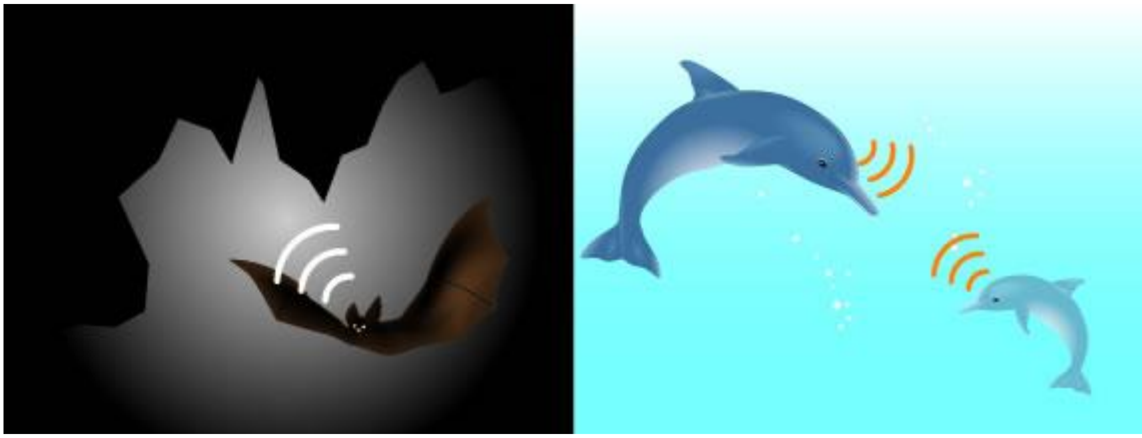
## Ultrasound and its properties

### What is ultrasound?

Ultrasound refers to a sound wave with a frequency greater than the upper limit of human hearing, which is generally over 20 kHz.
In general, humans can hear sounds with a frequency between 20 Hz and 20 kHz. Any sound with a frequency higher than 20,000 hertz (20 kHz = 20,000 cycles of oscillation per second) cannot be sensed by a human's ear. Among audible sounds not higher than 20 kHz, those not intended to be heard by humans have also come to be called ultrasound.

Some animals including bats and dolphins rely on ultrasound to live.
Bats emit ultrasound from their mouths and receive its echo. From the time interval between sending the sound and receiving the echo as well as the angle of the echo received, they can determine the distance to targets and their location. Bats can thus sense the terrain and detect their prey.
Similarly dolphins use ultrasound to capture the surrounding conditions and communicate with their peers.



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### Major properties of ultrasound

Ultrasound travels through various media including gases, liquids and solids, but cannot travel through a vacuum. The speed of sound varies by the medium it travels through. Sound is likely to travel faster through solids, followed by liquids and gases.

For example, the speed of sound in the air is about 340 meters per second (m/s). That in water is about 1530 m/s and that in iron as high as about 5,850 m/s. Another typical property of sound is that its energy is more likely to be lost in gases while it travels through liquids or solids more efficiently.

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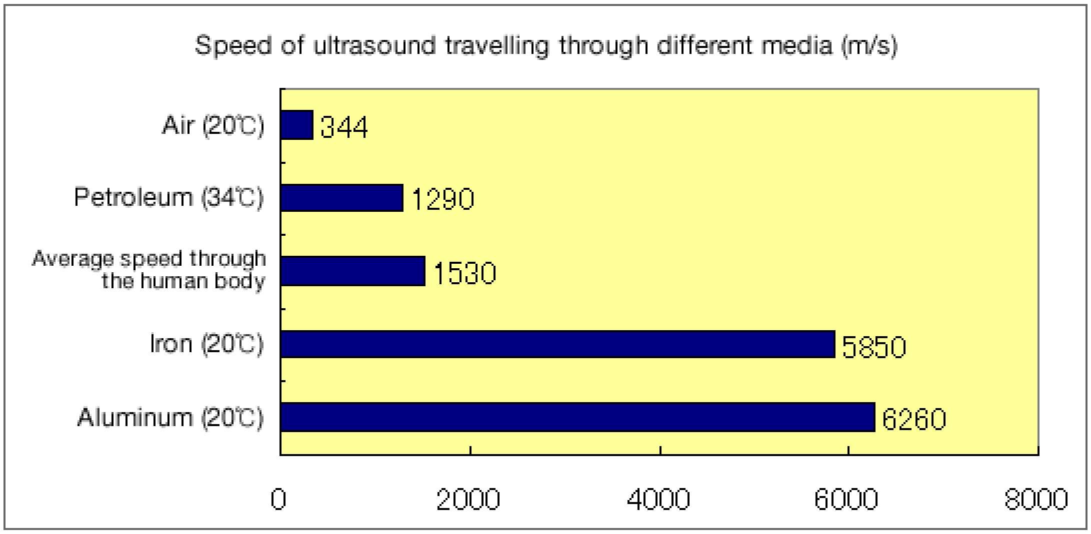


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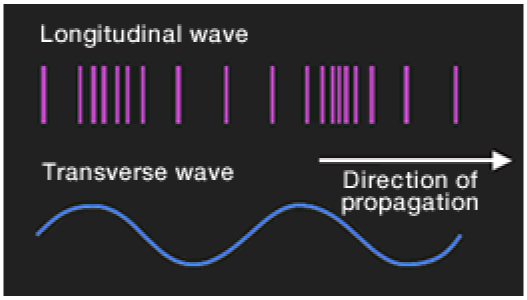


The type of sound waves also depends on the medium. Sound travels through the air and liquids as longitudinal waves (i.e., waves vibrating in the same direction as that of propagation). Through solids, however, it can be transmitted as both longitudinal waves and transverse waves (i.e., waves vibrating at the right angle to the direction of propagation) as well as surface waves.

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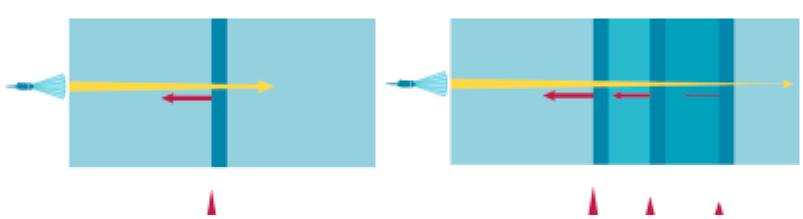
Ultrasound travels in a very straight line. An ultrasonic wave is reflected when it strikes an interface between materials with different speeds of sound (acoustic impedance). Furthermore, an interface between materials with a larger difference in acoustic impedance reflects ultrasonic waves more strongly and that with a smaller difference in acoustic impedance reflects them less strongly and lets part of them travel through.

For example, the human body consists of a variety of cells and tissues with their acoustic impedance different from each other. Ultrasonic waves striking these cells or tissues are reflected differently. Using the difference in energy level of the echoes makes it possible to image the internal tissues of the body.

Ultrasonic waves are gradually attenuated to become weaker while travelling through the medium. Those with a higher frequency show a higher attenuation factor.

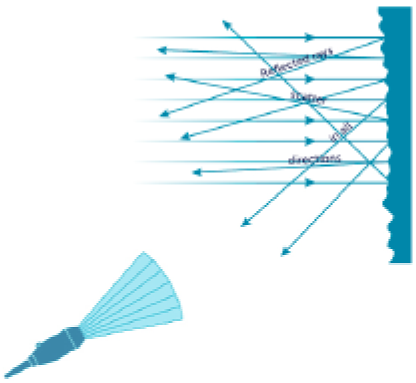
# Ultrasound and Tissue

Ultrasound is marked by a number of properties when it passes through tissue. Reflection occurs on border surfaces between tissues with different wave propagation properties (such as fat, muscle, and blood). The degree of reflection depends on the magnitude of this difference. The remaining ultrasound energy may either penetrate deeper or be absorbed by the tissue. Usually the ultrasound wave hits several different reflector surfaces. Interaction with tissue causes the ultrasound energy to diminish and become weaker as it penetrates deeper. This is also known as attenuation and is similar to sound that becomes fainter when one moves further away from it. You will read more about attenuation when we discuss 2D imaging and artifacts.



Reflection at the tissue boundary - Multiple reflections and attenuation

As border zones are usually marked by more or less irregular surfaces, the ultrasound waves are scattered in all directions. This allows some of the reflected ultrasound waves to return to the transducer and be used to generate an image.



