Principles of Musculoskeletal Ultrasound

Outline

- Introduction
- Benefits and Limitations of US
- Ultrasound (US) Physics
- Terminology
- Equipment
- Normal US appearance of structures
- Artifacts
- Injection technique
- Conclusions

Introduction

- Physiatrists involved in US ~ 7 decades

- MSK Sono = MRI
- MSK Sono > MRI
  - Claustrophobic, metal implants, dynamic

- MRA for Labral tear, ACL/PCL, intra-articular lesions

- Diagnostic
- Therapeutic/Interventional

- Use of high frequency sound waves (3-17 MHz) to image soft tissues and bony structures in the body for the purposes of diagnosing pathology or guiding interventional procedures

- Higher resolution than MRI for superficial structures
- Detailed images of MSK system

- Extension of physical exam.
- Built in control.
- Quick exam with quick answers.
- Pain-free with no claustrophobia.
- Dynamic examination.
- Digital images to print, save, transport.

Introduction -Indications

- Interventional
  - Injections
  - Tenotomy
  - Aspiration/lavage
  - Biopsy
- Diagnostic
  - Tendon (tendinopathy, tears)
  - Muscle (strains, contusions)
  - Nerve (entrapment)
  - Ligament
  - Joint
  - Dynamic

Benefits of MSK US

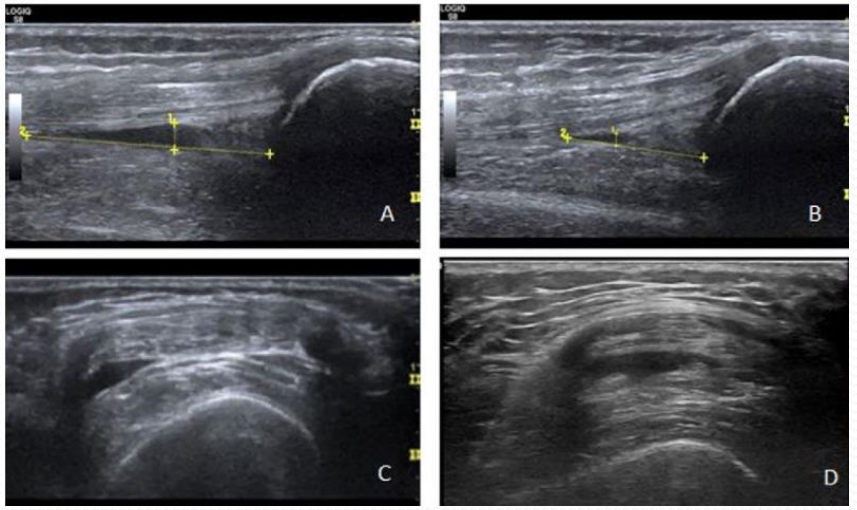
- Ability to image in real-time = hands-on, dynamic, fast
- Interactive –allows feedback from patient (sono-palpation)
- Generally unaffected by metal artifacts
- No radiation to patient or provider
- Exam of contralateral limb for comparison (split-screen comparison)
- High resolution
- Real-time guidance for interventional procedures
- Portable
- Relatively inexpensive

Limitations of MSK US

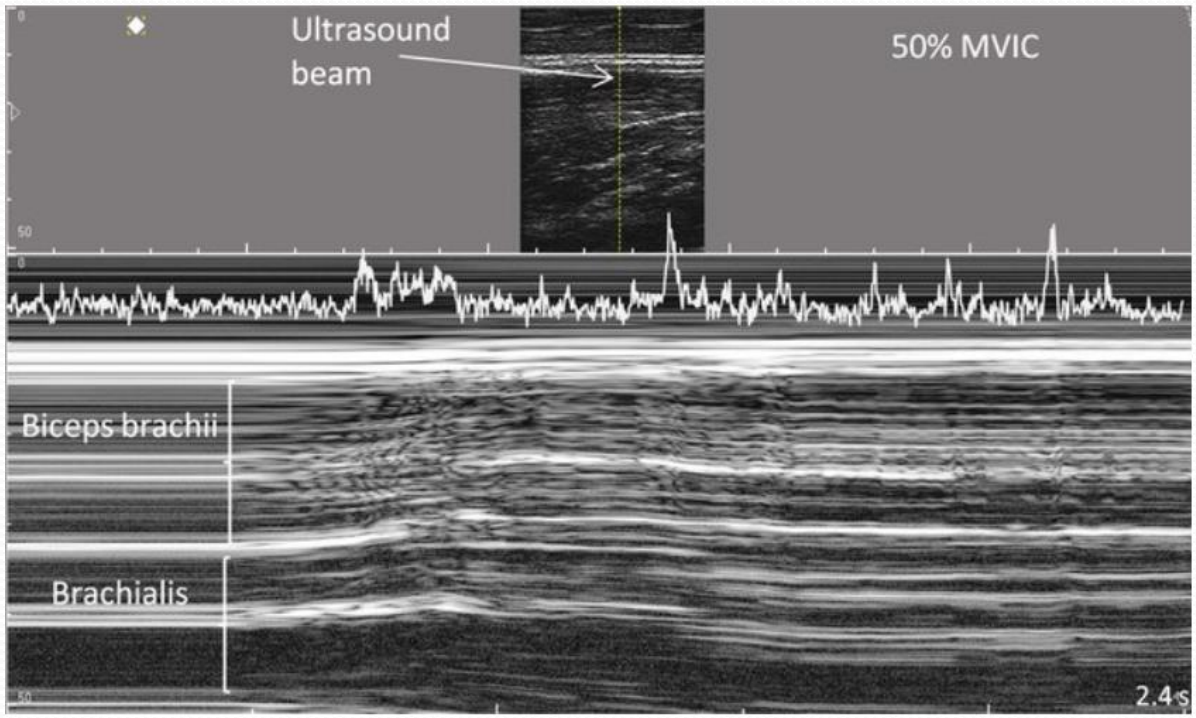
- Detailed picture of relatively small area
- Limited penetration
- Lower resolution at greater depths
- Unable to penetrate bone
- **Operator dependent**
- Education (anatomy), scanning skills and interpretation
- Equipment –cost, quality variable

The Machine

- There are various types (modes) of ultrasound images that are commonly obtained.
- In B-mode (brightness mode) ultrasound, a linear array of transducers about the width of a credit card simultaneously scan a plane through the body that can be viewed as a two dimensional image on screen. This is sometimes described as 2D mode, and it provides the single still images that are frequently used for documentation purposes to define structures.



- M-Mode (motion mode) is used to capture multiple images in sequence. In simple terms, it collects a video of a particular scan

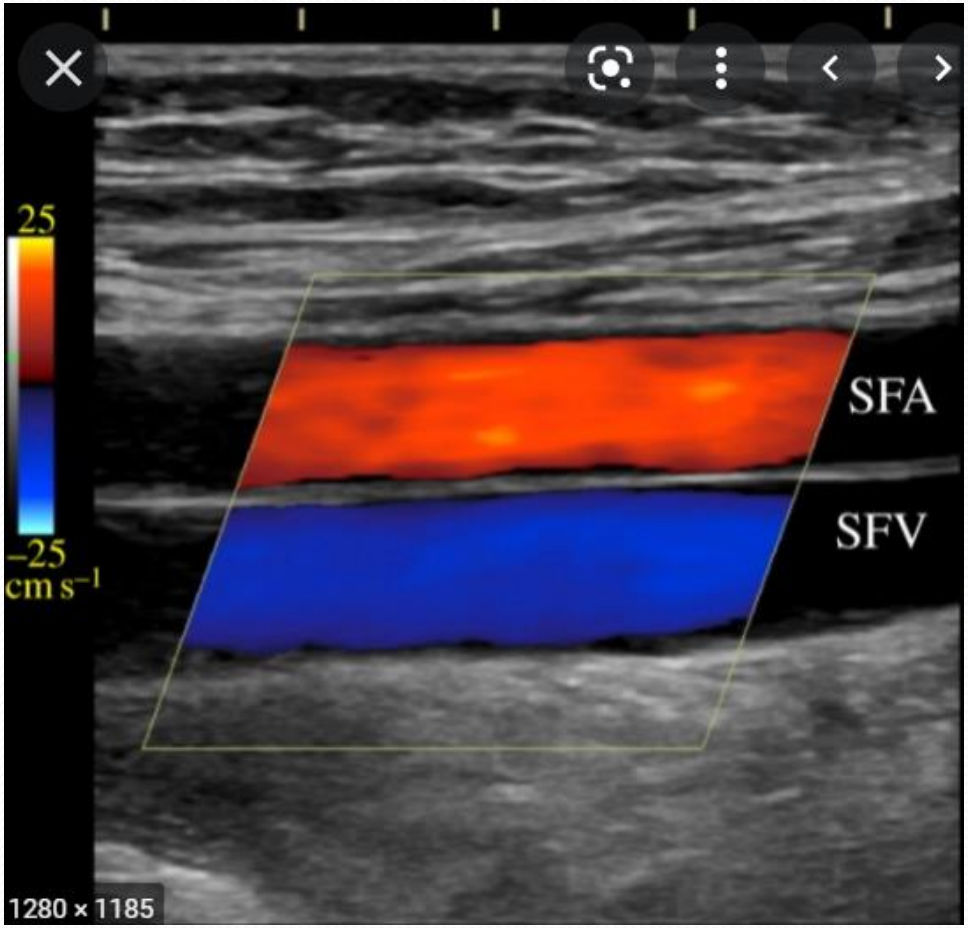


Doppler Mode

- The Doppler effect, where the sound frequency of an object changes as the object travels toward or away from the transducer, is used to help define the presence, direction, and velocity of blood flow on ultrasound. It is useful to help provide adequate information about the blood flow around a particular anatomical area. There are several different types of Doppler modes that can be used with most ultrasound machines.

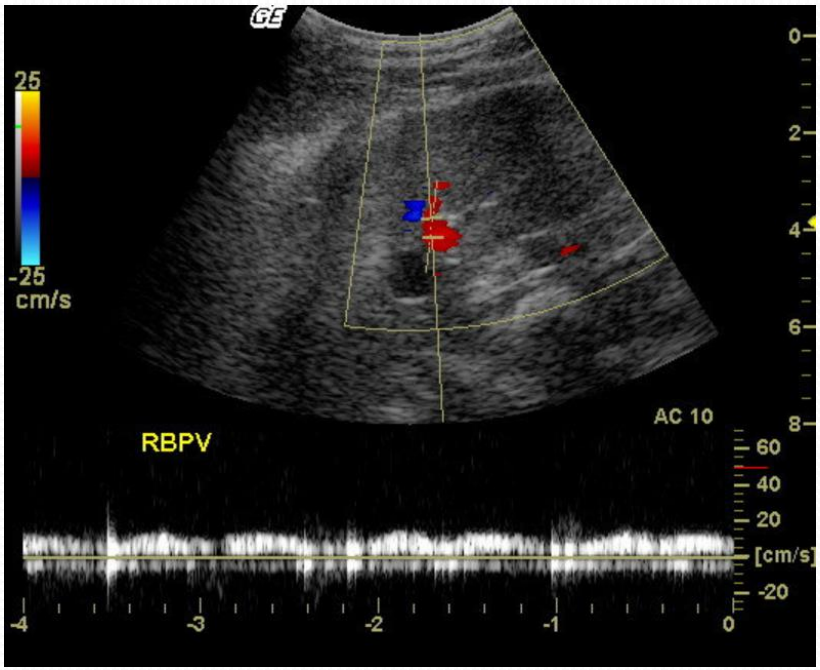
Color Doppler

- This mode is used to define blood flow by superimposing color on a gray-scale ultrasound image. The use of color Doppler helps determine whether blood flow exists (i.e., identifies location of blood vessels) and is conventionally set up to show blue color when the blood flows away from the transducer and red color when it flows toward it. Flow velocity cannot be measured within this feature.
- Clinical Application When performing a joint injection – of the hip joint, for example – the use of color Doppler can identify the location of blood vessels so the angle of approach can be set to avoid the path of the vessel.


25
−25
cm s⁻¹
SFA
SFV
1280 × 1185

Pulsed Wave or Duplex Doppler

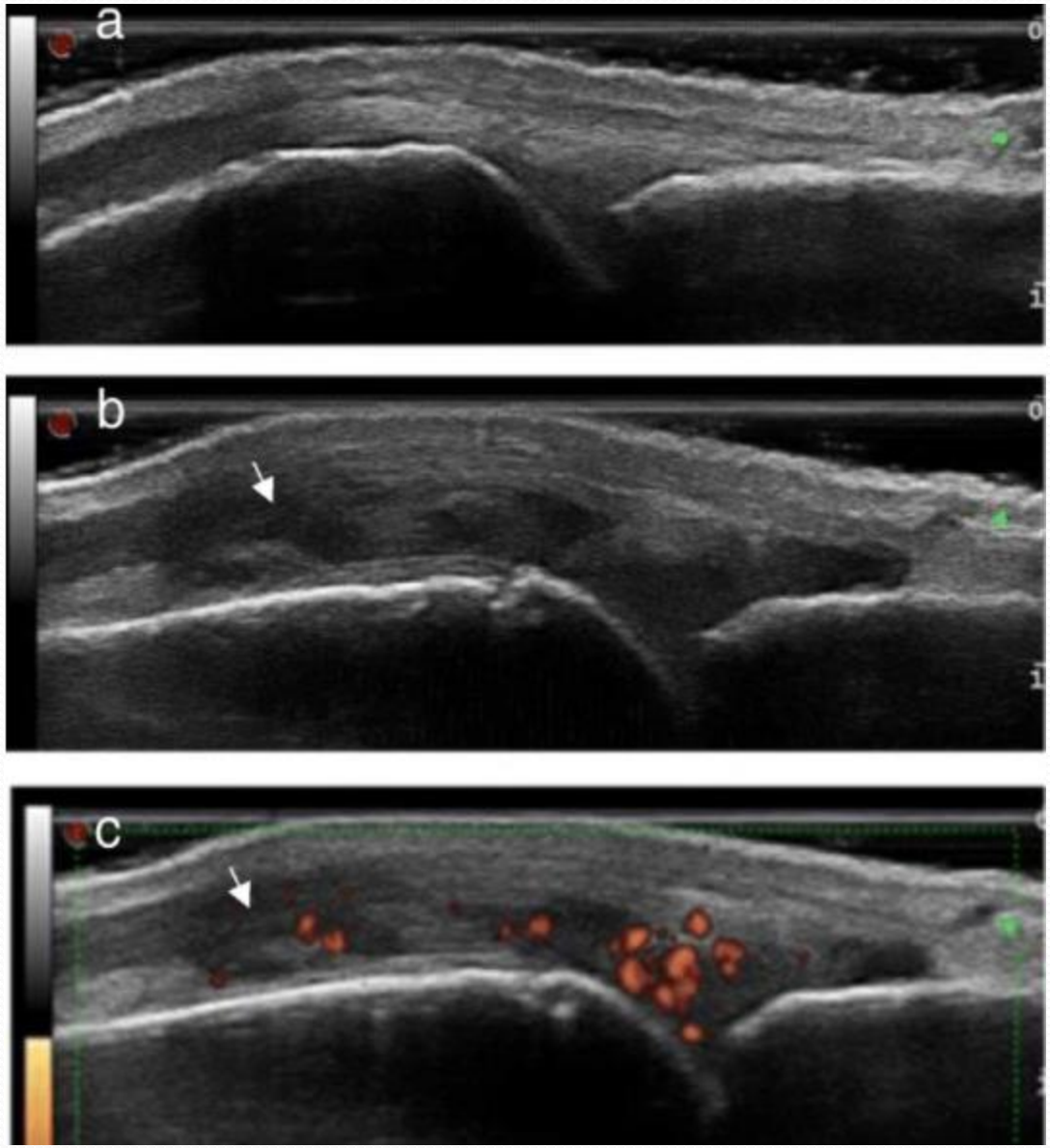
- This provides an image of a moving object along with its waveform. It shows both the presence of flow and defines the velocity of blood flow within a vessel. Clinical Application During echocardiograms, this setting can define the presence and velocity of flow across a valve



Power Doppler

- this is color Doppler mode with a high sensitivity to blood flow to help visualize small vessels or vessels with slow flow. This mode assigns color regardless of the direction in which the blood flow is traveling. Color will appear when there is increased perfusion of an area secondary to infammation or neovascularization. The weakness in using this technique is that its high sensitivity can create artifact in certain situations, such as transducer motion, thus making it seem as though vessels are present when they are not. This typically appears as a dense area of “color” on the screen. Additionally, it does not tell directionality or velocity of the flow seen.

