1.2 Frequency inversely proportion to wavelength. **a** Low frequency and long wavelength. **b** High frequency and shorter wavelength

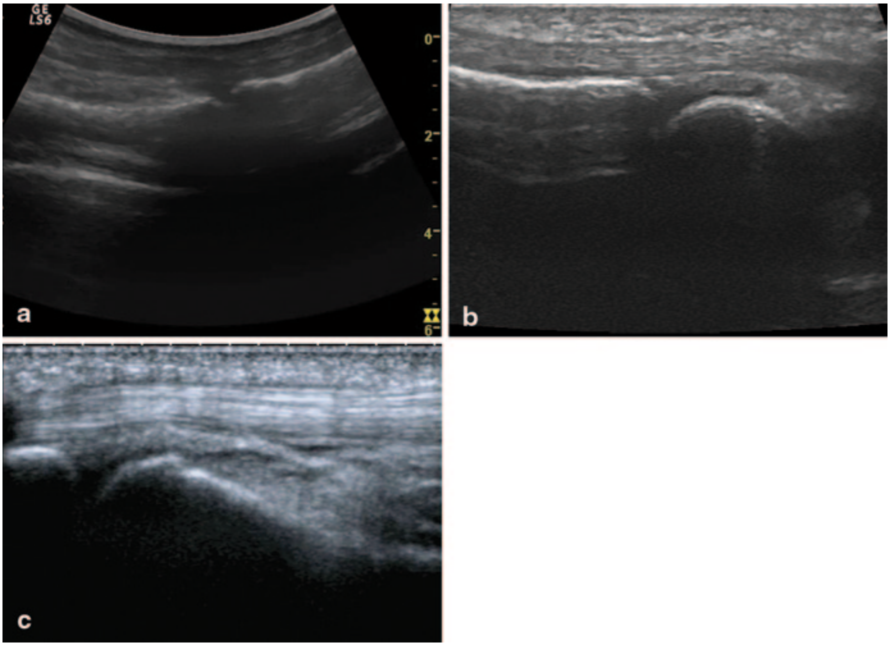


Fig. 1.3 Influence of different frequency on the resolution of flexor tendon at the level of MCP joint. **a** Very poor resolution at frequency 3.5 MHz. **b** Good resolution at frequency at 8 MHz. **c** High resolution at frequency 18 MHz. *MCP* metacarpophalangeal

penetration. To examine the musculoskeletal system, electronic high-frequency linear transducers are used, which provide uniform anatomical information on all images, have good resolution in both near and distance fields, and are easy to apply and maintain (Fig. 1.3). For overview and guidance, transducers with frequencies between 7.5 and 10 MHz are recommended, while for deeper-located structures, such as hip or shoulder joints, transducers with lower frequencies (2–6 MHz) are recommended. Detailed study of musculoskeletal structures requires the use of high-frequency transducers, 15–18 or 20 MHz [4, 10].

Acoustic Impedance is resistance at the interface between the two media or tissues. If the acoustic impedance between the two tissues is high, most of the sound beam will not be transmitted to the deeper tissues and it will be reflected back to the probe (air/soft tissue interface and soft tissue/bone interface). Minimal acoustic impedance between the tissues (subcutaneous/muscle interface) will lead to some of the sound beams being transmitted to the deeper tissue and some being reflected back. If the acoustic impedance between tissues is very low, almost all of the sound beam will be transmitted to the deeper tissue and minimal will be reflected back (soft tissue/fluid interface).

Reflection: Ultrasound images are created by the reflected ultrasound beam at the interface between tissues or media. The higher the reflection of sound beam at tissue interface, the higher the echogenicity in the image at the soft tissue/bone

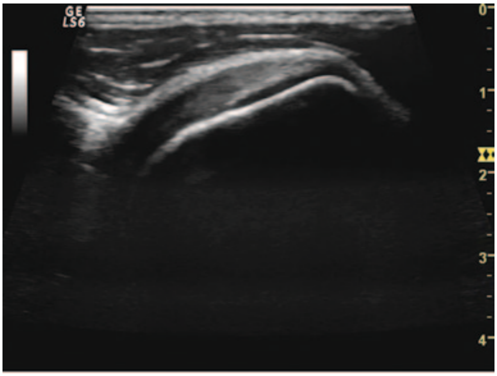


Fig. 1.4 High reflection of sound beam at soft tissue/bone interface with high echogenicity (*white*) of cortical outline

interface where the bone cortex appears highly echogenic (white) (Fig. 1.4). On the other hand, fluid in a bursa or blood vessels has a very low acoustic impedance resulting in a low reflection at fluid, so it appears black (Fig. 1.5).