Scatter of ultrasound waves, allowing waves to reflect back to the transducer



Diathermy

Medically reviewed by University of Illinois — Written by Anna Giorgi — Updated on September 29, 2017



## What is diathermy?

Diathermy is a therapeutic treatment most commonly prescribed for muscle and joint conditions. It uses a high-frequency electric current to stimulate heat generation within body tissues.

The heat can help with various processes, including:

- increasing blood flow
- relieving pain
- improving the mobility of tissues as they heal

**What are the types of diathermy?**

There are three main types of diathermy: shortwave, microwave, and ultrasound.

Shortwave

Shortwave diathermy uses high-frequency electromagnetic energy to generate heat. It may be applied in pulsed or continuous energy waves. It has been used to treat pain from kidney stones, and pelvic inflammatory disease. It's commonly used for conditions that cause pain and muscle spasms such as:

- sprains
- strains
- bursitis
- tenosynovitis

Microwave

Microwave diathermy uses microwaves to generate heat in the body. It can be used to evenly warm deep tissues without heating the skin. Since it can't penetrate deep muscles, it's best suited for areas that are closer to the skin, such as the shoulders.

# Ultrasound diathermy

Ultrasound diathermy uses sound waves to treat deep tissues. Heat is generated by the vibration of the tissue. This promotes blood flow into the area. Ultrasound diathermy is used for:

- musculoskeletal sprains
- strains
- muscle spasms
- joint contractures or adhesions
- neuromas

**How does diathermy work?**

Diathermy uses high-frequency electric current to produce heat deep inside a targeted tissue. It can reach areas as deep as two inches beneath the skin's surface.

The diathermy machine does not apply heat directly to the body. Instead, the waves generated by the machine allow the body to generate heat from within the targeted tissue.

Diathermy is usually part of a complete physical therapy or rehabilitative regimen. Frequency and length of treatments vary.

**What are the benefits of diathermy?**

Treating injuries with heat can increase blood flow and make connective tissue more flexible. It can also help minimize inflammation and reduce the incidence of edema, or fluid retention.

By increasing blood flow to the site of an injury, the deep heat generated with diathermy can accelerate healing.

Diathermy is used to treat the following conditions:

- arthritis
- back pain
- fibromyalgia
- muscle spasms
- myositis
- neuralgia

- sprains and strains
- tenosynovitis
- tendonitis
- bursitis

However, there is still not a lot of evidence to prove that diathermy is the most effective treatment for these conditions.

**What are the risks of diathermy?**

The electromagnetic energy used in shortwave and microwave diathermy can cause extreme heat in metal devices such as:

- bone pins
- dental fillings
- metal sutures

This could cause burns in the tissue near the implant. The procedure should not be used over these areas to avoid the risk of burning.

During diathermy treatment, you become a part of the electrical field. Touching a bare metal object, including a metal part of the diathermy cabinet, can cause a shock or burn.

Diathermy should be avoided over open growth plates in children.

**Who’s qualified for diathermy?**

People with implanted metal devices may be at risk for injury if they undergo any type of diathermy. These devices include:

- pacemaker
- prosthesis
- intrauterine device (IUD)

You may not be an appropriate candidate for this treatment if you have:

- cancer
- reduced skin sensation
- peripheral vascular disease
- tissue with restricted blood supply (ischemia)
- infections
- fractured or broken bones
- bleeding disorders
- severe heart, liver, or kidney conditions
- low skin sensation
- pregnancy
- perspiration
- wound dressings

Diathermy is not considered safe for certain areas of the body. These include:

- eyes
- brain
- ears
- spinal cord
- heart
- reproductive organs
- genitalia

**How should I prepare for diathermy?**

Before a diathermy session, you must remove:

- all metal jewelry

- clothing that includes metal, such as zippers or buttons
- accessories containing metal

You may be given a gown to wear during the procedure. You also may be asked to wear goggles.

**What are the steps?**

Depending on the type of diathermy and the location of the affected area, you lie on a table or sit in a chair during the procedure.

For ultrasound diathermy, the therapist applies a gel to the affected area of your body. In shortwave and microwave diathermy, gel is not used, and the affected area may be wrapped in a towel to avoid direct contact between the skin and the electrodes.

During shortwave and microwave diathermy, two electrodes are positioned near the affected area. In ultrasound diathermy, a therapist moves a wand continuously over the affected area.

You must remain still while the treatment is being administered. You may feel a warm or tingling sensation during the treatment, or you may feel nothing at all.

**What is the outlook after diathermy?**

After a diathermy treatment, the affected area may feel more flexible. You may be able to participate in physical therapy behaviors more comfortably and for a longer period of time.

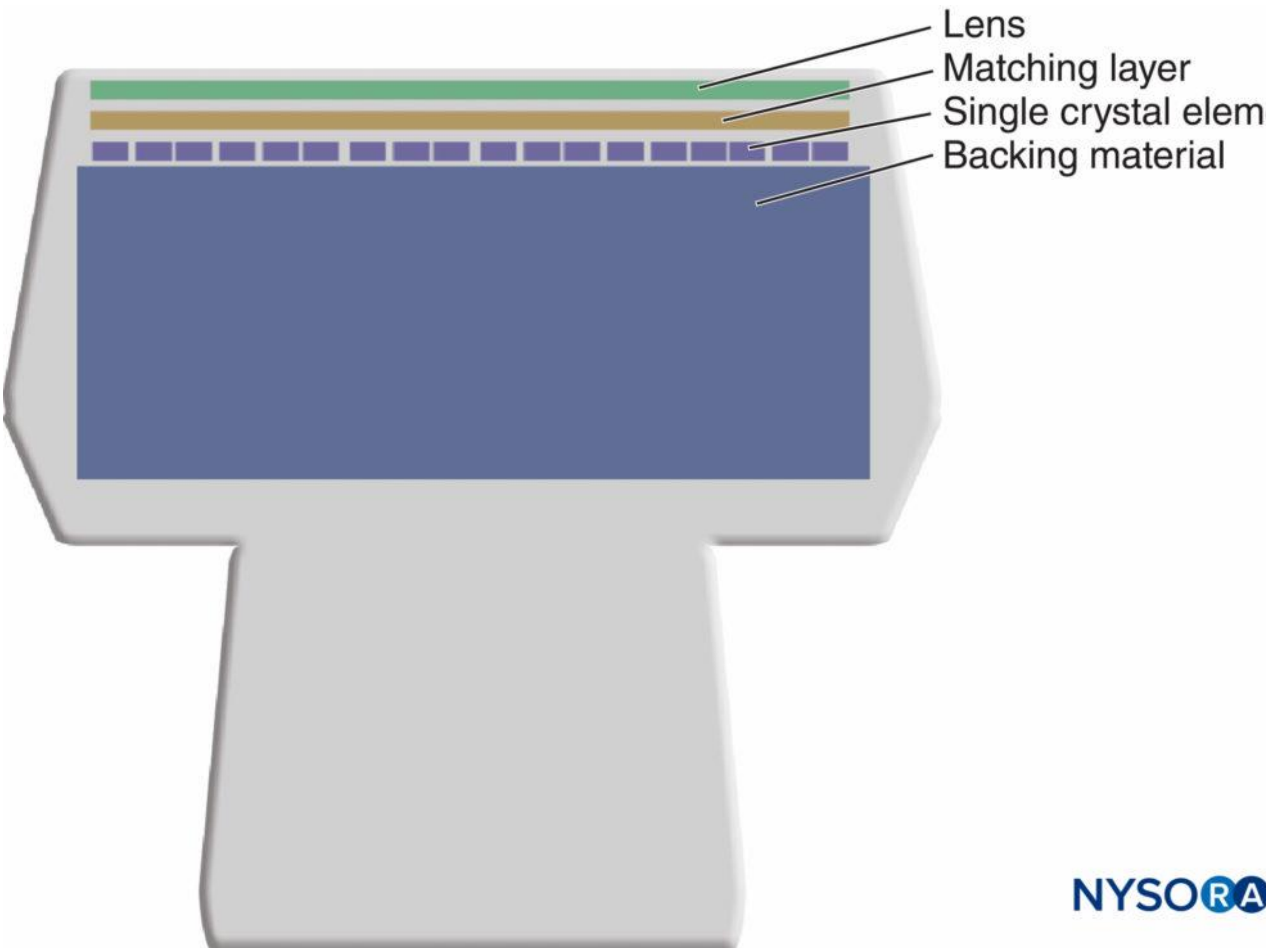
The increased blood flow to the affected area may induce healing and tissue repair.