- Clinical Application Power Doppler can be used to evaluate neovascularization of the patellar tendon in the setting of chronic tendinosis

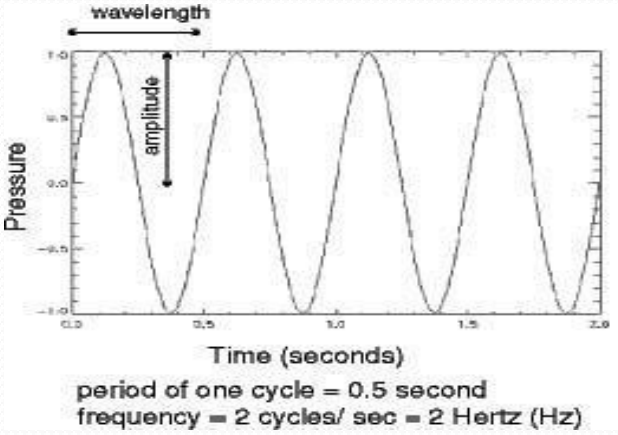

a
b
c

Ultrasound Physics

- Transducer (probe)
  - crystals (lead zirconate titanate)

Size, design and frequency
depend upon the examination

- Machine
  - Applies a rapidly alternating *electrical* current to the crystals ➡ vibration ➡ generate sinusoidal sound wave (*mechanical* energy) =



Piezoelectricity definition

- Also called piezoelectric effect is the ability of certain materials to generate an AC voltage when subjected to mechanical stress or vibration , or to vibrate when subjected to an AC voltage , or both.

Ultrasound Physics

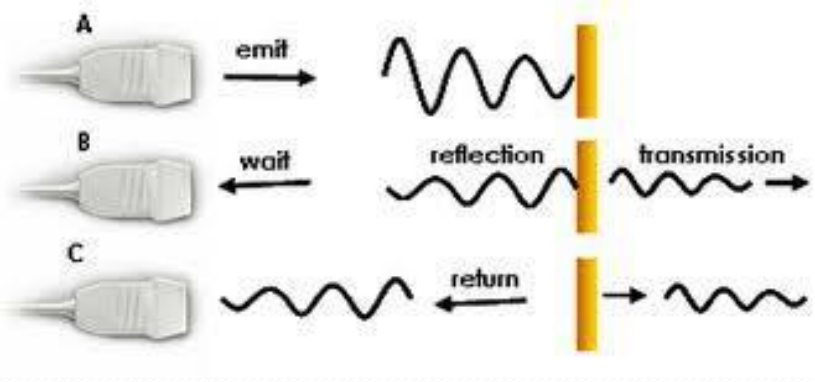
- The frequency and amplitude of the sound waves are determined by:
  - electrical current used to stimulate the crystals
  - material properties of the crystals
  - thickness of the crystals

- A range of frequencies are produced (Bandwidth)
- There is a preferential frequency

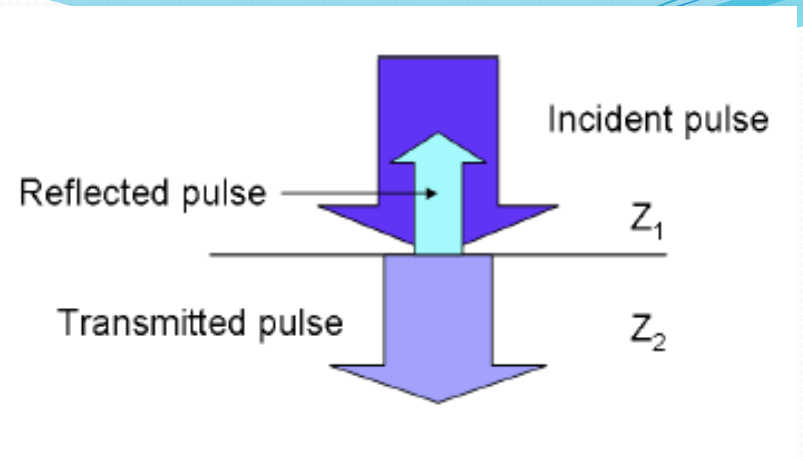
- Higher frequency : higher resolution but increased absorption (reduced penetration)

Ultrasound Physics

- Emission (requires a medium)
- Forward transmission until acoustic interface (change in the density of adjacent tissues): **Recognizes differences**
- Partial Reflection
- Back to the transducer (now a receiver) (Sound energy transformed into electrical signal)
- Processing
- Computer calculates amplitude , depth and time of return signal and generates 2-D black/white B-mode image of the body

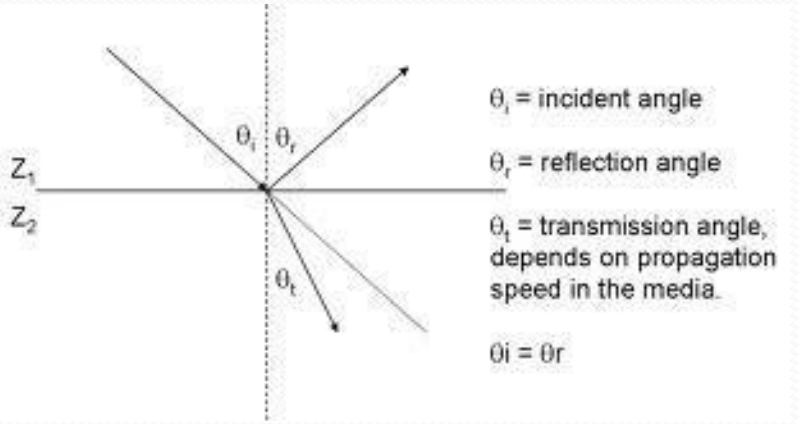


Ultrasound Physics

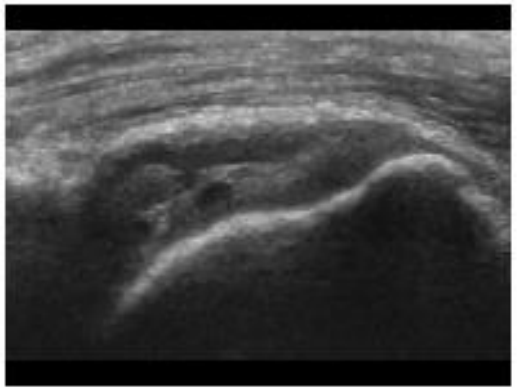


- Echoes
  - Perpendicular incidence
  - Reflected pulse -reflected directly back
  - Transmitted pulse –passes straight through

  - Oblique incidence
  - Some reflected back at an angle
  - Some passes through refracted (transmission angle)

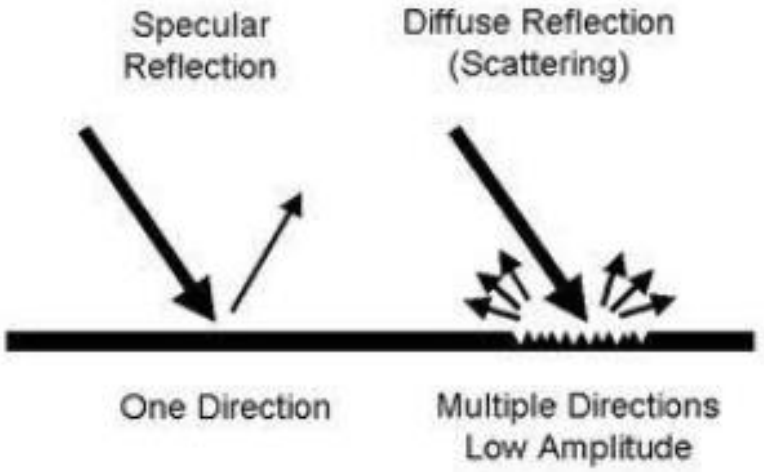


Reflection



- Specular Reflection
  - Reflection from a smooth surface
- Scattering
  - Redirection of sound in several directions due to rough edges (torn tissue) or heterogeneous media
  - Some of the sound is reflected back to the transducer (= backscatter)

→ visualization of the media



Interaction of Ultrasound with Tissue

- Greater the Acoustic impedance , greater the returned signal
- largest difference is solid-gas interface
- we don't like gas or air
- we don't like bone for the same reason
- GEL!!

Standoff Pad

- The standoff pad is made of an acoustically transparent medium that provides a compliant surface to image bony or uneven surfaces.
- Standoff pads also assist in imaging shallow or sensitive areas by increasing the depth of the structures and providing a cushioned surface

Ultrasound Physics

- Impedance (Acoustic interface)
- US waves are reflected at the interface of two different tissues, dependent on the properties of each tissue
- Echogenicity = Ability to reflect sound waves back to transducer
- If reflects large amount of sound → brighter
  - Interface composed of very *different* tissues
  - e.g. interface between bone and muscle (bone = bright)
- Less reflection → darker
  - More *similar* tissues
- Important point:
  - Images are based on the *relative* material properties of the tissue compared with adjacent regions

Acoustic Impedance

- Greater the difference=Greater reflection

Material	Density (kg/m^3)	Velocity (m/s)	Acoustic Impedence (kg/m^2s)
Air	1.3	330	429
Water	1000	1500	1.5×10^6
Fat	925	1450	1.38×10^6
Blood	1060	1570	1.59×10^6
Muscle	1075	1590	1.70×10^6
Bone	1908	4080	7.78×10^6

Ultrasound Use

- Step 1
- Transducer selection
- Step 2
- Depth
- Step 3
- Focal zone & Adding focal zones
- Step 4
- Gain

Step 1: Transducers

- Frequency
  - Expressed in megahertz (MHz)
  - High frequency
    - Greater resolution, shallow penetration (attenuation)
    - Best for more superficial structures
  - Low frequency
    - Lower resolution, greater penetration
    - For deeper structures

Transducers

Linear array

- End of transducer flat
- Sound waves exit perpendicular
- Less anisotropy
- Limited field of view
- Good for superficial structures

Curvilinear array

- End of transducer curved
- Sound waves emitted in a fan
- Increased anisotropy
- Large field of view
- Good for deep structures

Transducer Care and Cleaning

- Proper care and cleaning of ultrasound transducers is important, not only to maintain proper probe functioning but also to prevent infections and transmission of communicable diseases.
- Instrumentation used for diagnostic testing must be maintained in good operating condition and undergo routine calibration at least once a year
- There must be routine inspection and testing for electrical safety of all existing equipment.

clean the transducer after each use (follow the manufacturer's guidelines).

Probe is not going to be exposed to blood or any other bodily fluids.

Wiping the transducer off with a soft cloth using a mild soap and water is acceptable after each use. •

An alternative to this is to clean the transducer with antimicrobial/germicidal wipes, with low alcohol content, a soft disposable cloth dampened with a bactericidal agent, or something similar. •

Before proceeding with any sterile procedure (injection or placing transducer near an open wound or lesion on the dermis), the transducer should be cleaned using an antimicrobial wipe.

Many practitioners use sterile sheaths, so the transducer is never directly exposed to bodily fluids. If this is not the case, care should be taken to not expose the transducer directly to bodily fluids. If this happens, follow manufacturer's guidelines to properly sanitize the transducer.

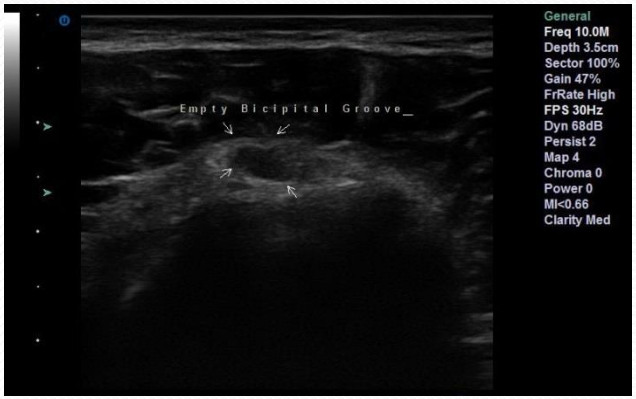
- Avoid direct contact of the transducer head and cable with sharp objects, such as needles or scalpels. •
- Do not clean the transducer with a brush or sponge without consulting the manufacturer, because these objects may damage the transducer head.