Resolution refers to an ultrasound machine's ability to discriminate between two closely spaced objects. The resolution of an ultrasound image includes the axial (along the beam) and lateral (across the image). *Axial resolution* refers to the ability of the ultrasound system to differentiate two closely spaced points that lie in the plain parallel to the sound beam (Fig. 1.6). Each sound pulse is composed of 2–3 wavelengths emitted in longitudinal (axial) direction. The system can resolve two separate points in the image when the distance between the two points is equal to a single wavelength. Increase in the frequency will decrease the wavelength which will result in increase in the axial resolution of the ultrasound image (Fig. 1.3). *Lateral resolution* is the ability of the system to display small structures side by side (same depth) as separate from each other (Fig. 1.7). The ultrasound beam initially converges with increasing depth, and then widens out again with decreasing intensity and resolution. The focal zone of the beam is 3–4 wavelengths wide and is the area where lateral resolution is the highest. The ultrasound beam can be focused to improve image quality.

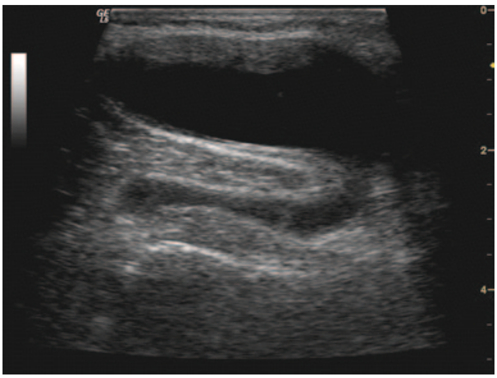


Fig. 1.5 Low reflection of sound beam at soft tissue/fluid interface with low echogenicity (*black*) of backer cyst fluid content

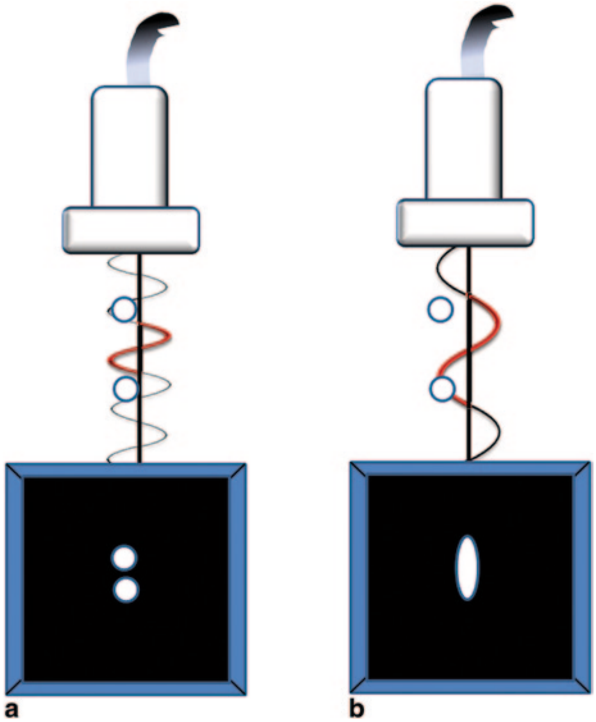


Fig. 1.6 Axial resolution. **a** & **c** Poor resolution at the near and far fields with both structures seen on the screen as single structure. **b** The best image seen at the level of the focus where both structures are seen as separate points on the image