**Get High Resolution Anatomical Data with B-Mode Ultrasound!**

B-Mode is a two-dimensional ultrasound image display composed of bright dots representing the ultrasound echoes. The brightness of each dot is determined by the amplitude of the returned echo signal. This allows for visualization and quantification of anatomical structures, as well as for the visualization of diagnostic and therapeutic procedures for small animal studies.

This universal imaging mode is great for:

- Image-guided injections for needle placement of an injection or aspiration procedure
- Identification of lesions, cysts or tumors
- Locating structural anomalies
- Visualizing cardiac and vascular movement across the cardiac cycle
- **B-mode**
- The B-mode is a two-dimensional (2D) image of the area that is simultaneously scanned by a linear array of 100–300 piezoelectric elements rather than a single one as in A-mode (**Figure 9**). The amplitude of the echo from a series of A-scans is converted into dots of different brightness in B-mode imaging. The horizontal and vertical directions represent real distances in tissue, whereas the intensity of the grayscale indicates echo strength (**Figure 10**). B-mode can provide an image of a cross section through the area of interest, and it is the primary mode currently used in regional anesthesia.




- Figure 9. The B-mode transducer incorporates numeric piezoelectric elements that are electrically connected in parallel.

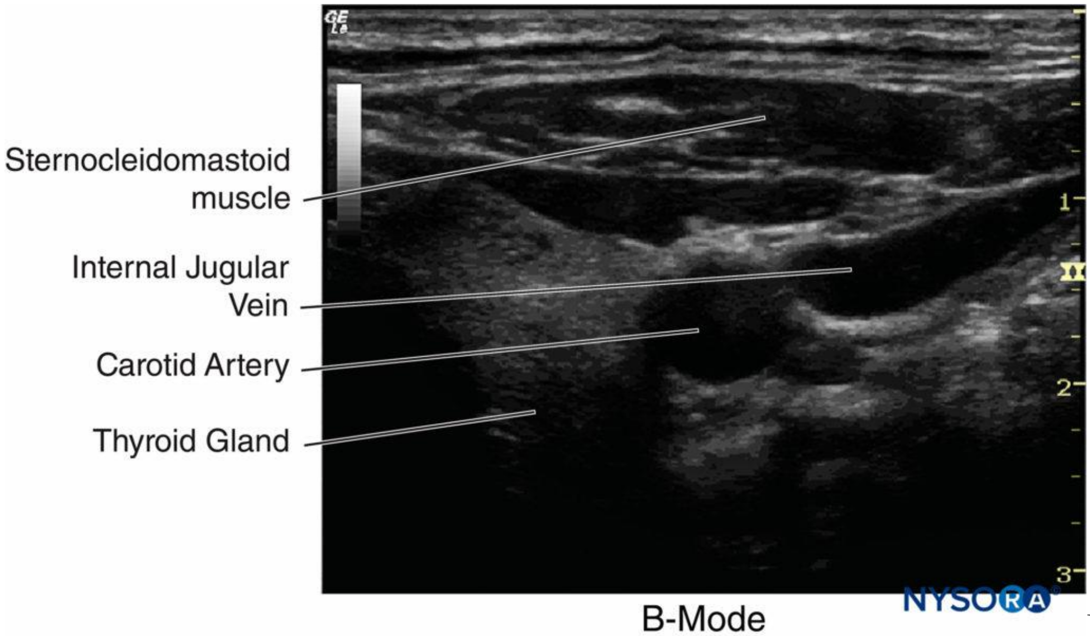
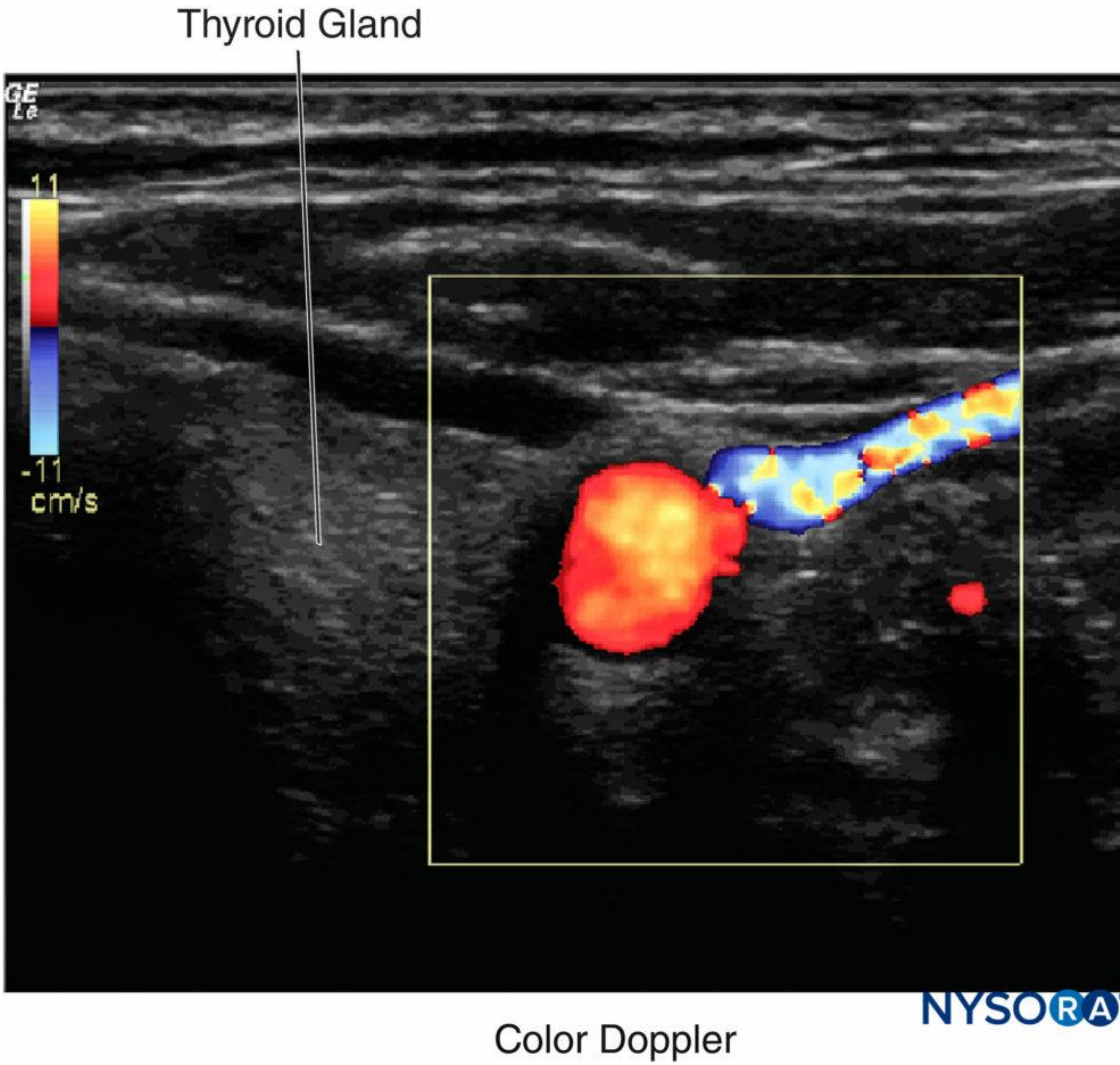


Figure 10. An example of B-mode imaging. The horizontal and vertical directions represent distances and tissues, whereas the intensity of the grayscale indicates echo strength. (Adapted with permission from Hadzic A: Hadzic's Peripheral Nerve Blocks and Anatomy for Ultrasound-Guided Regional Anesthesia, 2nd ed. New York: McGraw-Hill, Inc; 2011.)

- **Doppler Mode**
- The Doppler effect is based on the work of Austrian physicist Johann Christian Doppler. The term describes a change in the frequency or wavelength of a sound wave resulting from relative motion between the sound source and the sound receiver. In other words, at a stationary position, the sound frequency is constant. If the sound source moves toward the sound receiver, the sound waves have to be squeezed, and a higher-pitch sound occurs (positive Doppler shift); if the sound source moves away from the receiver, the sound waves have to be stretched, and the received sound has a lower pitch (negative Doppler shift) (**Figure 11**). The magnitude of Doppler shift depends on the incident angle between the directions of emitted ultrasound beam and moving reflectors. With a 90° angle there is no Doppler shift. If the angle is 0° or 180°, the largest Doppler shift can be detected. In medical settings, the Doppler shifts usually fall in the audible range.