Transducer positioning

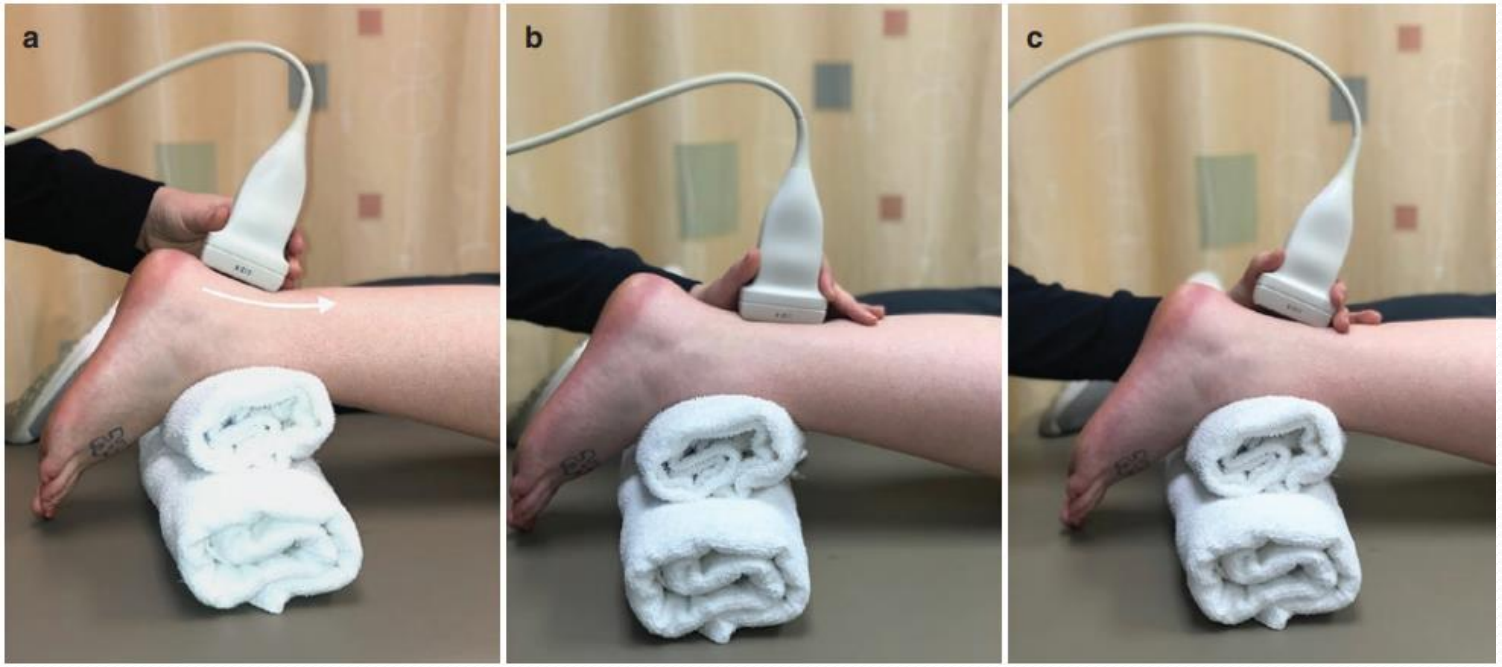
- Simultaneous contact with:
  - Transducer
  - Examiner's 4th & 5th finger with Skin surface

- Longitudinal
- Parallel to long axis of the structure

- Transverse
- Perpendicular to the long axis of the structure

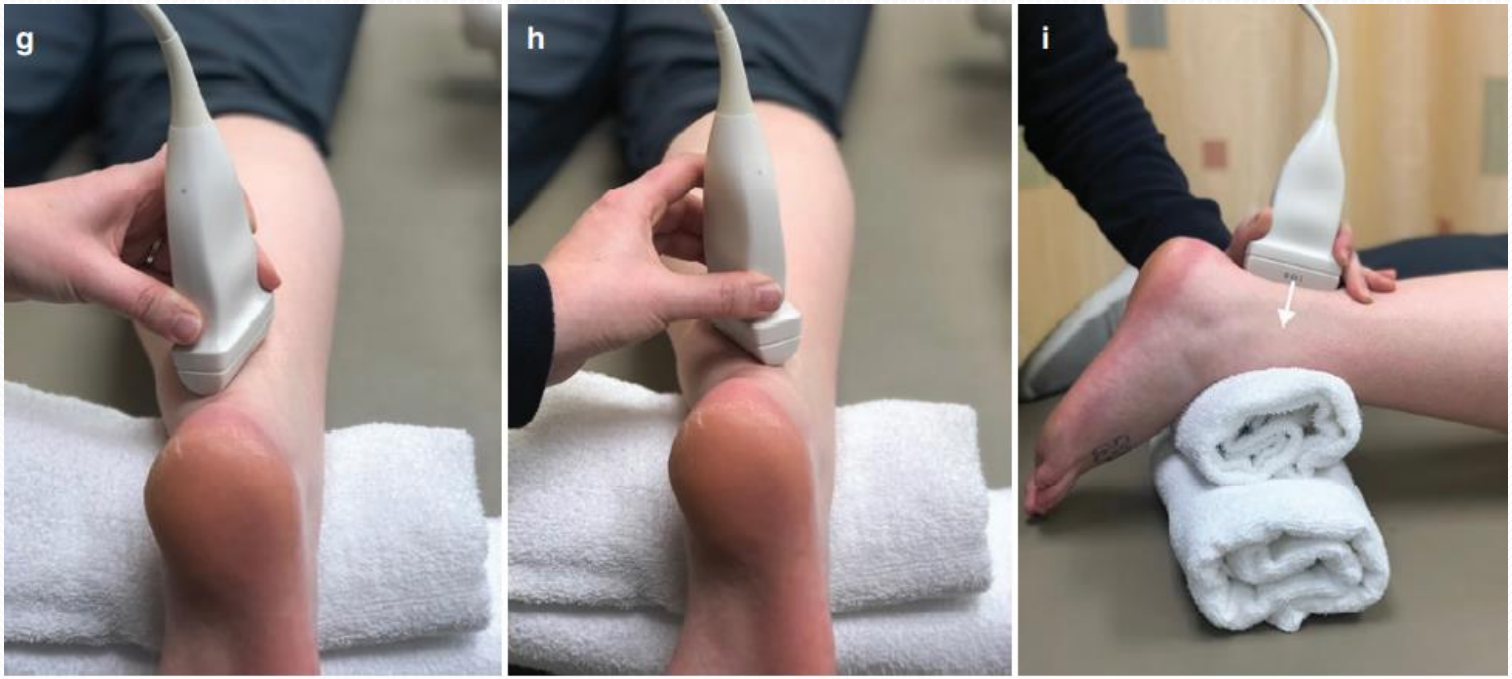


Probe manipulation



- a sliding
- b , c rocking (heel toe maneuver)

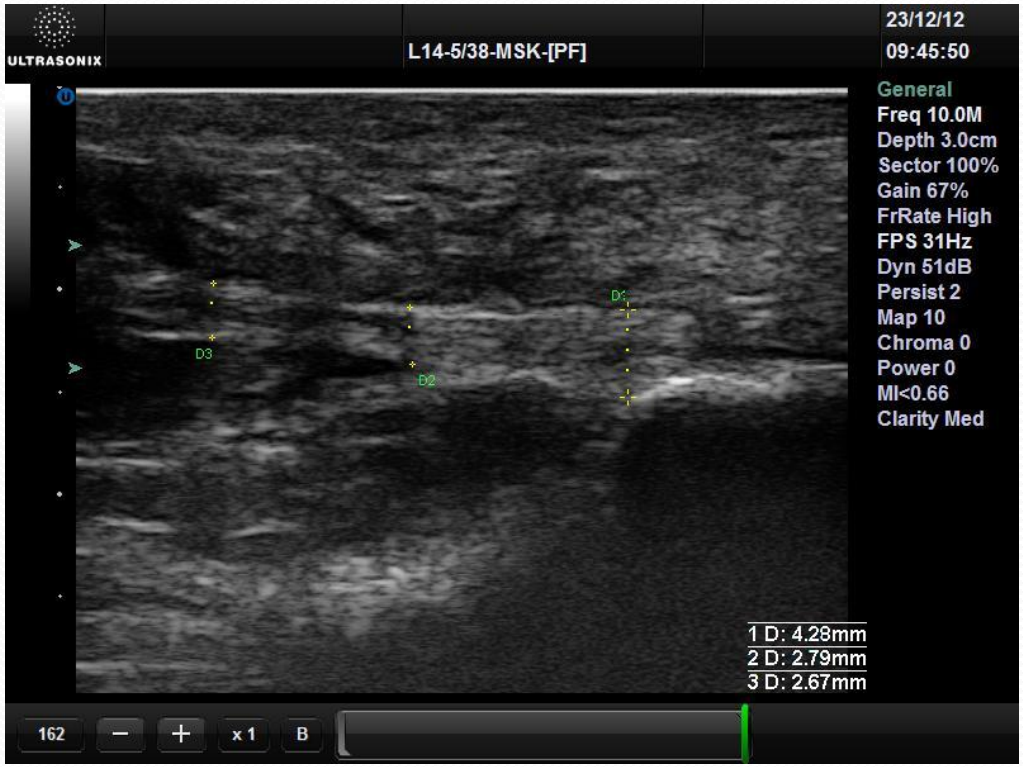
- e, f tilting (toggling)



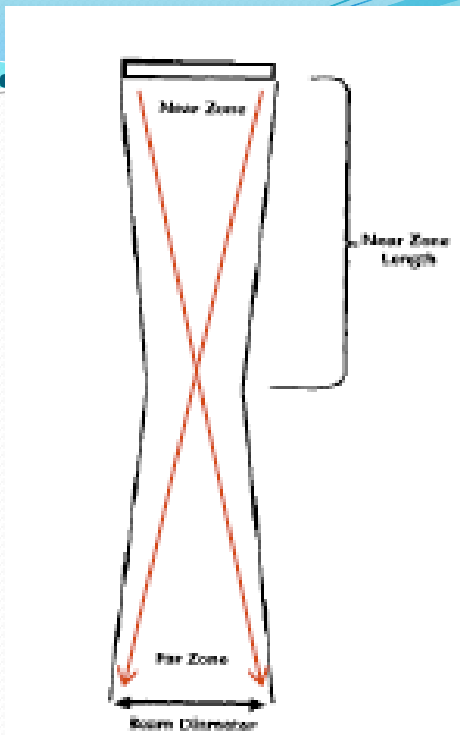
- g, h rotating
- i compressing

Step 2: Depth

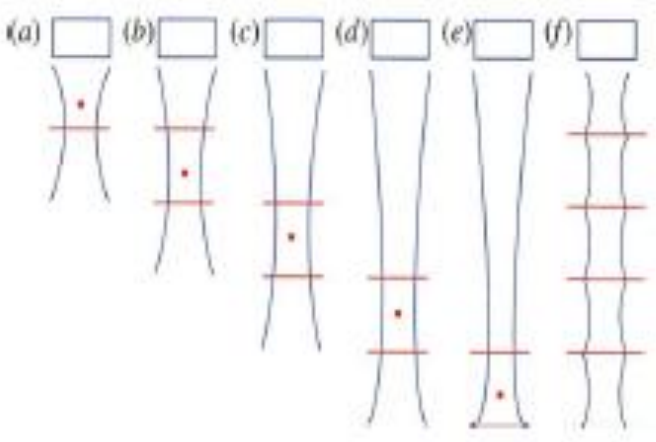
- Adjust depth to place image at middle to bottom of screen
- Decreases attenuation, increases resolution



Step 3: Focal Zone & Adding..

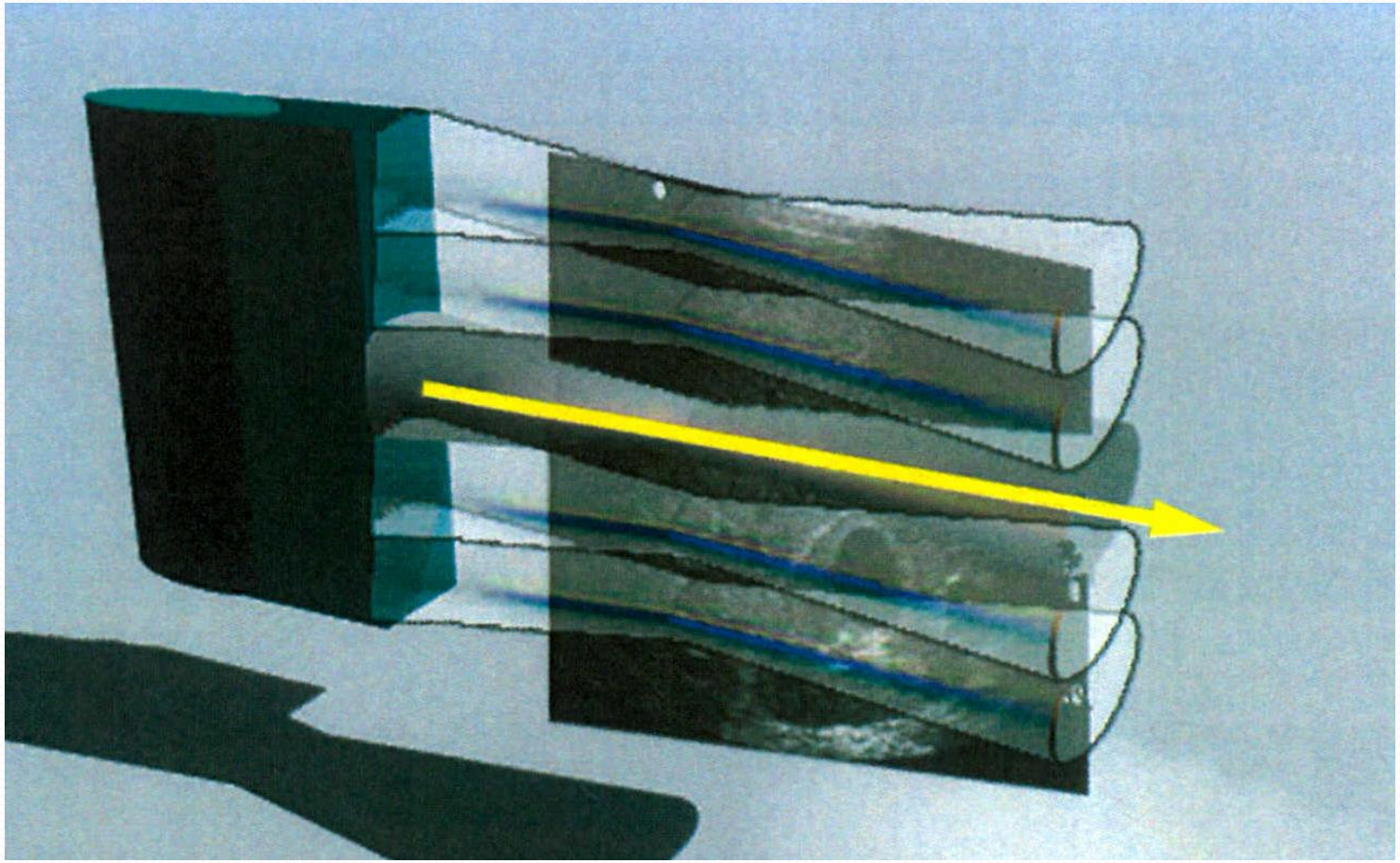


- Beam narrows to ½ width and then widens
- Narrowest region of beam has most concentrated sound waves : best resolution



- Set Focal Zone to location of interest

- Can add zones if multiple areas or broad area of interest
- Multiple focal zones reduce temporal resolution



Step 4: Gain

- Overall Brightness of image
- Auto gain on some machines
- Optimize for structure of interest