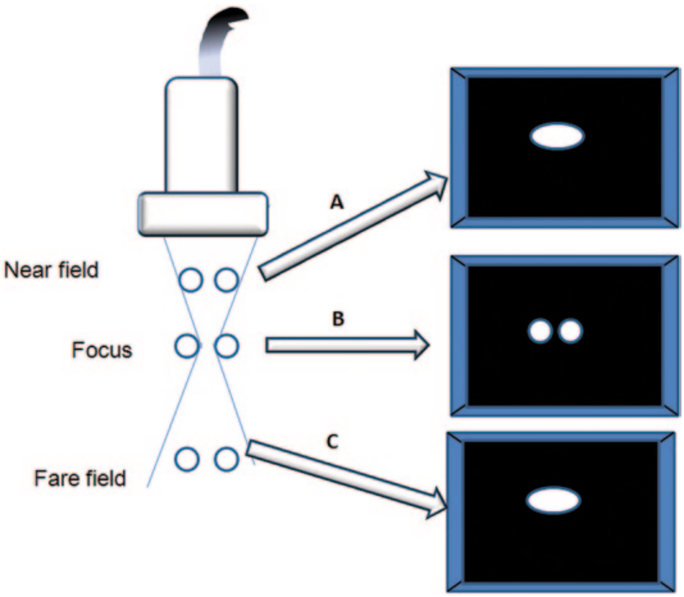


Fig. 1.7 Lateral resolution. **a** & **c** Poor resolution at the near and far fields with both structures seen on the screen as single structure. **b** The best image seen at the level of the focus where both structures are seen as separate points on the image

Color Doppler

Color Flow Imaging (**CFI**) is the ability to show blood flow in a selected area within B-mode image. It represents both direction and velocity of blood flow in this area. The color in the image represents color coding of Doppler frequency shift detected within each pixel of the returning echoes, and the detected color is superimposed on the corresponding B-mode image. The flow towards the transducer is usually coded in red while the flow away from the transducer is usually coded blue. Color Doppler has disadvantage of aliasing affected by the steering angle and its low sensitivity to slow flow.

Power Doppler Imaging (**PDI**) is based on the integrated power (or amplitude) of the Doppler signal, instead of the mean Doppler frequency shift as in color Doppler sonography. The color map in power Doppler (PD) sonography displays the integrated power of the Doppler signal, which is related to the number of red blood cells that produce the Doppler shift [3, 8]. PDI has three times the sensitivity of conventional color Doppler for the detection of flow and is particularly useful for small vessels and those with low-velocity flow [2].

Color Gain: The Doppler gain is different from the B-mode gain. Setting the color gain is crucial for accurate diagnosis of tissue hypervascularity which indicates the degree of disease activity. Increased gain causes noise and overestimation of the tissue vascularity. On the other hand, lowering the color gain decreases the color sensitivity resulting in underestimation of the activity. To adjust the color gain, first the gain must be increased until noise appears in the image then gradually decreased until noise disappears (Fig. 1.8).

Scale and Pulse Repetition Frequency: Pulse repetition frequency (PRF) is the Doppler sampling frequency of the transducer and is reported in hertz. The maximum Doppler shift frequency that can be sampled without aliasing is PRF/2, which is called the Nyquist limit. The Nyquist limit may be presented on-screen as a blood velocity (the maximum measurable velocity of blood moving directly towards or away from the transducer) or in Hertz (maximum measurable Doppler shift). If the blood velocity is above the Nyquist limit, the machine will misinterpret the velocity and aliasing will occur. This is not an issue with PD [11].

The sensitivity of CFI and PDI is directly affected by the PRF; lowering the PRF will increase the colur sensitivity to low flow which is highly preferable in rheumatology to detect the lowest activity in inflammatory diseases. Using high PRF will decrease the sensitivity of the machine to lower velocities.

Image Control

Gain: Gain correction is crucial to obtain an interpretable image as it affects the gray scale of the whole image. Decreased gain will give a black image, and details will be masked. Increased gain will give a white image, and details will be saturated (Fig. 1.9).