- **Figure 11.** The Doppler effect. When a sound source moves away from the receiver, the received sound has a lower pitch and vice versa. (Adapted with permission from Hadzic A: Hadzic's Peripheral Nerve Blocks and Anatomy for Ultrasound-Guided Regional Anesthesia, 2nd ed. New York: McGraw-Hill, Inc; 2011.)
- Color Doppler produces a color-coded map of Doppler shifts superimposed onto a B-mode ultrasound image. Blood flow direction depends on whether the motion is toward or away from the transducer. Selected by convention, red and blue colors provide information about the direction and velocity of the blood flow. According to the color map (color bar) in the upper left-hand corner of the figure (**Figure 12**), the red color on the top of the bar denotes the flow coming toward the ultrasound probe, and the blue color on the bottom of the bar indicates the flow away from the probe.




- **Figure 12** Color Doppler produces a color-coded map of Doppler shapes superimposed onto a B-mode ultrasound image. Selected by convention, red and blue colors provide information about the direction and velocity of the blood flow. (Adapted with permission from Hadzic A: Hadzic's Peripheral Nerve Blocks and Anatomy for Ultrasound-Guided Regional Anesthesia, 2nd ed. New York: McGraw-Hill, Inc; 2011.)

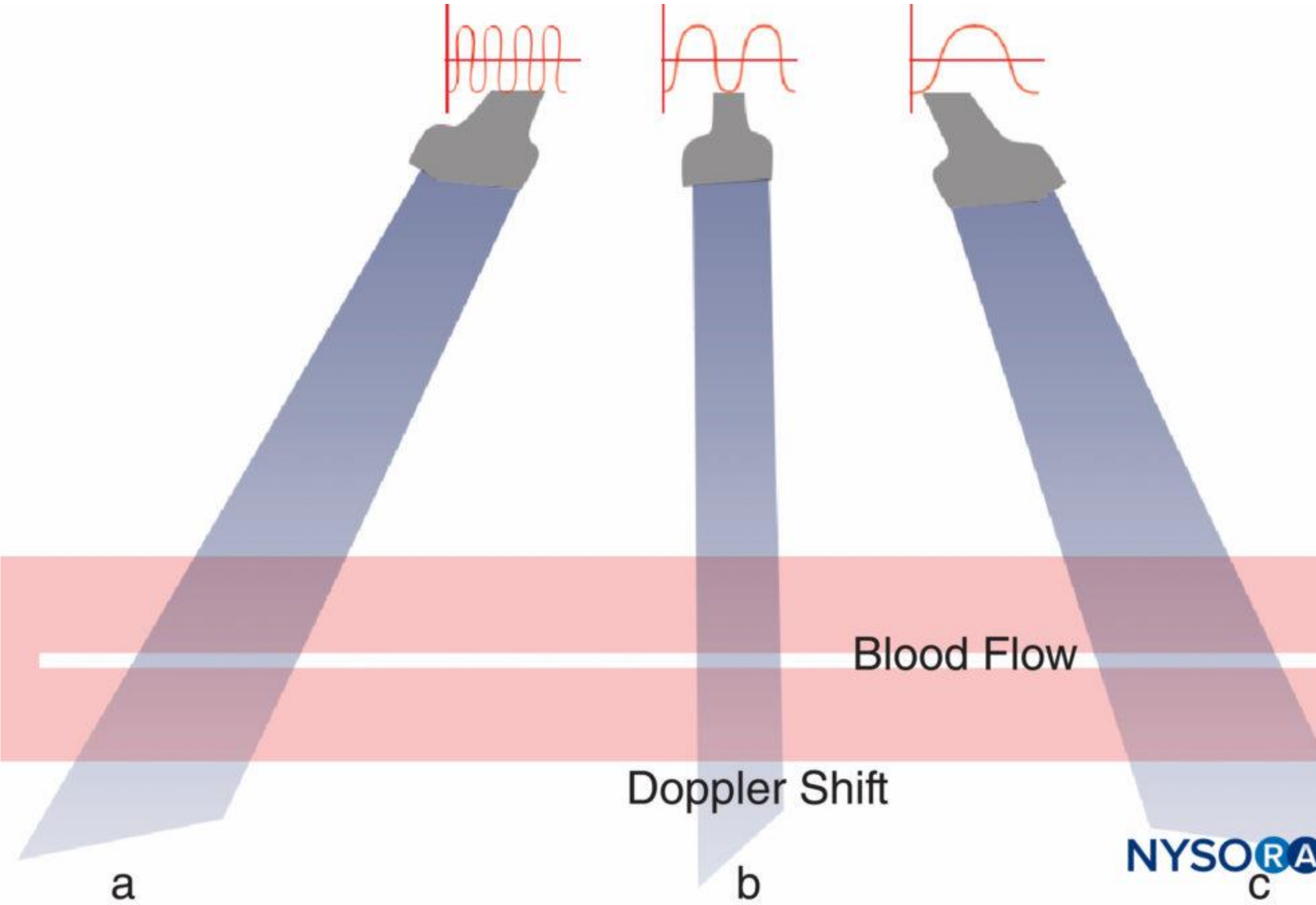
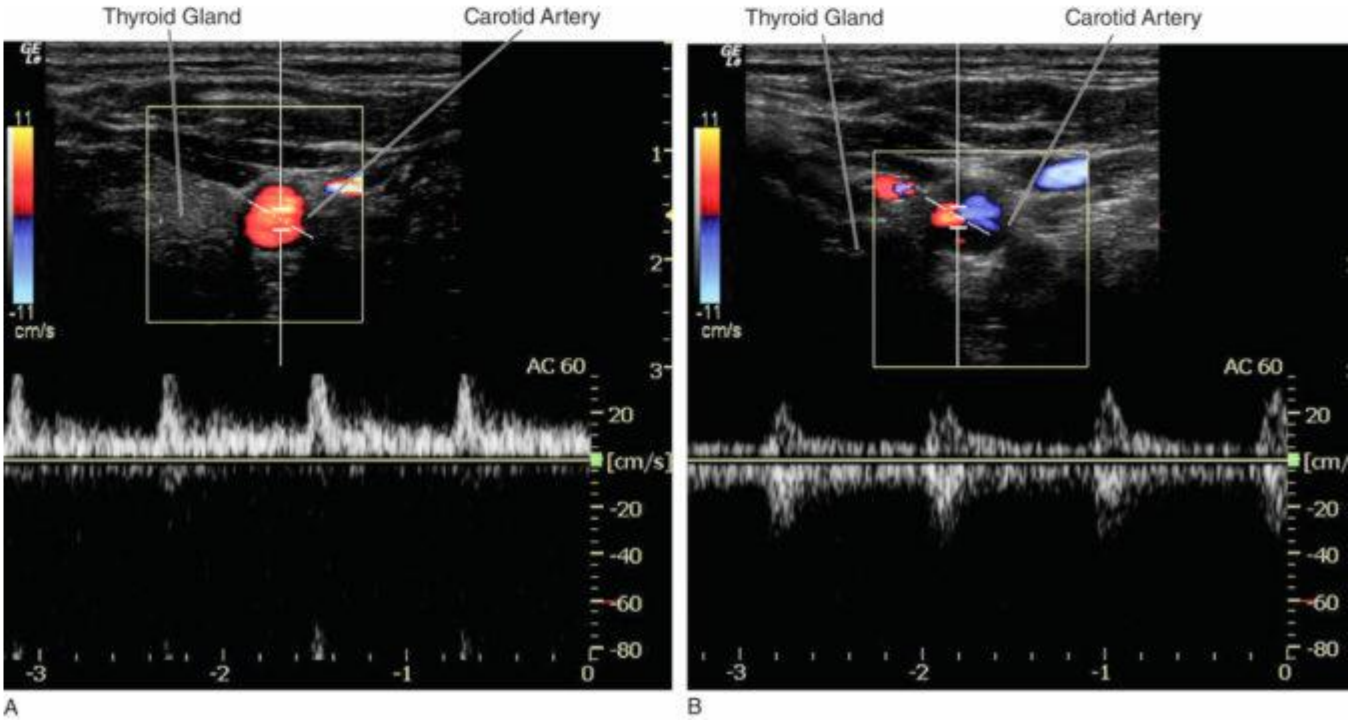



**Figure 13.** Color Doppler mode is used to detect the direction of the blood vessel.

- In ultrasound-guided peripheral nerve blocks, color Doppler mode is used to detect the presence and nature of the blood vessels (artery vs. vein) in the area of interest. When the direction of the ultrasound beam changes, the color of the arterial flow switches from blue to red, or vice versa, depending on the convention used (Figures 13, 14A, 14B, and 14C). Power Doppler is up to five times more sensitive in detecting blood flow than color Doppler, and it is less dependent on the scanning angle. Thus, power Doppler can be used to identify the smaller blood vessels more reliably. The drawback is that power Doppler does not provide any information on the direction and speed of blood flow (Figure 15).