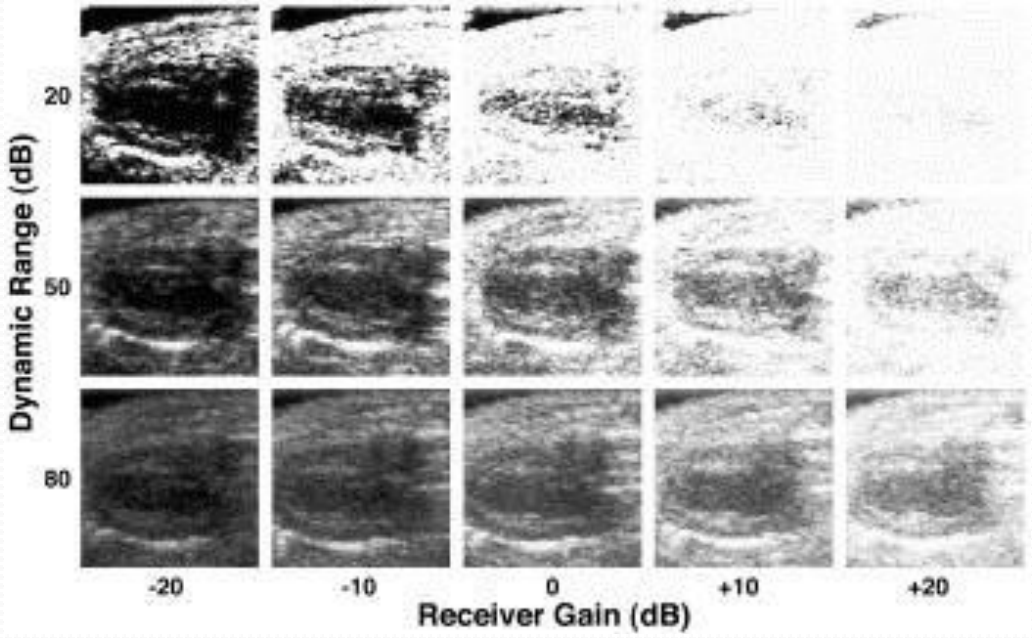
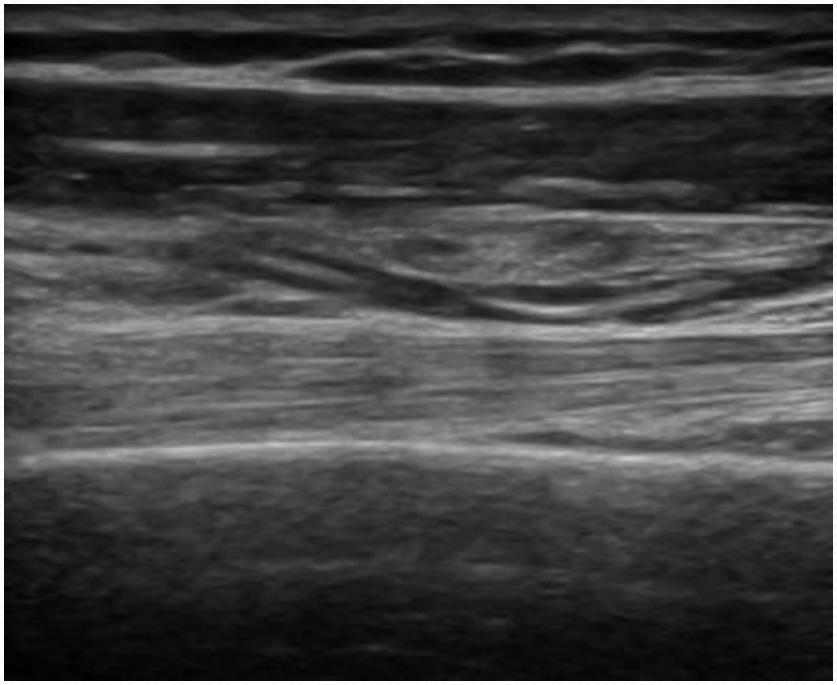
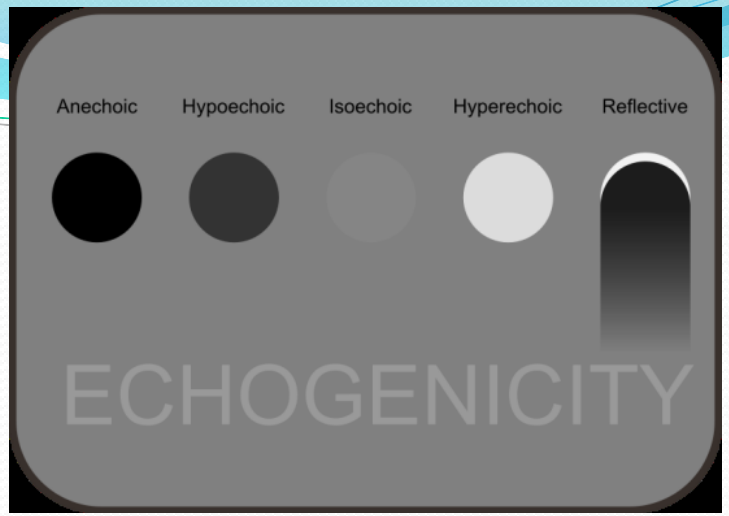


Image Identification in MSK Ultrasound

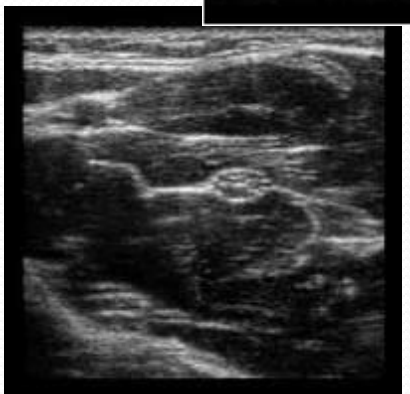
Terminology -Echotexture

- Refers to the internal pattern of echoes
- Homogeneity and heterogeneity





- Hyperechoic
- More sound waves reflected
- Isoechoic
- Same amount of sound waves reflected
- Hypoechoic
- Fewer sound waves reflected
- Anechoic
- No sound waves reflected



- Difference is more important
- Consider surrounding tissues

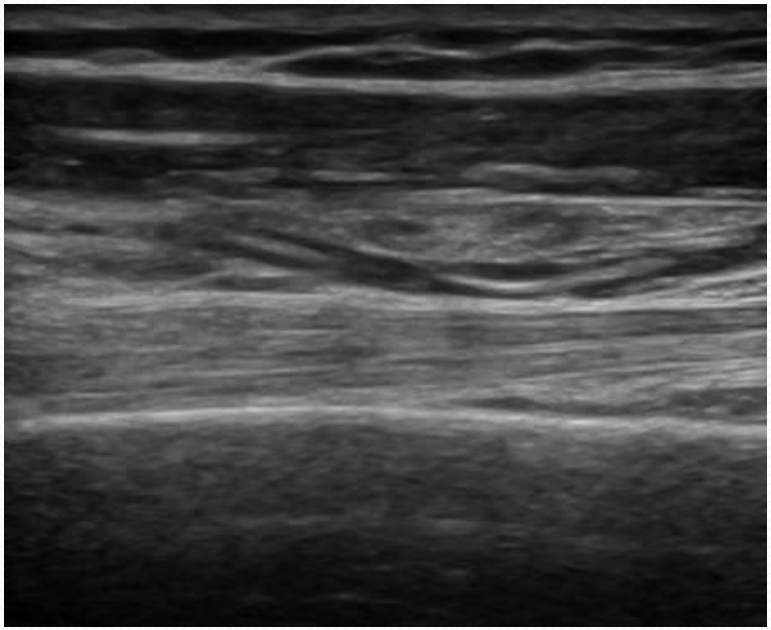
Normal US Characteristics

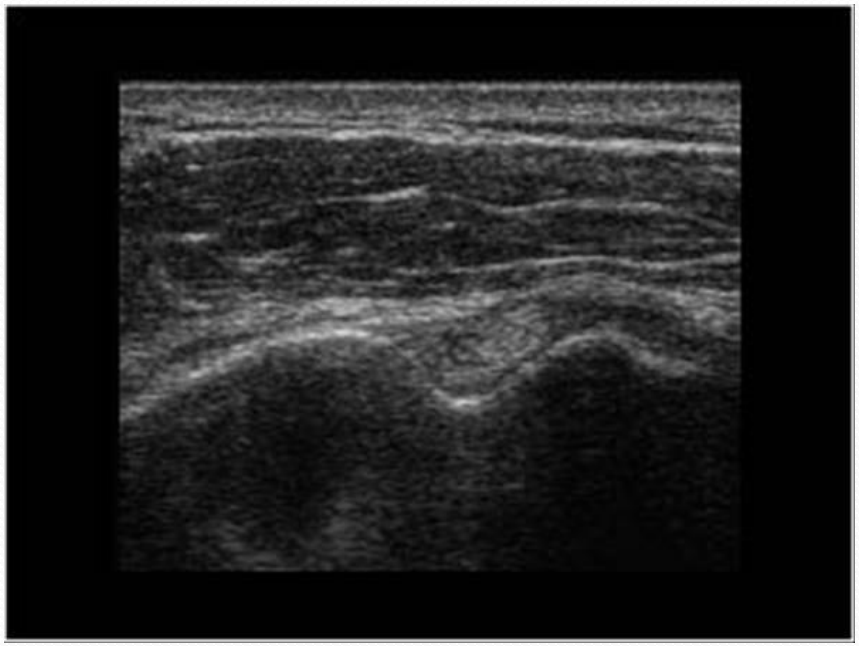
Table 1. *Normal ultrasonographic characteristics of soft tissues*

Tissue	Echogenicity	Echotexture Appearance		Susceptibility to Anisotropy	Compressibility	Doppler Flow
		Transverse	Longitudinal			
Tendon	Hyperechoic	Broom end	Fibrillar	+++	−−	−−
Ligament	Hyperechoic	Broom end	Fibrillar	++	−−	−−
Nerve	Mixed echogenicity	Honeycomb	Fascicular	+	−−	−−
Muscle	Mixed echogenicity	Starry night	Pennate or "feather like"	+	−−	−−
Vessel	Hypoechoic or anechoic	−−	−−	−−	$++^{a}$ - $+++^{v}$	$+^{v}$ - $+++^{a}$

−− = absent; + = mildly present; ++ = moderately present; +++ = significantly present; ^{a}= arteries; ^{v}= veins.

Normal Appearance -Tendon





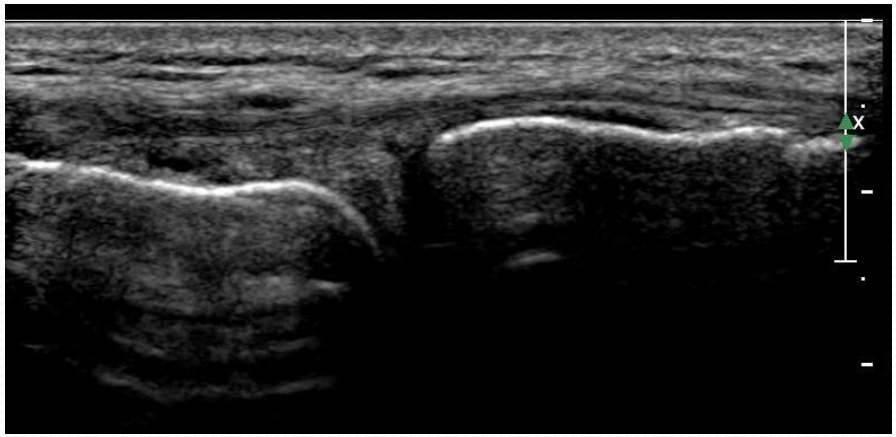
- **Longitudinal**

“Fibrillar appearance”

- **Transverse**

“Broom end pattern”

Normal Appearance -Ligament



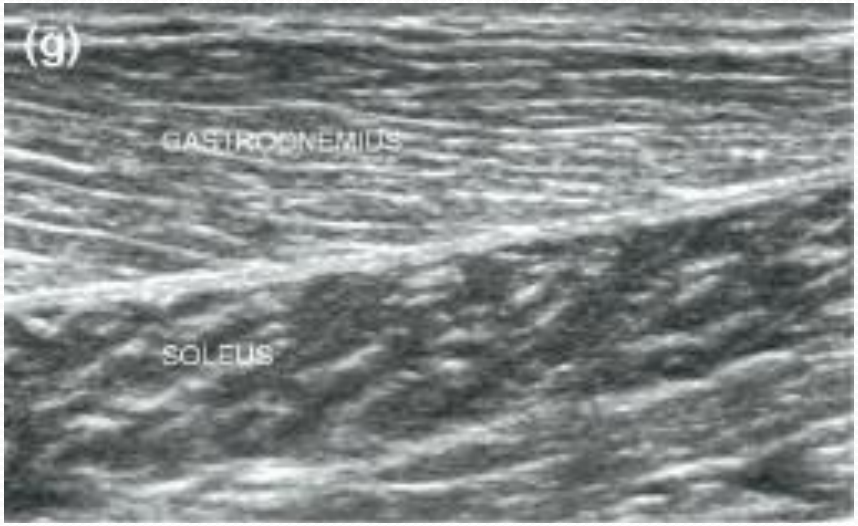
- **MCL Longitudinal**

“Fibrillar”

- **MCL Transverse**

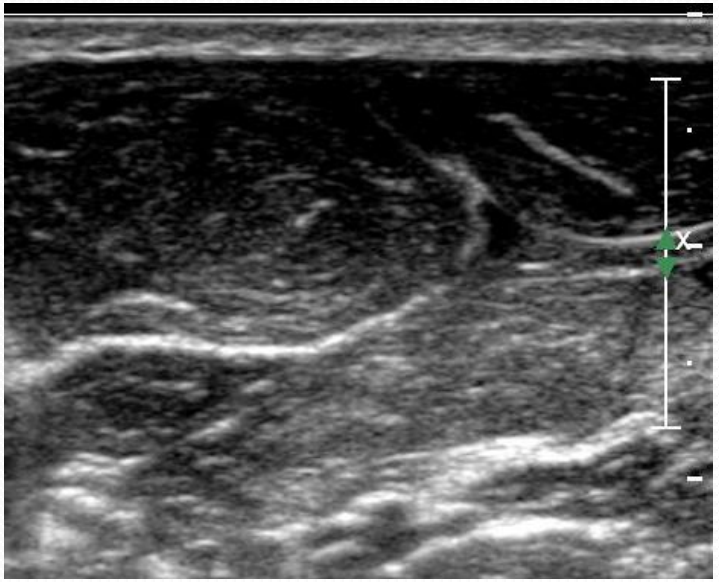
“Broom end”

Normal Appearance -Muscle



- **Longitudinal**

"Feather or veins on a leaf pattern"