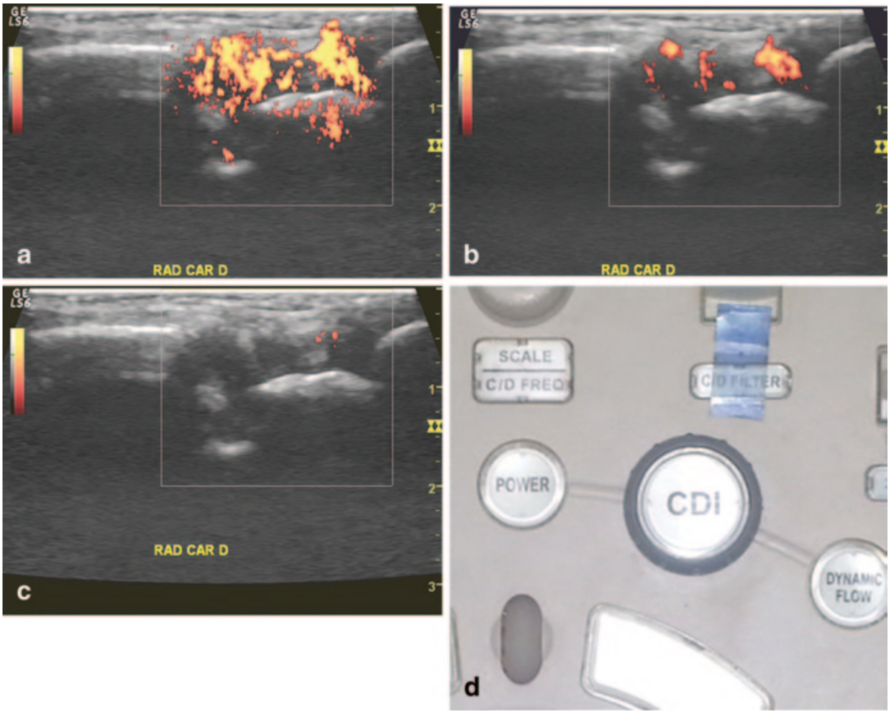


Fig. 1.8 Color gain adjustment. **a** High gain: color noise with overestimated hypervascularity. **b** Proper gain: with no color noise. **c** Poor color gain with false poor hypervascularity. **d** An example of color gain button

Time gain compensation (*TGC*): Echoes returning from deeper tissues within the body are weaker than those arising from structures closer to the transducer. Since the distance they have to travel is longer, they experience greater attenuation. Without TGC, the far field (bottom of the screen, deeper tissue) would always appear darker than the near field (top of the screen, tissue closest to probe); TGC correct the gain on the echoes returning from the far fields. Most of machines have multiple slider levers that allow you to control the gain throughout the entire scanning depth (Fig. 1.10).

Focus The focus of the image is usually marked on the side of the screen by a small arrowhead (Fig. 1.11). The ultrasound beam is narrowed at that depth revealing the best lateral resolution which improves the image quality and ensures high definition of tissue at that depth. The focus is usually adjusted by means of a knob or an up/down button on the control panel; the focus pointer should move to region of interest.

Depth adjustment increases or decreases the depth of the examined region on the image. It is best to have the structure that is being examined in the center of the screen.

Dynamic range (DR) at the receptor level has also modeled the relationship between the strongest and the weakest echoes by establishing a DR of echoes values.

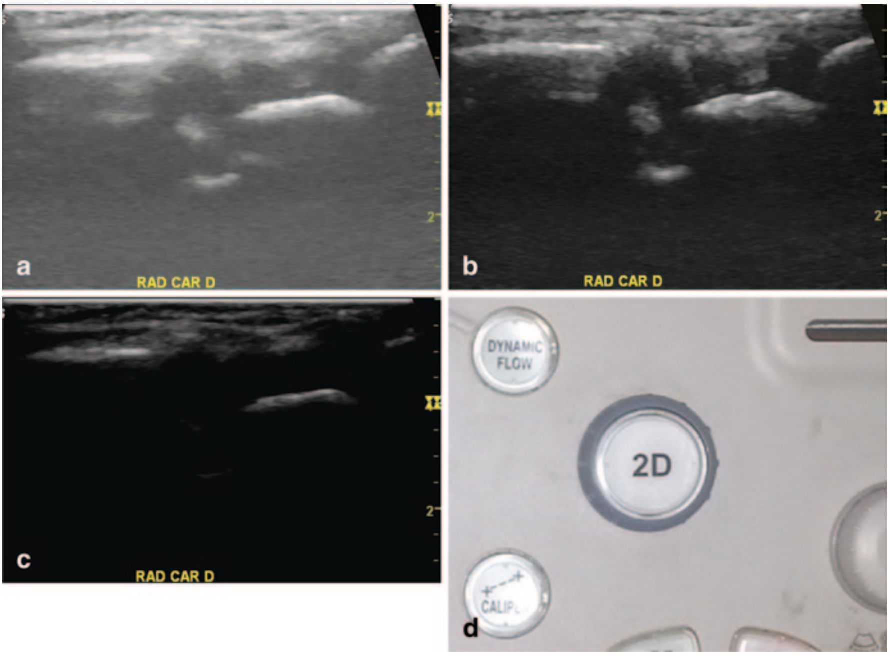


Fig. 1.9 B-mode gain adjustment. **a** High gain: bright image with poor details. **b** Proper gain: with no color noise. **c** Low gain: dark image with poor details. **d** B-mode gain button

The range of difference between echoes is 100 dB, which means ten billion times. The TGC can compensate 60 dB due to attenuation. It is necessary to compress the amplification elective of echoes; thus, weak echoes will be amplified, while strong echoes will not be amplified. Elective amplification is performed using a logarithmic curve. Another function of the receiver is the primary filtering of the electrical signal to eliminate very weak electrical signals corresponding to noise and multiple reflections.