- **Figure 14.** A: Carotid artery displays a red color when the blood flows toward the transducer. B: Carotid artery displays ambiguous color at a 90° Doppler angle; the equal waveform can be seen on both sides of the baseline. C: Carotid artery displays blue color when the blood flows away from the transducer.

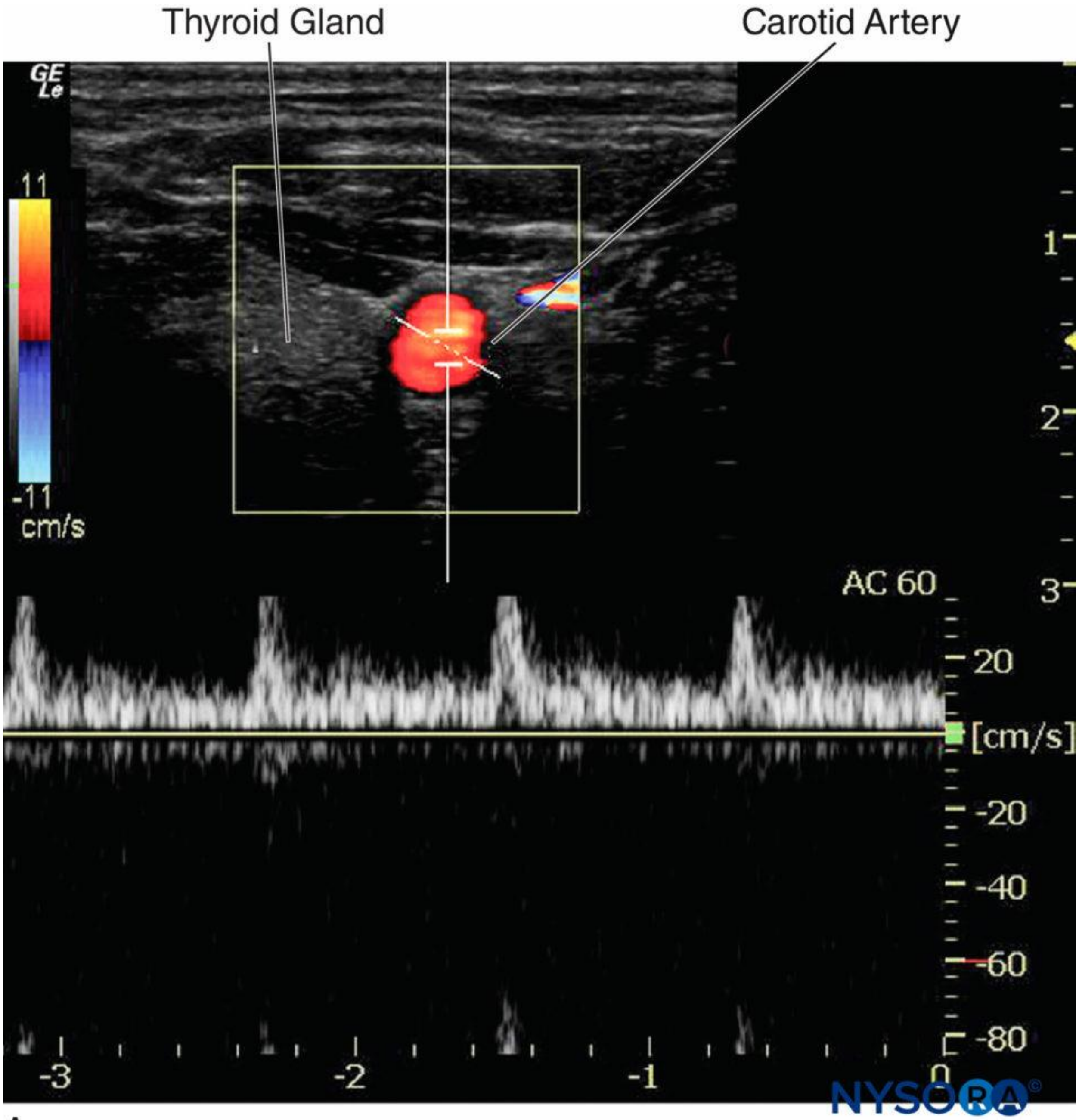



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**Figure 15.** Although the power Doppler may be useful in identifying smaller blood vessels, the drawback is that it does not provide information on the direction and speed of blood flow. (Adapted with permission from Hadzic A: Hadzic's Peripheral Nerve Blocks and Anatomy for Ultrasound-Guided Regional Anesthesia, 2nd ed. New York: McGraw-Hill, Inc; 2011.)

- **M-Mode**
- A single beam in an ultrasound scan can be used to produce a picture with a motion signal, where movement of a structure such as a heart valve can be

depicted in a wave-like manner. M-mode is used extensively in cardiac and fetal cardiac imaging; however, its present use in regional anesthesia is negligible (**Figure 16**).