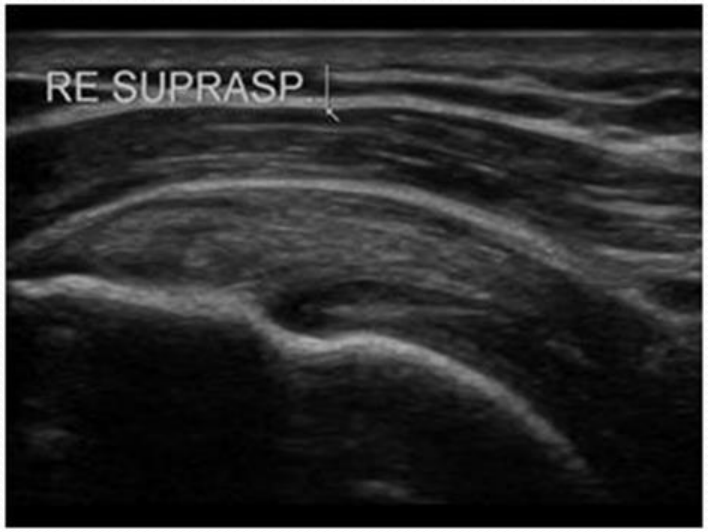


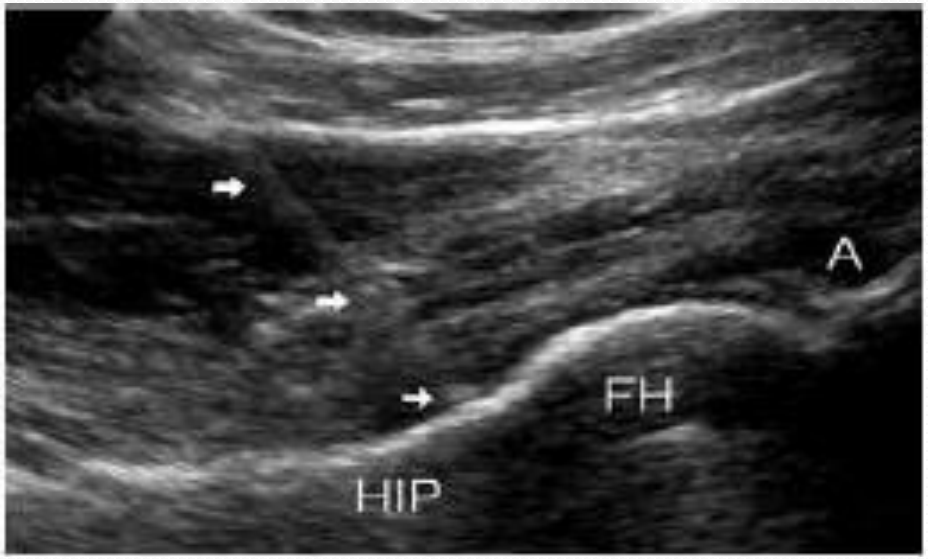
- **Transverse**

"Starry night pattern"

Normal Appearance -Bone

- Cortex=bright
- Hyperechoic

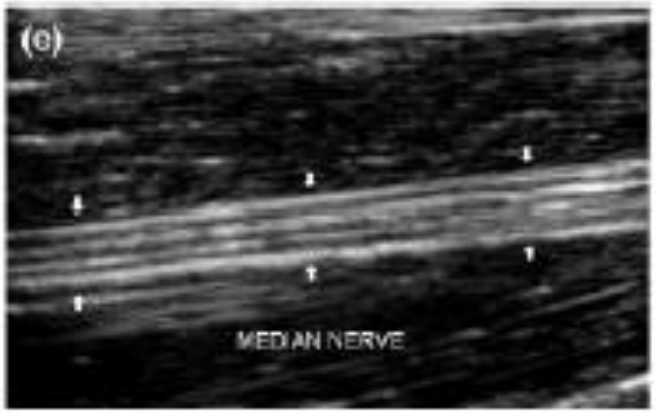


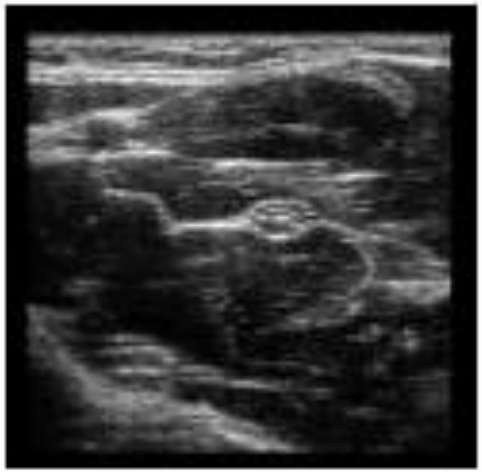


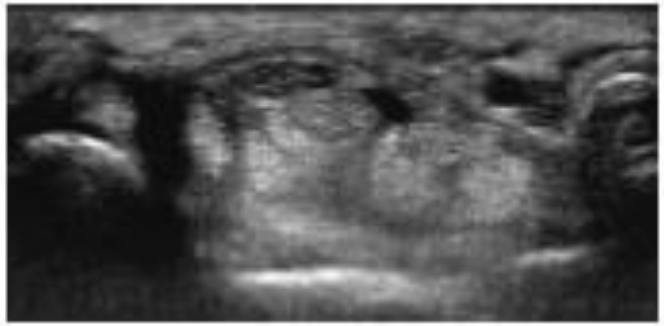
Normal Appearance –Hyaline Cartilage

- Anechnoic
- Not to be confused with effusion
- Hyerechoic cortex deep

Normal Appe





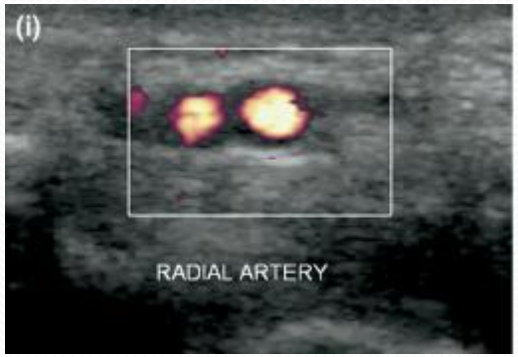


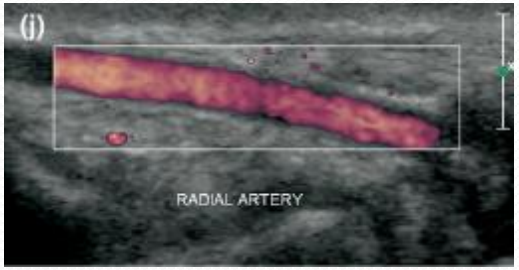
- **Longitudinal**

“Fascicular”

- **Transverse “Honeycomb pattern”**

Normal Appearance –Vasculature

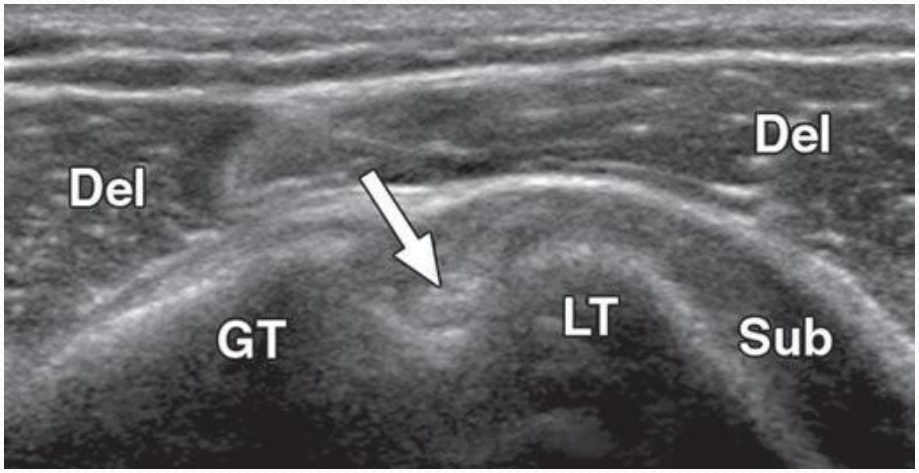


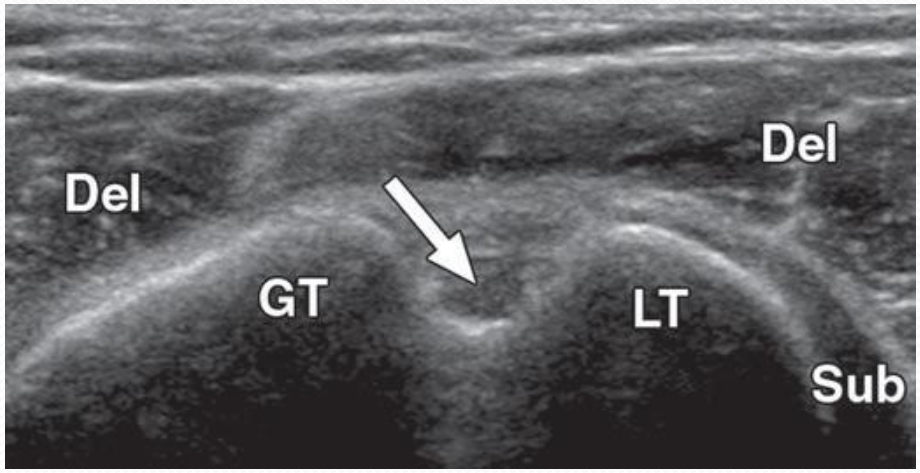


Artifacts

Artifacts -Anisotropy

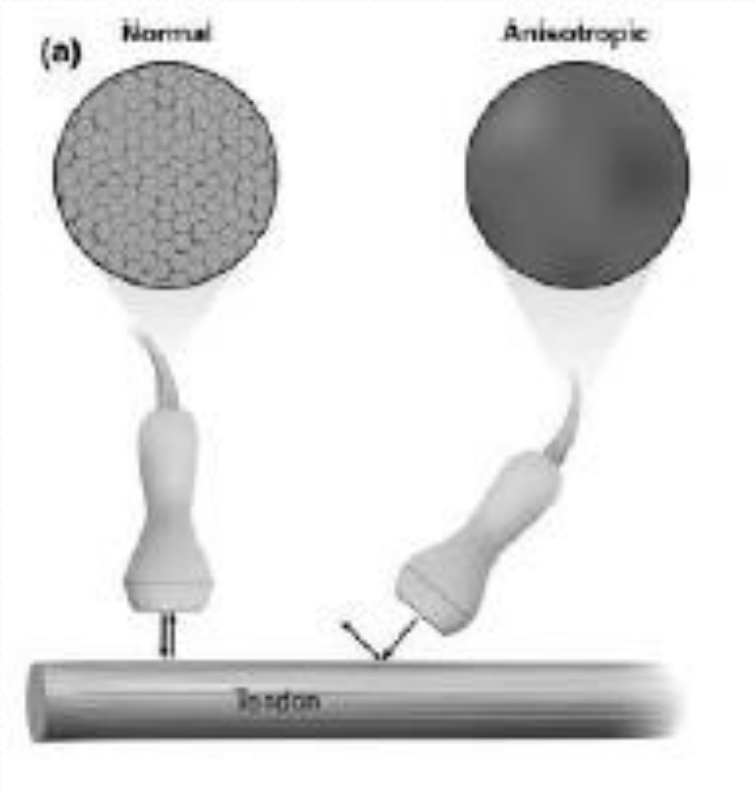
- US beam not parallel to structure
- Structure appears dark or pathologic due to reflection
- Avoided by manipulating the transducer to direct the US beam perpendicular to the structure (tilting, heel-toe)
- Always look for pathology in multiple planes

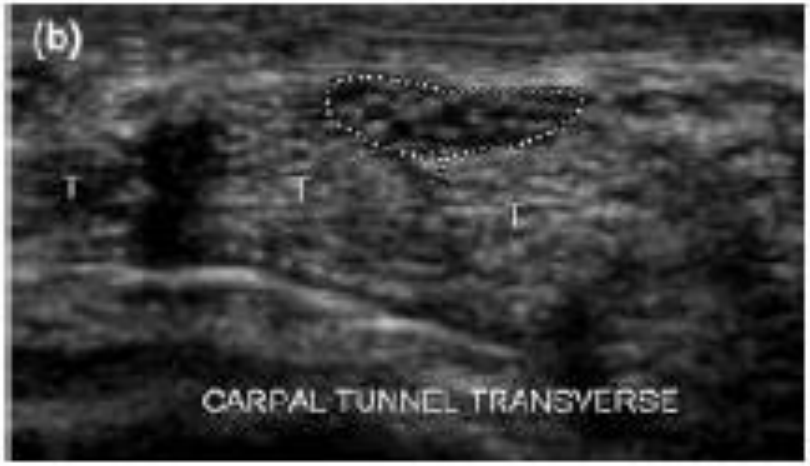




Artifacts - Anisotropy

- Some times useful





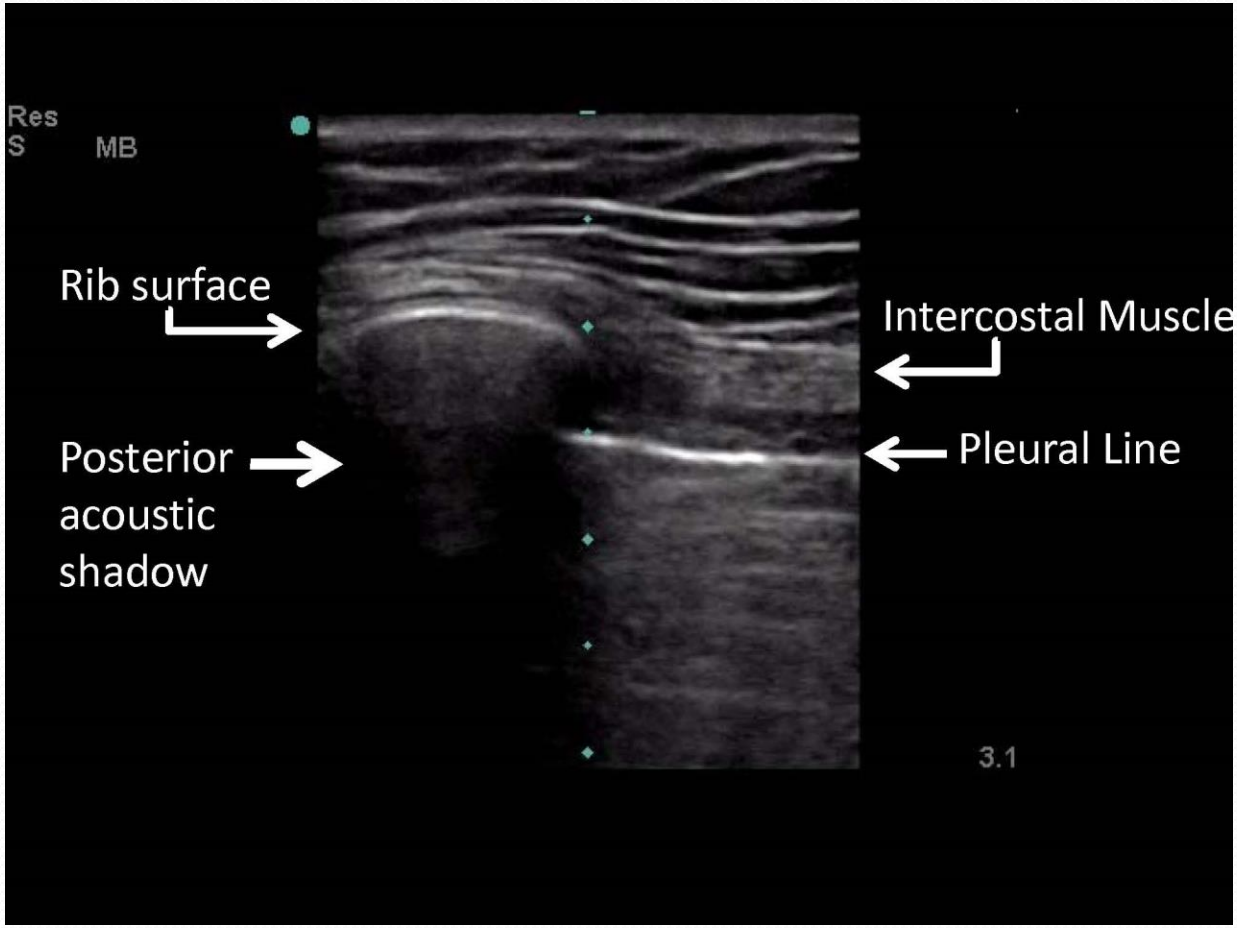
Artifacts –Posterior reverberation

- Smooth and flat objects
  - Metal
  - Bone
  - Needle
- Reflects back and forth
- Series of echoes