Ultrasound Equipment

An ultrasound device consists of a console, comprising a computer, a monitor, a keyboard, and transducers.

The transducer or probe is the centerpiece of the equipment, with built-in piezoelectric crystals that emit and receive ultrasound. It contains a linear array of very thin crystals, characterized by a piezoelectric property. This property can be described as: the appearance of a difference in the electric potential between two surfaces of a piezoelectric crystal, when it is subjected to mechanical deformation. The phenomenon occurs inversely as well: A piezoelectric crystal subjected to a potential difference suffers a mechanical deformation, which generates ultrasound.

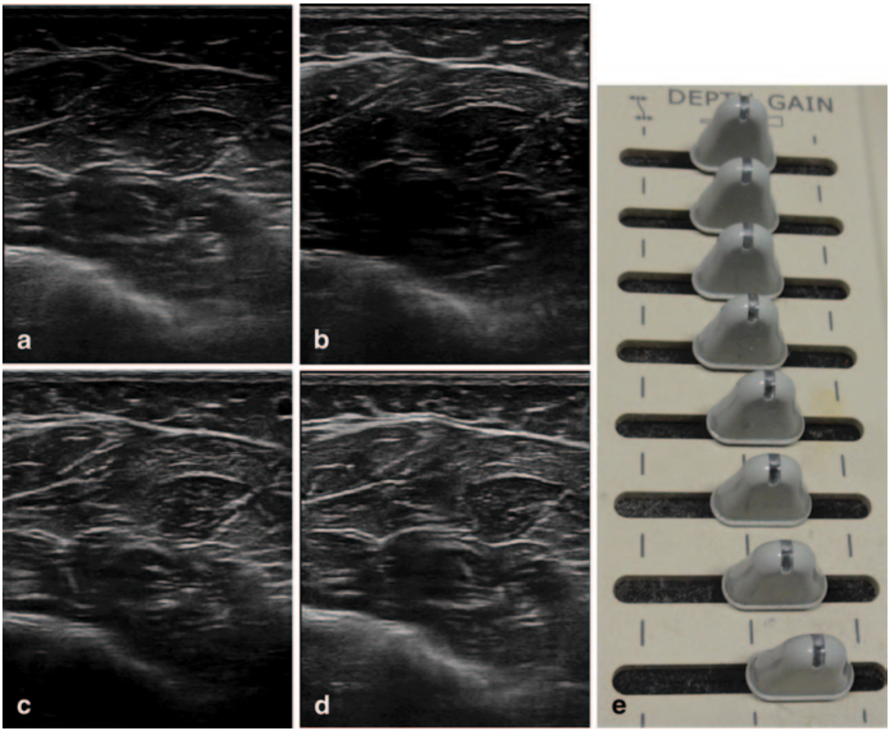


Fig. 1.10 TGC adjustment. **a** Too low gain in superficial part of the image. **b** Too low gain in the middle of the ultrasound image. **c** Too low gain in the deeper part of the image. **d** Proper gain in the entire image. **e** The TGC buttons. TGC time gain compensation

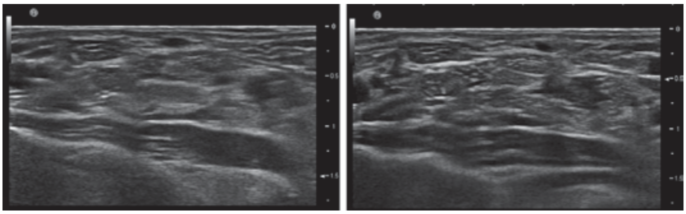


Fig. 1.11 Focus position is indicated by arrow head. **a** Positioning too low. **b** Proper positioning

The generated ultrasounds are characterized by frequency, amplitude, period, wavelength, and propagation speed [5, 6, 10]. Ultrasound frequency that can be generated and received by a transducer is determined by the resonance frequency and the thickness of the piezoelectric crystals. The nominal frequency of the transducer is predetermined by the construction unit.