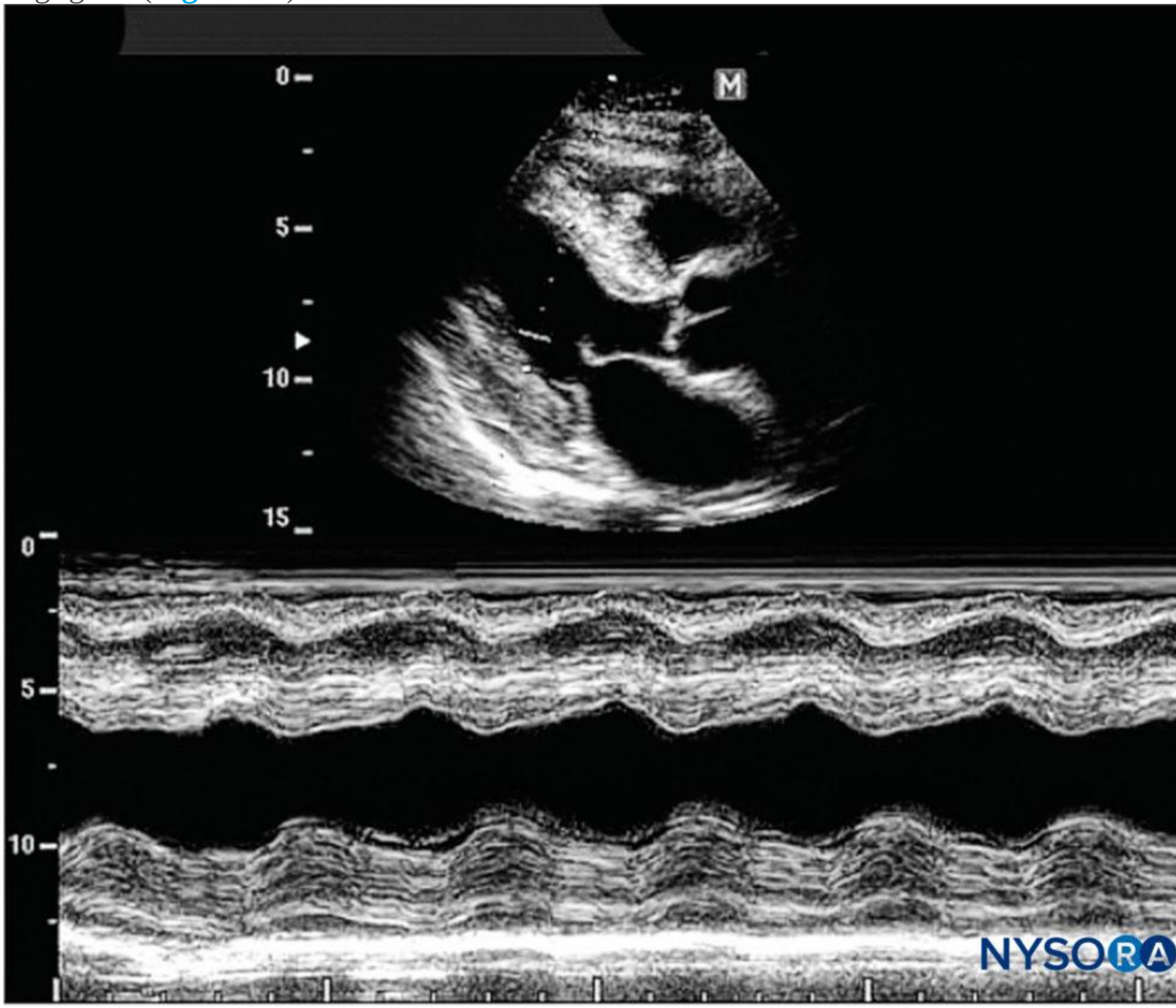
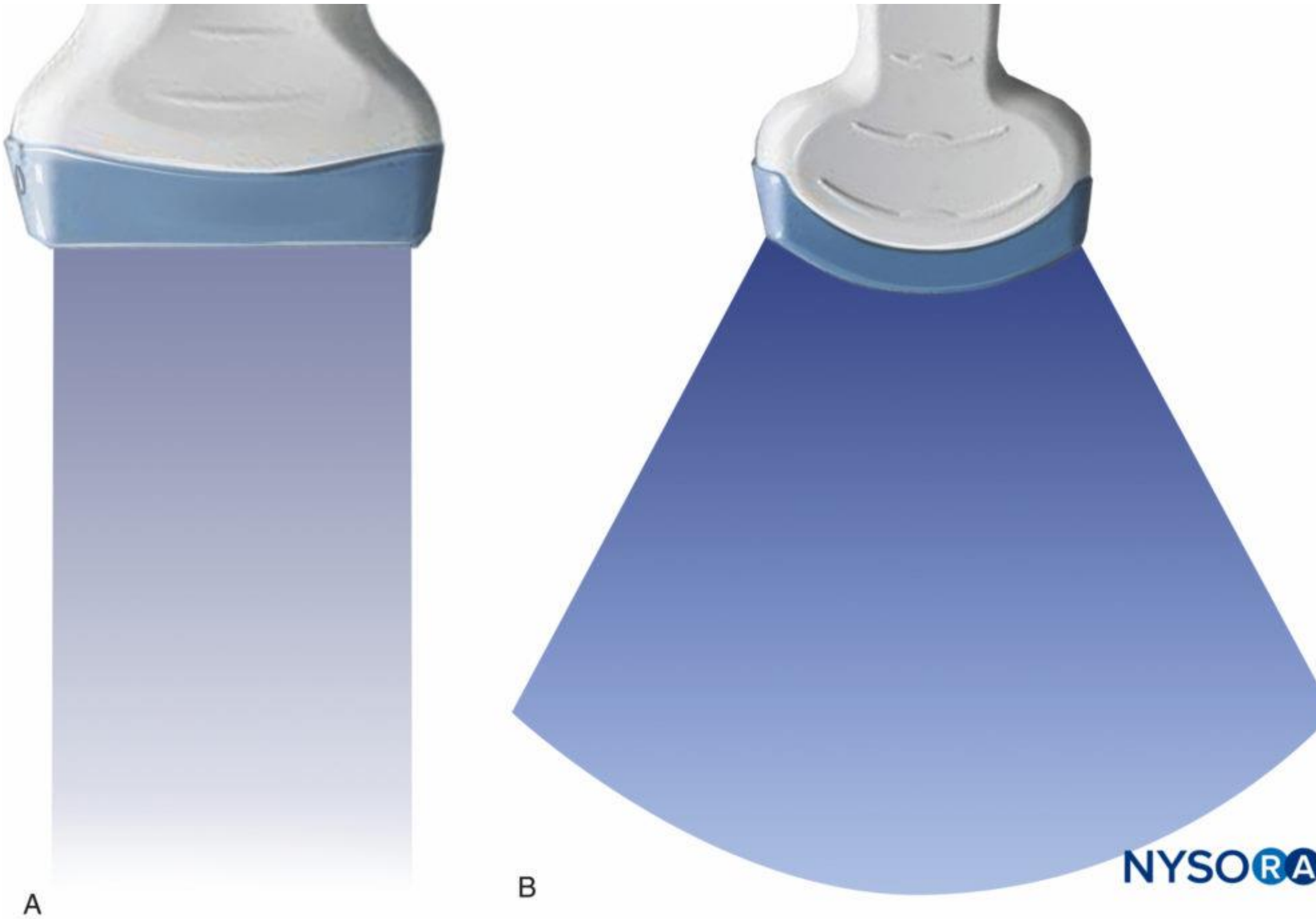



**Figure 16.** M-mode consists of a single beam used to produce an image with a motion signal. Movement of a structure can be depicted in a wavelike matter. (Reproduced with permission from Hadzic A: Hadzic's Peripheral Nerve Blocks and Anatomy for Ultrasound-Guided Regional Anesthesia, 2nd ed. New York: McGraw-Hill, Inc; 2011.)

- **ULTRASOUND INSTRUMENTS**
- Ultrasound machines convert the echoes received by the transducer into visible dots, which form the anatomic image on an ultrasound screen. The brightness of each dot corresponds to the echo strength, producing what is

known as a grayscale image. Two types of scan transducers are used in regional anesthesia: linear and curved. A linear transducer can produce parallel scan lines and a rectangular display, called a linear scan, whereas a curved transducer yields a curvilinear scan and an arc-shaped image (**Figures 17A and 17B**). In clinical scanning, even a very thin layer of air between the transducer and skin may reflect virtually all the ultrasound, hindering any penetration into the tissue. Therefore, a coupling medium, usually an aqueous gel, is applied between surfaces of the transducer and skin to eliminate the air layer.

- The ultrasound machines currently used in regional anesthesia provide a 2D image, or “slice.” Machines capable of producing three-dimensional (3D) images have recently been developed. Theoretically, 3D imaging should help in understanding the relationship of anatomic structures and the spread of local anesthetics. There are three major types of 3D ultrasound imaging: (1) Freehand 3D is based on a set of 2D cross-sectional ultrasound images acquired from a sonographer sweeping the transducer over a region of interest (**Figures 18A and 18B**). (2) Volume 3D provides 3D volumetric images using a dedicated 3D transducer. The transducer elements automatically sweep through the region of interest during the scanning; the sonographer is not required to perform hand motions (**Figure 18C**). (3) Real-time 3D takes multiple images at different angles, allowing the sonographer to see the 3D model moving in real time. However, typical spatial resolution of 3D imaging is about 0.34–0.5 mm. At present, 3D imaging systems still lack the resolution and simplicity of 2D images, so their practical use in regional anesthesia is limited.




- **Figure 17.** A: Rectangular scan field given by linear transducer. B: Arc-shaped scan field given by curved transducer. (Adapted with permission from Hadzic A: Hadzic's Peripheral Nerve Blocks and Anatomy for Ultrasound-Guided Regional Anesthesia, 2nd ed. New York: McGraw-Hill, Inc; 2011.)

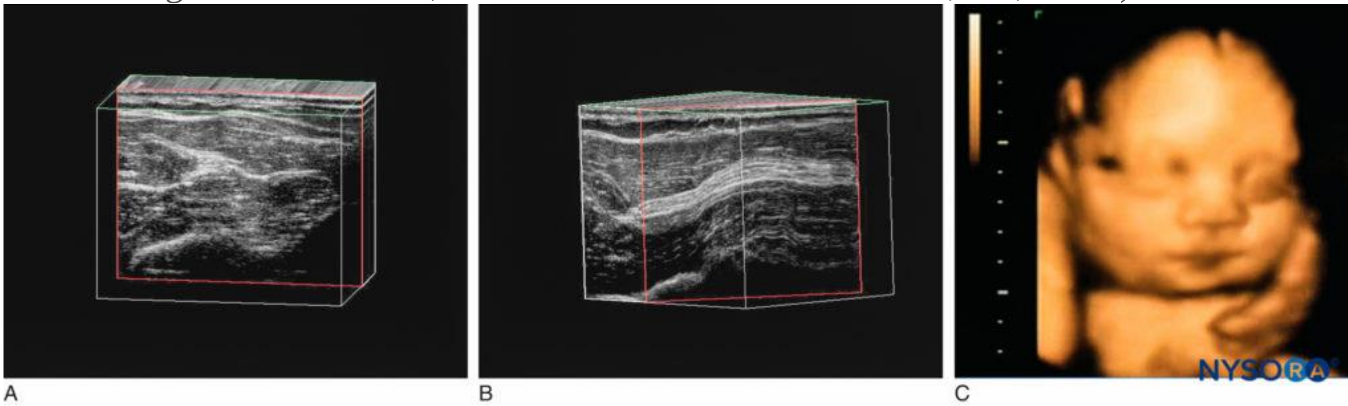



**Figure 18.** A: Freehand 3D imaging. A linear transducer produces parallel scan lines and a rectangular display; linear scan. B: Freehand 3D imaging. A curved "phase array" transducer results in a curvilinear scan and an arch-shaped image. C: Fetal face viewed by volume 3D imaging. (Reproduced with

permission from Hadzic A: Hadzic’s Peripheral Nerve Blocks and Anatomy for Ultrasound-Guided Regional Anesthesia, 2nd ed. New York: McGraw-Hill, Inc; 2011.)