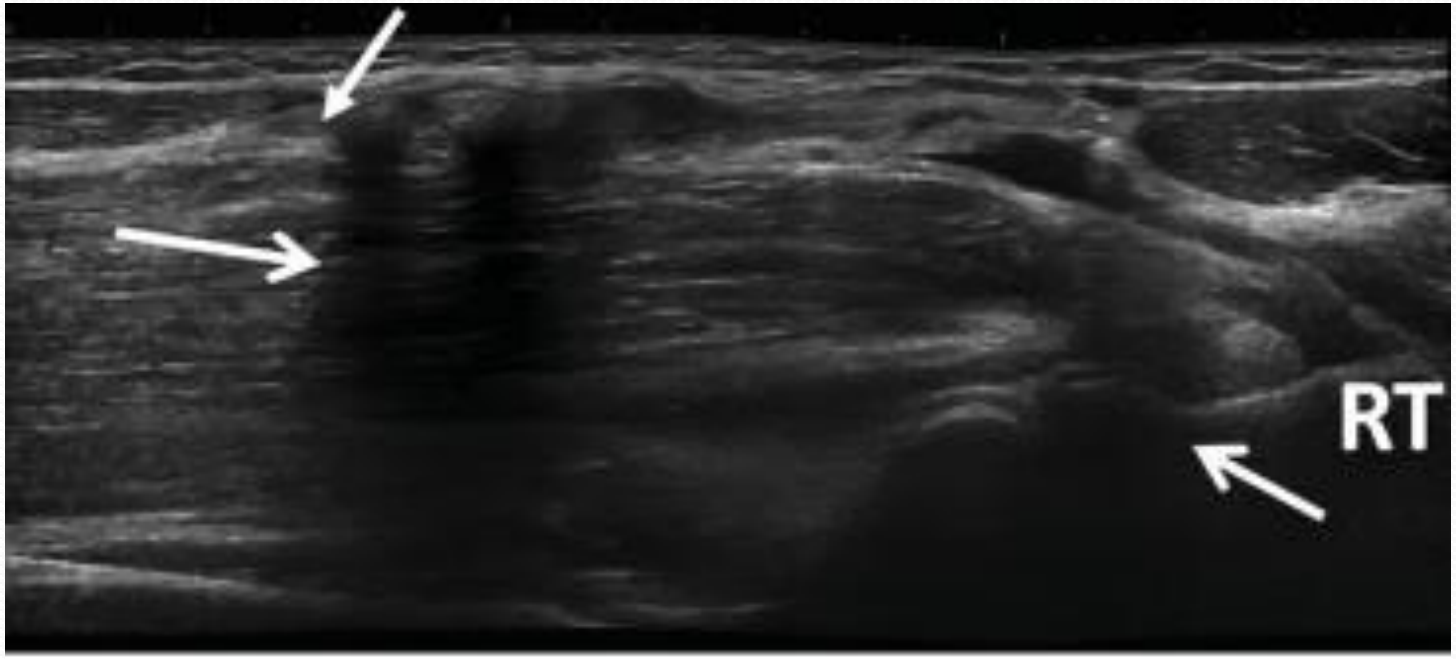
Artifacts –Posterior Acoustic Shadowing

- Anechoic below bone or calcification
- i.e. calcific tendinitis

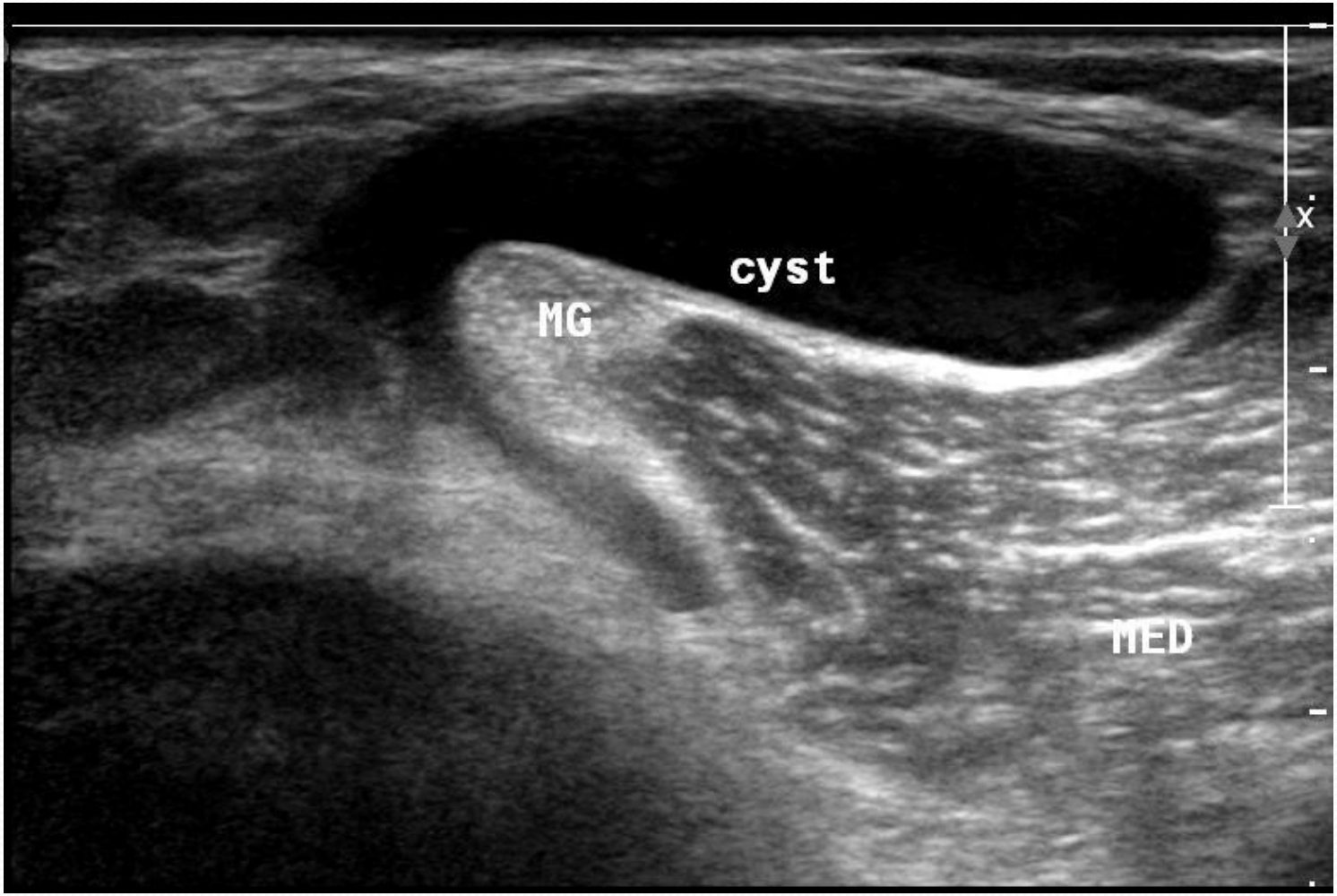
Artifact-shadowing



Artifact-refractile shadowing



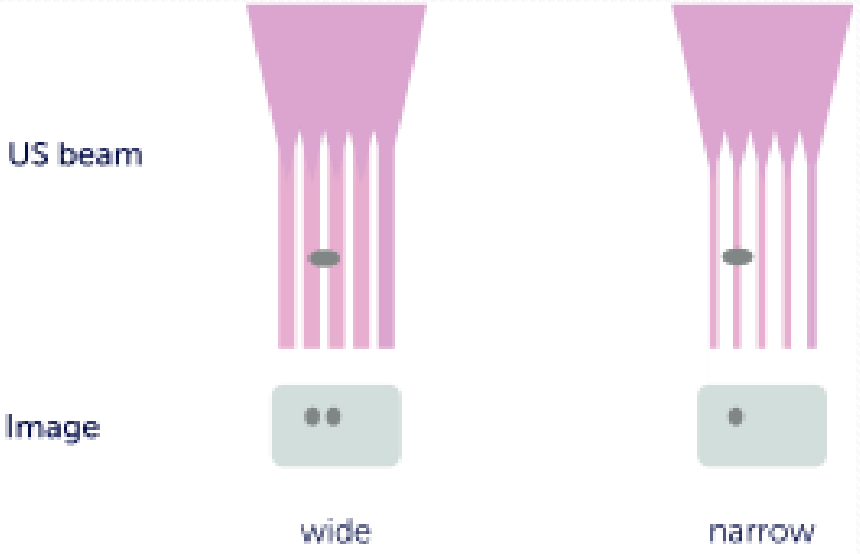
Artifacts –Posterior acoustic enhancement (increased through-transmission)



Artifacts- Beam-width artifact

- If a structure is smaller than the ultrasound beam, artifact may be eliminated (e.g. small calcification with no posterior acoustic shadowing)

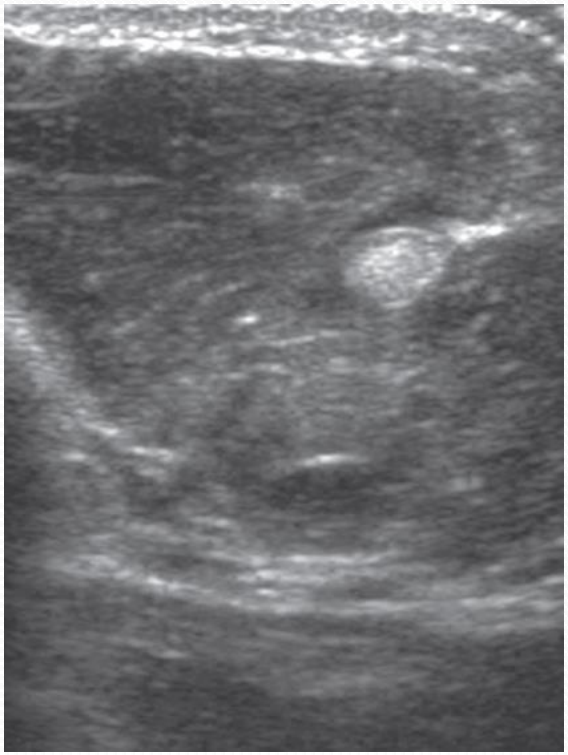
- Adjust focal zone
- Scan in multiple planes

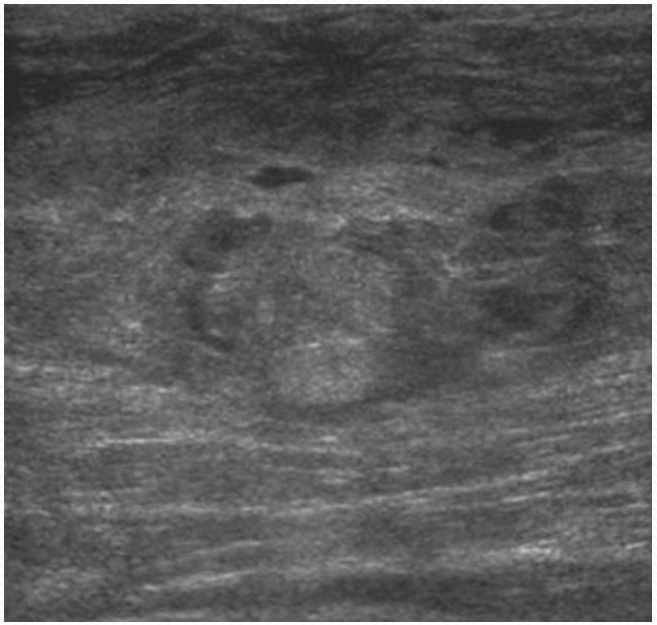


Pathologic tissues

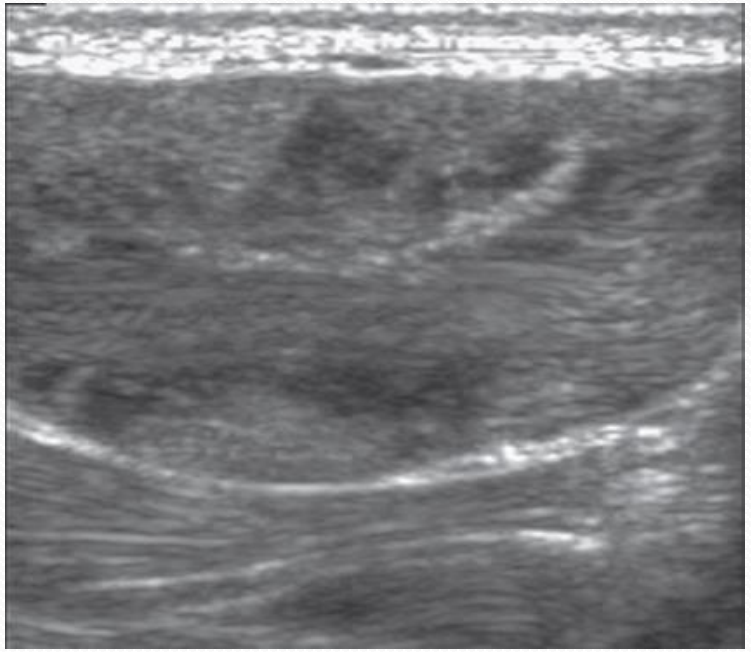
Muscle and tendon

- Acute
- Chronic
- Muscle contusion and acute hemorrhage ..hyperechoic



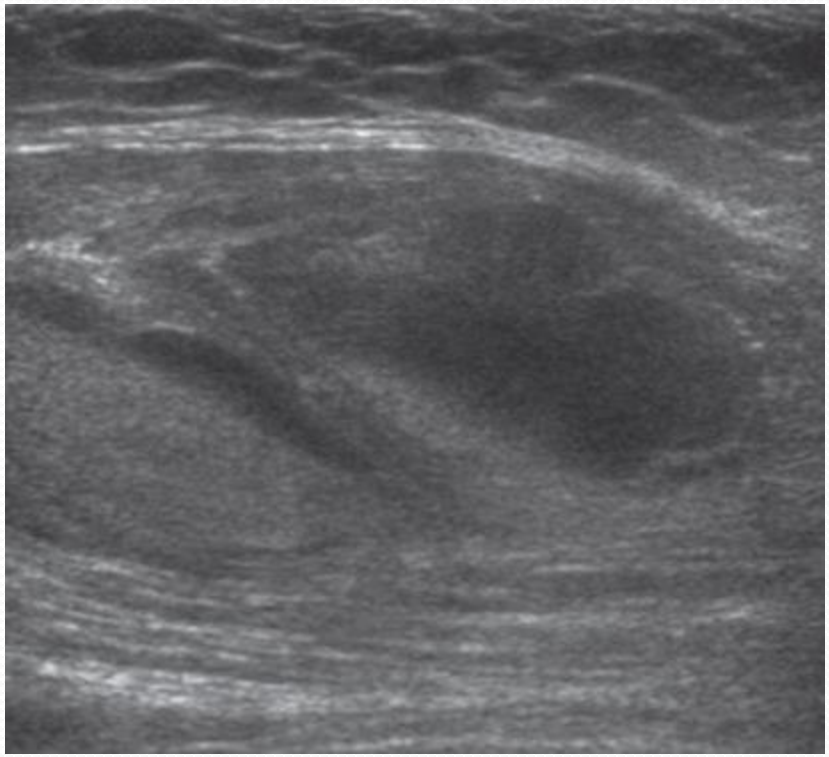


- Partial thickness tear ….
- Full thickness tear….
- retraction at the site of the injury that indicates full-thickness tear
- In subacute injury hematoma shows heterogeneous areas of hypoechoic hemorrhage