Depending on the ultrasound transducers' emission and sequencing beam, they are classified into: linear, sectorial, and combined, with functions and/ or multiple frequencies (Fig. 1.12) [10].

Fig. 1.12 Types of transducers

Linear transducers are able to cover almost all musculoskeletal ultrasound examinations. On this type of transducers, the ultrasound beam emerges parallel to each other and perpendicular to the surface of the transducer and the image produced is a rectangular one. These may have a contact surface length, with the skin, between 2 and 6 cm. Larger transducers provide a better overview and are used particularly for large joints, such as the hip joint, or for knee or shoulder joint stability tests. Smaller transducers, also known as “the hockey stick” or “fingerprint” because of their shape, were originally developed for intraoperative use, but are excellent for small and superficial structures and for the evaluation of inaccessible areas such as metacarpophalangeal (MCP), metatarsophalangeal (MTP), proximal interphalangeal (PIP), or distal interphalangeal (DIP) joints [4, 10].

Sectorial transducers have a small area of contact, providing a greater angle with good visualization of regions located deeper. They produce a triangular image on the screen (the area of a circle), the apex of the surface corresponding to the emission of ultrasound beam, because this emerges divergent from a common point on the transducer surface. These transducers are used to explore the musculoskeletal system for examination of meniscus, but they have a low resolution due to the low frequency.

Convex transducers have a curved, convex ultrasound emission, with electronic activation of the piezoelectric crystals and obtain a trapezoidal image. They are mainly used for abdominal ultrasound, whereas in musculoskeletal ultrasonography they are used to explore the hip joint, especially in overweight patients.

Combined transducers combine the several possibilities presented before. These include multifrequency transducers known as “broadband” (wide-band transducer), which include in a one-piece the necessary elements for an examination with a wide range of frequencies. Another type of combined transducers is transducers with multiple functions, which allow examination in several ways: bidimensional (2D) mode, M-mode, Doppler (continuous and pulsed), harmonic, three-dimensional elastography, etc.

Electronic memory is a fundamental component of any ultrasound machine. The electrical signal from the receiver is converted into binary data by an analog–digital converter. The information is stored and processed in the internal memory layers. Digital–analog convertor turns the processed information into an electrical signal. This electrical signal is demodulated and subjected to rectification and filtering processes to become video signal, which is send to the TV monitor.

The TV monitor consists of a cathode tube, whose electron beam is activated as horizontal lines. Each line corresponds to a row in digital memory. The ultrasound information is obtained and stored in columns, but is displayed in rows. An image displayed on the monitor is made up of 525 lines. In order to reduce the oscillation ("blinking") of image, each image is divided in two fields: field even-numbered lines and field odd-numbered lines, displayed alternately. During examination in real time, the monitor screen displays 30 images (60 fields) per second [10].

Probe Orientation and Handling

Probe Markers: Every probe has a mark on one of its sides (Fig. 1.13); it could be a raised marker or indentation or some other identifier that is correlated to a dot or the manufacturer's logo on the display screen. Structures on the same side of the probe marker will appear on the side of the screen mark on the display screen while structures on the opposite side of the probe marker will appear on the other side of the screen marker (Fig. 1.14). Most machines have a button that lets you flip the screen marker from right to left (Fig. 1.15).

Probe Handling When Scanning: To scan a structure in the longitudinal or sagittal view, the transducer is oriented along the long access of the body with the probe marker directed towards the patient head (Fig. 1.16), so the cephalad structures will appear on the side of the display screen with the marker. The transverse or axial is obtained by rotating the probe 90 ° from the long axis of the patient; the probe marker should be directed to the right side of the patient so that the right-side structures of the body will appear on the side of the display screen with the marker (Fig. 1.17).