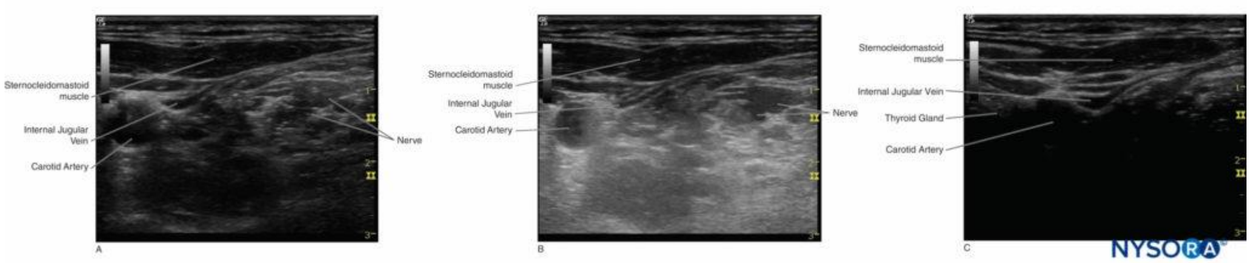
- **TIME-GAIN COMPENSATION**
- The echoes exhibit a steady decline in amplitude with increasing depth. This occurs for two reasons: First, each successive reflection removes a certain amount of energy from the pulse, decreasing the generation of later echoes. Second, tissue absorbs ultrasound, so there is a steady loss of energy as the ultrasound pulse travels through the tissues. This can be corrected by manipulating time-gain compensation (TGC) and compression functions. *Gain* is the ratio of output to input electric power; it controls the brightness of the image. The gain is usually measured in decibels (dB). Increasing the gain amplifies not only the returning signals, but also the background noise within the system in the same manner. TGC is a time-dependent amplification. TGC function can be used to increase the amplitude of incoming signals from various tissue depths.
- The layout of the TGC controls varies from one machine to another. A popular design is a set of slider knobs. Each knob in the slider set controls the gain for a specific depth, which allows for a well-balanced gain scale on the image (**Figures 19A**, **19B**, and **19C**).
- 


**Figure 19**: A, B, and C: The effect of the time-gain compensation settings. Time-gain compensation is a function that allows time- (depth) dependent amplification of signals returning from different depths. (Adapted with permission from Hadzic A: Hadzic’s Peripheral Nerve Blocks and Anatomy for Ultrasound-Guided Regional Anesthesia, 2nd ed. New York: McGraw-Hill, Inc; 2011.)

- *Amplification* is the conversion of the small voltages received from the transducer into larger ones that are suitable for further processing and storage. There are two amplification processes considered to increase the magnitude of ultrasound echoes: linear and nonlinear amplification. Currently, the ultrasonic imaging system with linear amplifiers is commonly used in medical diagnostic applications. However, the strength of echoes attenuates exponentially as the distance between the transducer and the reflector increases. Ultrasonic imaging instruments equipped with logarithmic amplifiers can display echo signals with a wider dynamic range than a linear amplifier and remarkably improve the sensitivity for a small magnitude of echoes on the screen.

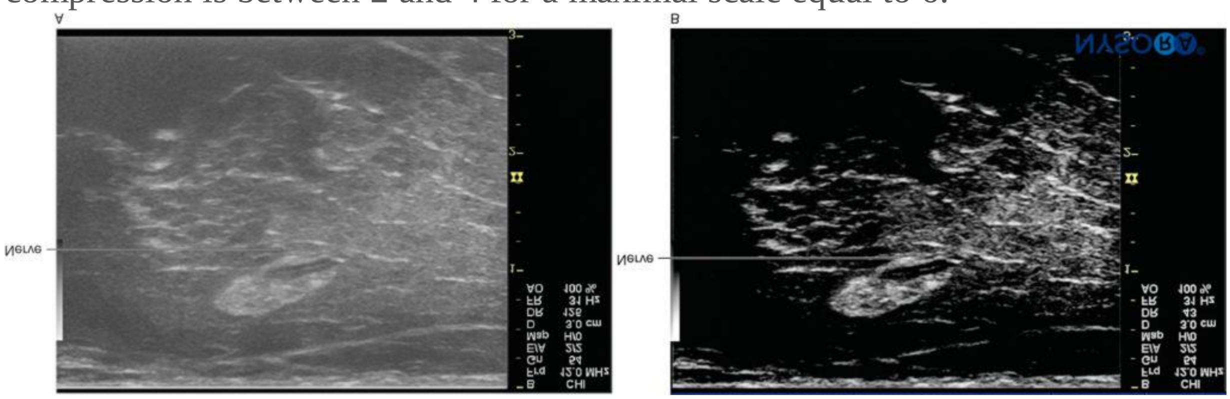
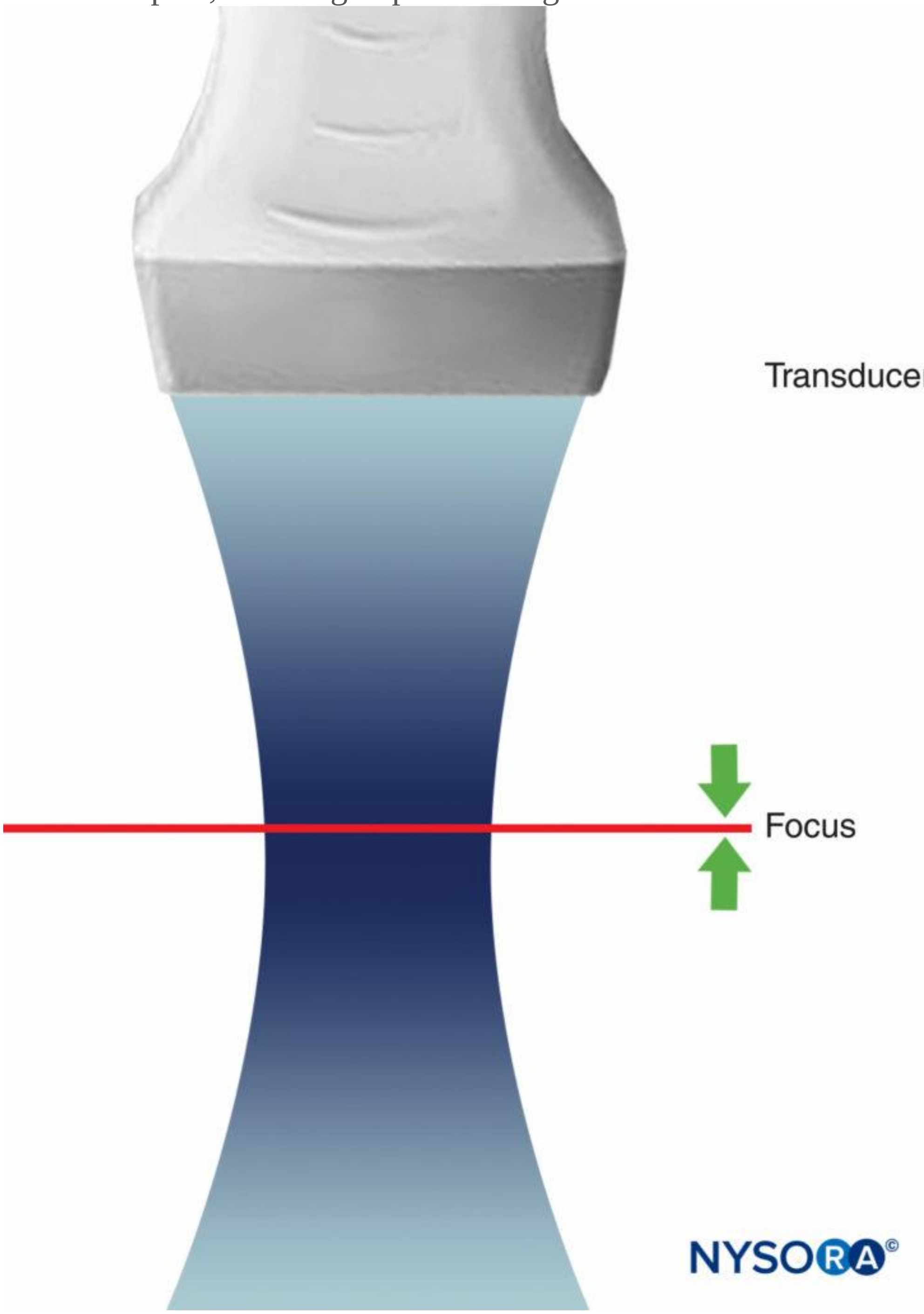
- *Dynamic range* is the range of amplitudes from largest to the smallest echo signals that an ultrasound system can detect. The wider/higher dynamic range presents a larger number of grayscale levels, and it creates a softer image; the image with a narrower/lower dynamic range appears with more contrast (**Figures 20A and 20B**). Dynamic range less than 50 dB or greater than 100 dB is probably too low or too high in terms of visualization of peripheral nerve. Compression is the process of decreasing the differences between the smallest and largest echo-voltage amplitudes; the optimal compression is between 2 and 4 for a maximal scale equal to 6.
- 