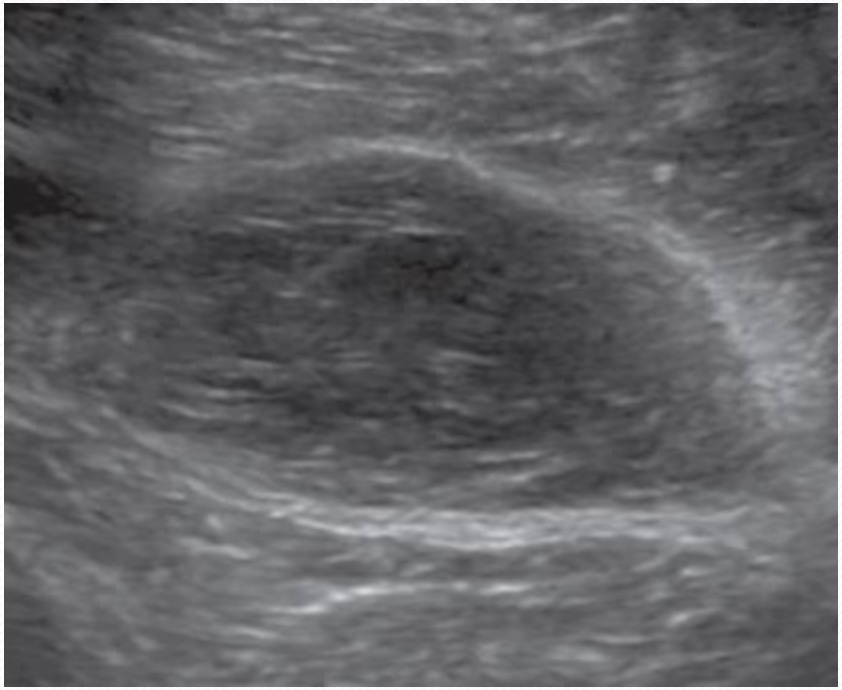
then

- heterogeneous mixed echogenicity hemorrhage



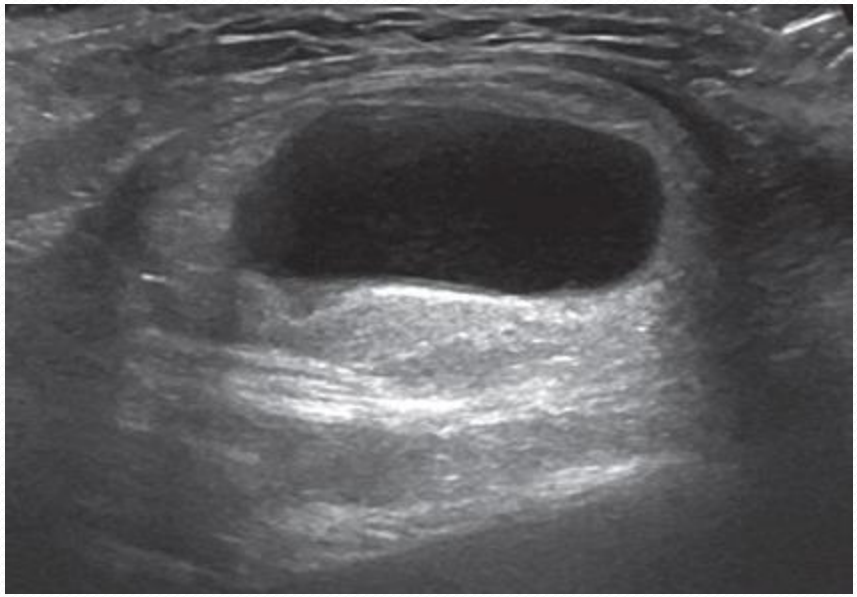
then

- decrease in size of hematoma with increased echogenicity at the periphery

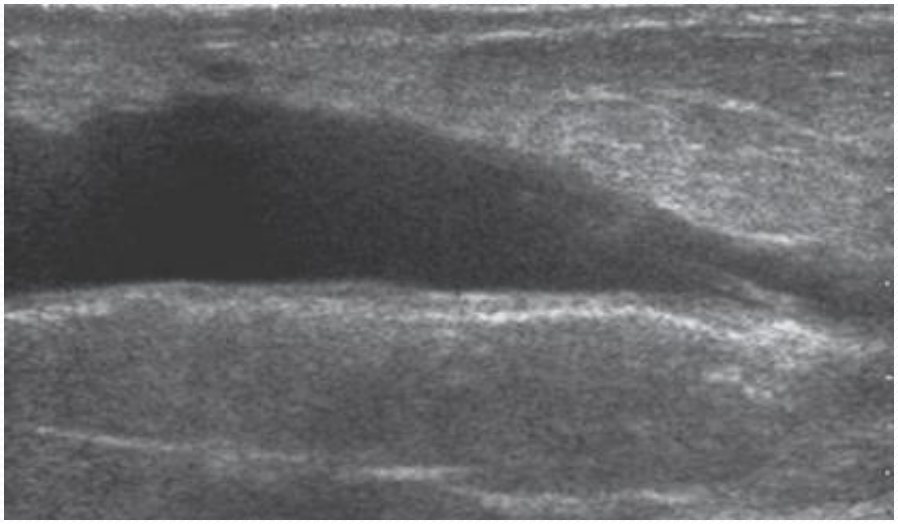


seroma

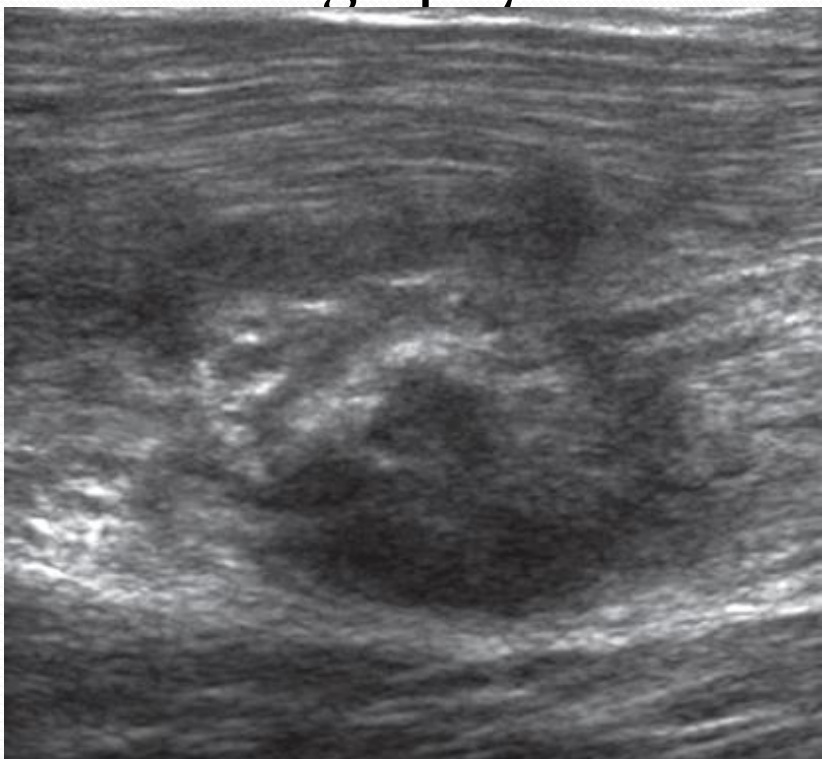
- anechoic fluid collection at site of prior hemmorhage



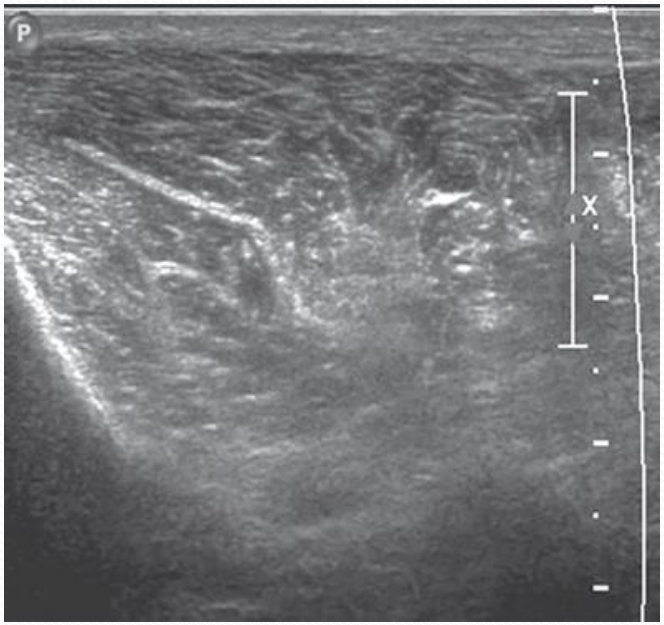
- Hemorrhage located between the subcutaneous fat and the adjacent hip musculature can occur with trauma as a degloving-type injury, called the *Morel-Lavallée lesion*

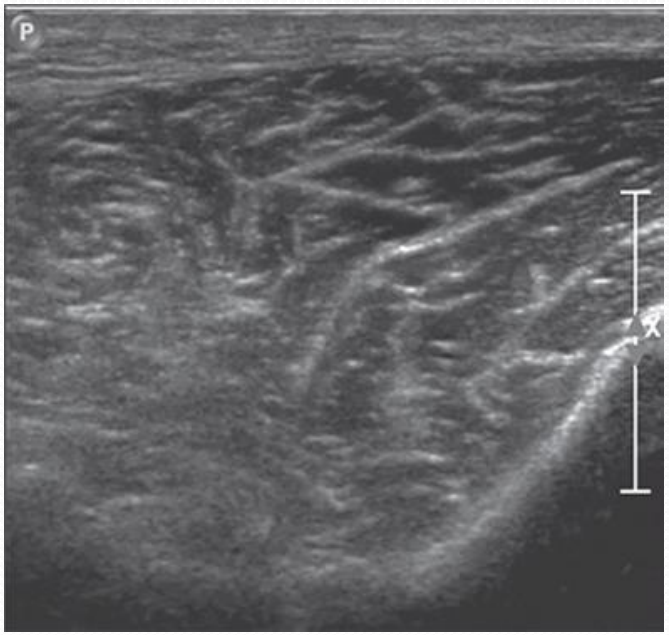


- An area of damaged muscle may ossify, terme *myositis Ossificans* ,and ultrasound can show early mineralization before visualization on radiography.



- Prior trauma to muscle or its nerve supply can result in muscle atrophy, which causes increased echogenicity and decreased size of the affected muscle

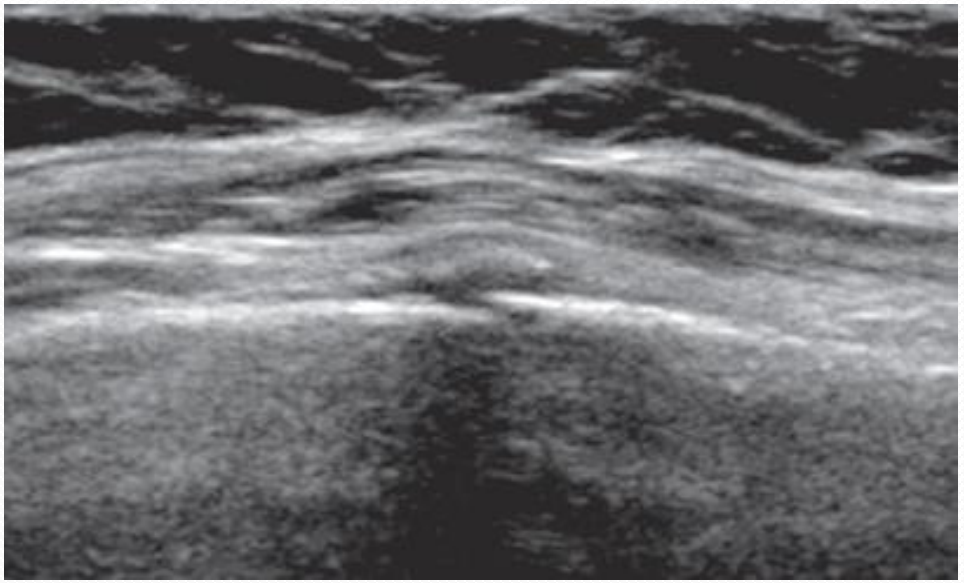




Bone injury

- The normal osseous surfaces are smooth and echogenic with posterior shadowing and possibly reverberation when imaged perpendicular

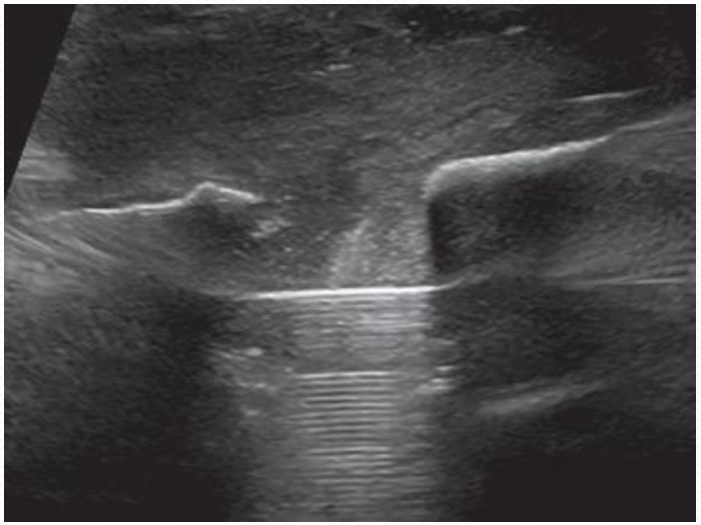
- The hallmark of an acute fracture is discontinuity of the bone cortex with possible step-off deformity
- Adjacent mixed echogenicity hemorrhage may also be present.