Fig. 1.13 **a** Probe side with marker. **b** Probe side with no marker

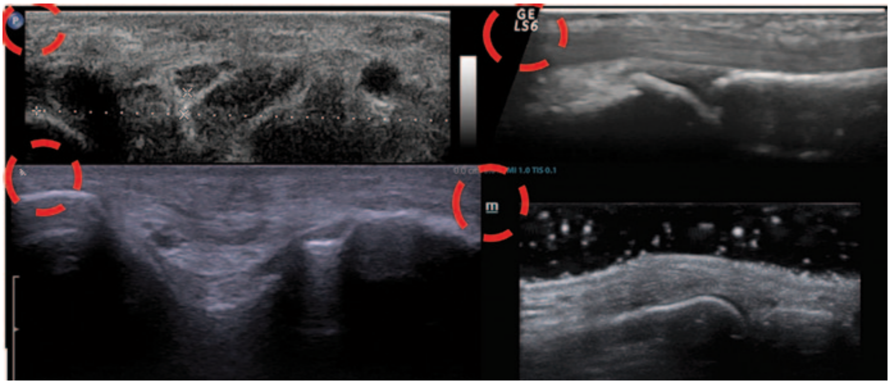
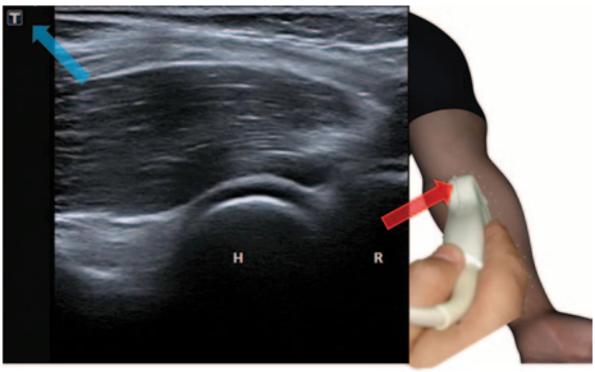


Fig. 1.14 Different screen marker showing either companies logo or initials' letter

Fig. 1.15 Button for flipping the screen marker from right to left

Fig. 1.16 Longitudinal (*sagittal*) examination of the elbow with the probe marker directed to the head (*red arrow*) and the hummers (*H*) seen on the same side of the screen marker (*blue arrow*)



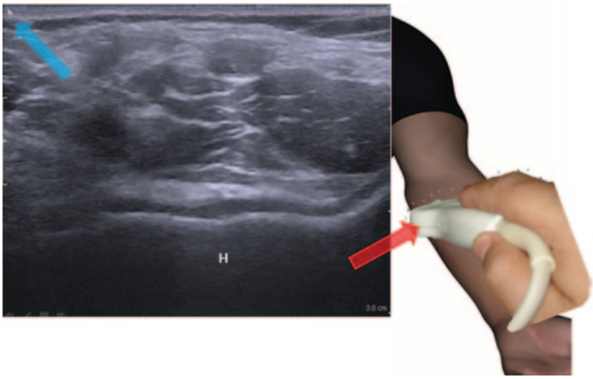


Fig. 1.17 Transverse examination of the elbow with the probe marker (*red* arrow) directed to the right side of the patient. The probe marker directed to the side of the display screen with the screen marker (*blue arrow*). Hummers (*H*)

Scanning Technique and Image Optimization

There are several notions of ultrasound techniques which are necessary to be known for achieving optimal ultrasound images. First of all, the examiner must choose the transducer (probe button) according to the region of interest. The capacity of penetration of the ultrasound beam is inversely proportional to the nominal frequency of the transducer. The frequency of the transducer is higher; the image resolution is better, but associated with the reduction of the penetration due to attenuation (which is proportional to the frequency of ultrasound). As a practical application, to obtain a detailed ultrasound image of superficial structures, transducers with high frequency and resolution are used, whereas for deeper structures, it is necessary to reduce the frequency and the resolution by default (Fig. 1.18).

Following transducer selection, ultrasound gel is placed on the transducer and the transducer is applied to the skin of the region of interest. Next step is to adjust the image depth (depth control on the console) so that the displayed image includes the region of interest without losing information and with no unused space (Fig. 1.19) [10].

The examiner must change the position (Fig. 1.11) and number of focuses so that the focal zone is located at the same position and depth as the targeted structure, in order to obtain an optimal lateral resolution [10].

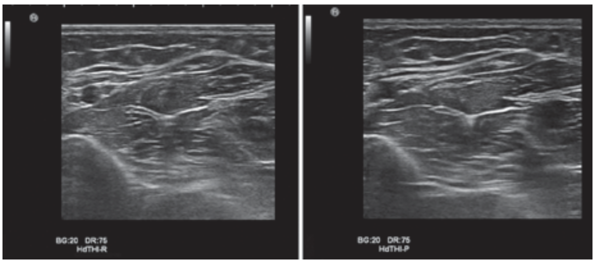


Fig. 1.18 Influence of frequency on the image with the same transducer. **a** Resolution frequency. **b** Penetration frequency