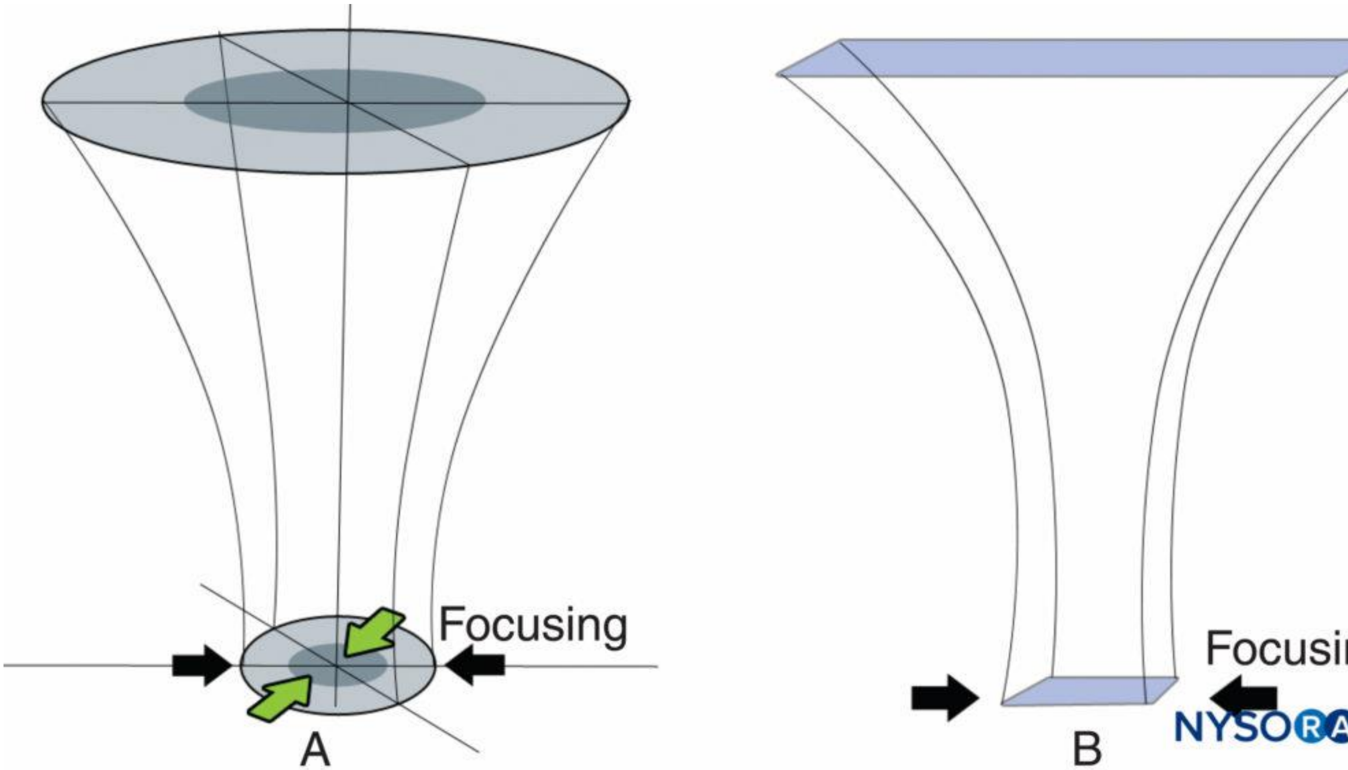
**Figure 20.**: A: A softer image provided by a higher dynamic range. B: An image with more contrast provided by a lower dynamic range.

- **FOCUSING**
- As previously discussed, it is common to use electronic means to narrow the width of the beam at some depth and achieve a focusing effect similar to that obtained using a convex lens (**Figure 21**). There are two types of focusing: annular and linear. These are illustrated in **Figures 22A** and **22B**, respectively.
- Adjusting focus improves the spatial resolution on the plane of interest because the beam width is converged. However, the reduction in beam width

at the selected depth is achieved at the expense of degradation in beam width at other depths, resulting in poorer images below the focal zone.




- **Figure 21**: A demonstration of focusing effect. An electronic means can be used to narrow the width of the beam at a specific depth, resulting in the focusing effect and greater resolution at a chosen depth. (Adapted with permission from Hadzic A: Hadzic's Peripheral Nerve Blocks and Anatomy for Ultrasound-Guided Regional Anesthesia, 2nd ed. New York: McGraw-Hill, Inc; 2011.)

- 


- **Figure 22**: A: Annular focusing is electronic focusing from all directions in the scan plane given by an annular transducer that contains several ring elements arranged concentrically. B: Linear focusing is electronic focusing applied along both lateral sides in the scan plane.
- **BIOEFFECT AND SAFETY**
- The mechanisms of action by which an ultrasound application could produce a biologic effect can be conceptually categorized into two aspects: heating and mechanical. In reality, these two effects are rarely separable except for extracorporeal lithotripsy, the therapeutic application of mechanical bioeffects alone. The generation of heat increases as ultrasound intensity or frequency is increased. For similar exposure conditions, the expected temperature increase in bone is significantly greater than in soft tissues. In in vivo experiments, high-intensity ultrasound (usually > 2 W/cm$^2$) is used to evaluate harmful biological effect; it is 5 to 20 times larger than therapeutic intensities (0.08–0.5 W/cm$^2$) and 8 to 100 times larger than diagnostic intensities (color flow mode 0.25 W/cm$^2$, B-mode scan 0.02 W/cm$^2$). Reports in animal models (mice and rats) suggest that application of ultrasound may result in a number of undesired effects, such as fetal weight

reduction, postpartum mortality, fetal abnormalities, tissue lesions, hind limb paralysis, blood flow stasis, and tumor regression. Other reported undesired effects in mice are abnormalities in B-cell development and ovulatory response and teratogenicity.

- In general, adult tissues are more tolerant of rising temperature than fetal and neonatal tissues. A modern ultrasound machine displays two standard indices: thermal and mechanical. The thermal index (TI) is defined as the transducer acoustic output power divided by the estimated power required to raise tissue temperature by 1°C. The mechanical index (MI) is equal to the peak rarefactional pressure divided by the square root of the center frequency of the pulse bandwidth. TI and MI indicate the relative likelihood of thermal and mechanical hazard in vivo, respectively. Either TI or MI greater than 1.0 is hazardous.
- The biologic effect due to ultrasound also depends on tissue exposure time. The researchers usually use pregnant mice to expose to ultrasound with a minimum intensity of 1 $W/cm^2$ for 60 to 420 minutes to evaluate the time-dependent adverse events that happen in rodent fetuses. Fortunately, ultrasound-guided nerve block requires the use of only low TI and MI values on the patient for a short period of time. Based on in vitro and in vivo experimental study results to date, there is no evidence that the use of diagnostic ultrasound in routine clinical practice is associated with any biologic risks.