US effective in

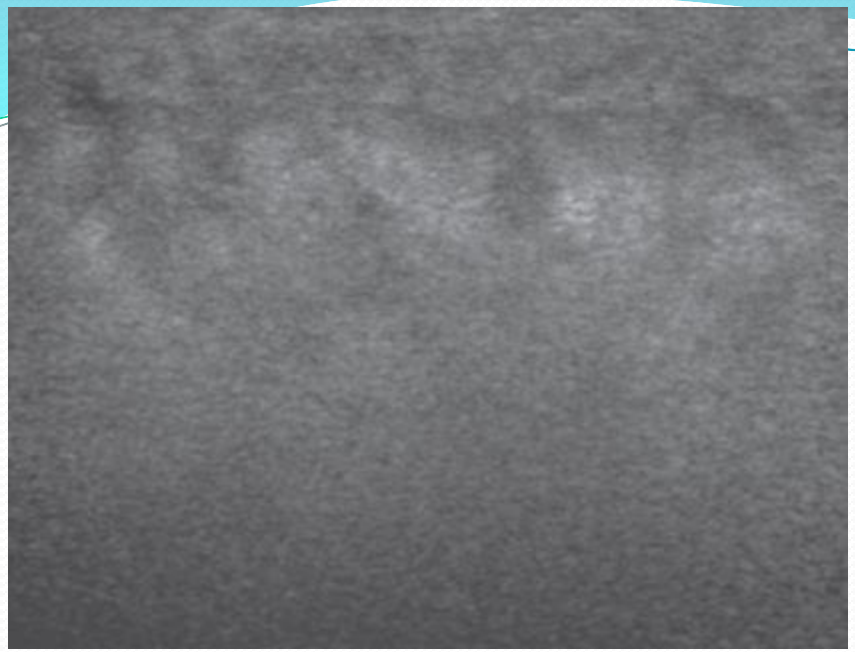
- diagnosis of tibial fracture nonunion with static interlocked nail placement; ultrasound can detect healing before radiography, whereas visualization

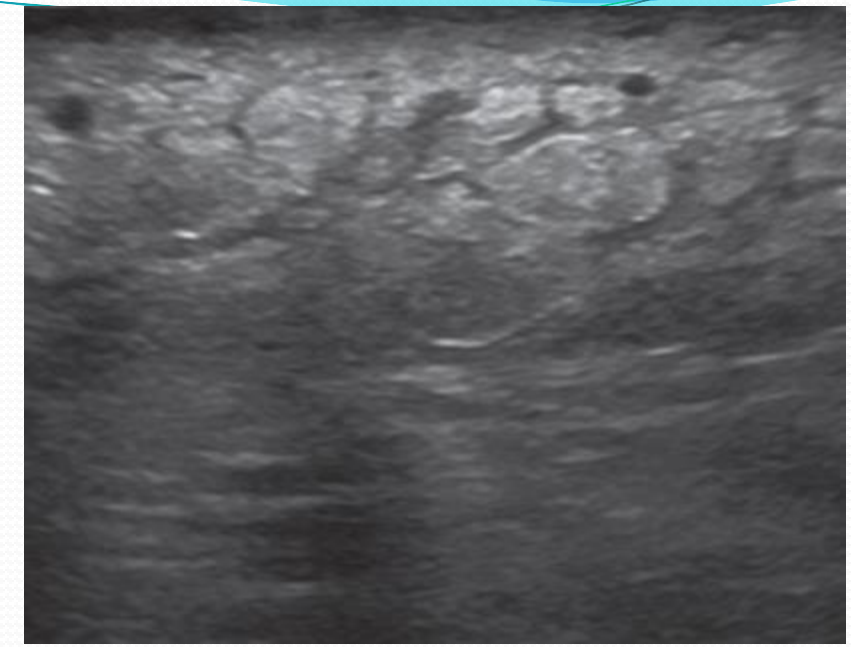
of the hyperechoic nail indicates no overlying callus formation

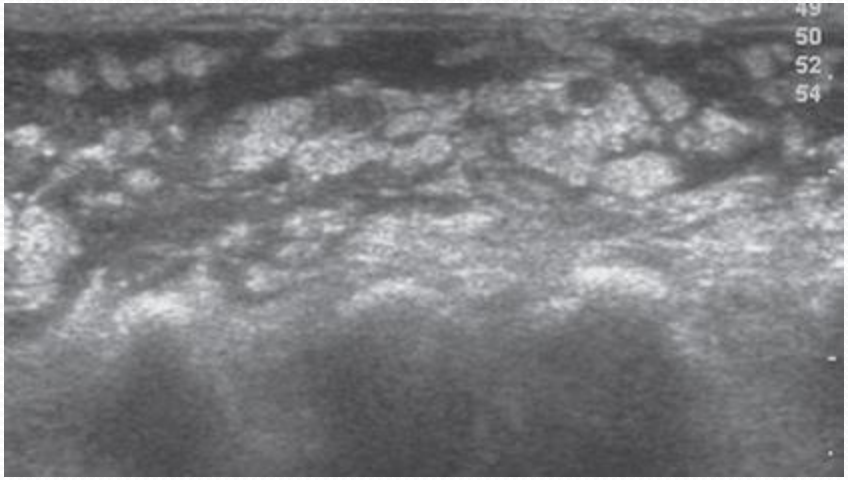


Infection

- commonly occurs through a puncture wound or skin ulcer…… infection of the soft tissues or cellulitis
- Acutely, cellulitis appears as hyperechoic and thickened subcutaneous tissue
- Later, hypoechoic or anechoic branching channels are visualized, with distortion of the soft tissues and possibly increased flow on color or power Doppler
- Such branching channels can coalesce as purulent fluid and can progress to frank abscess, where ultrasound-guided aspiration may be of benefit.



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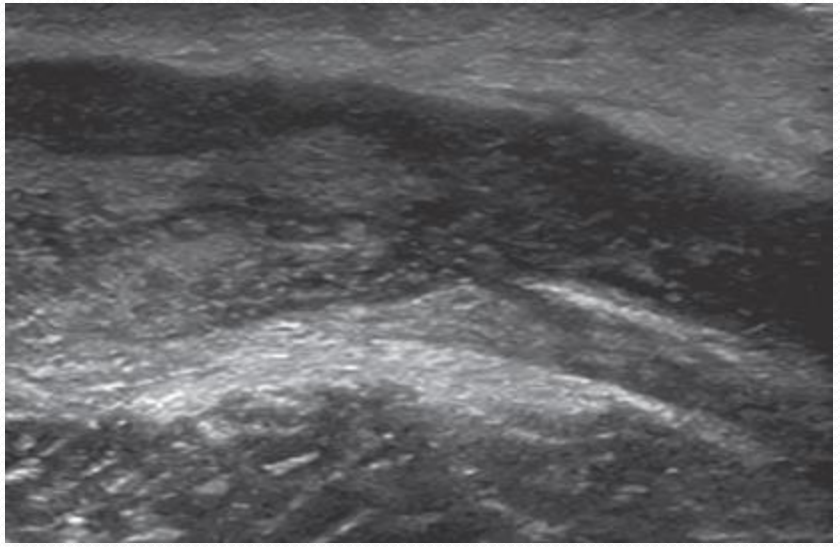
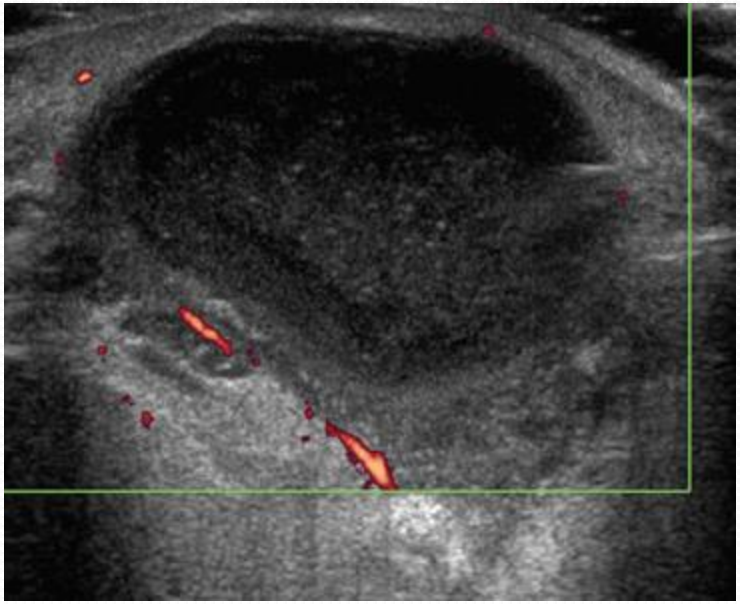
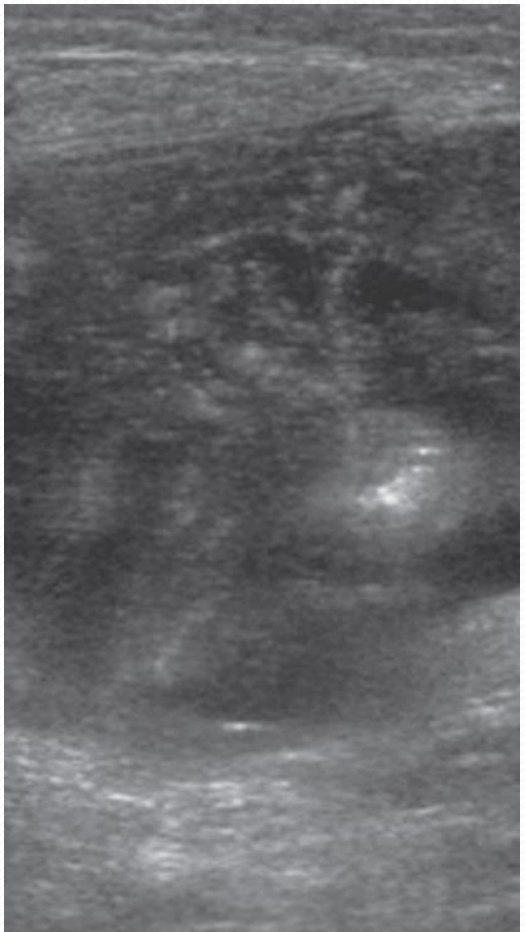


abscess

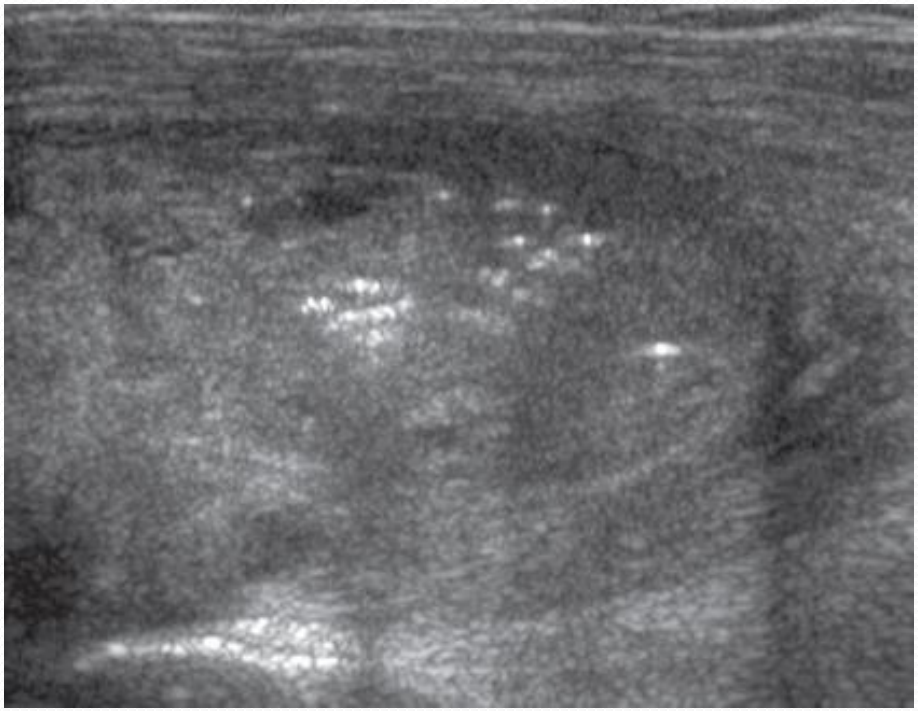
- As well defined hypoechoic heterogeneous fluid collection with posterior through-transmission and peripheral hyperemia on color or power Doppler imaging





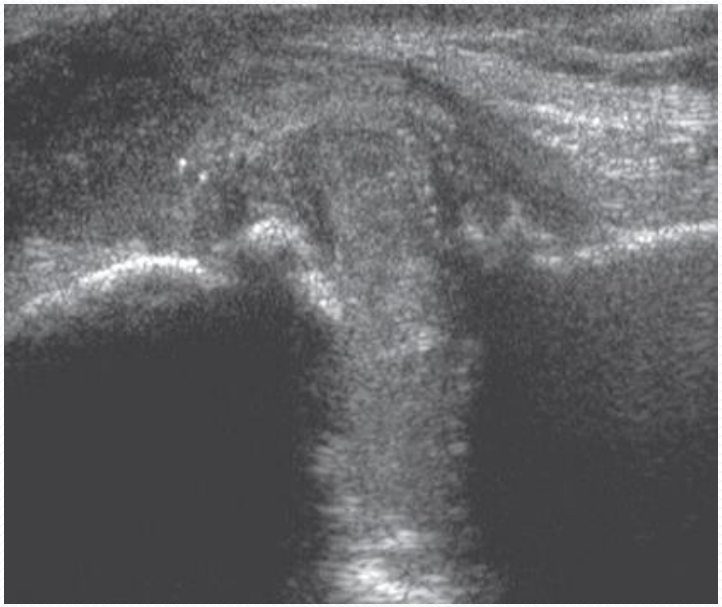
bursitis

- can produce complex fluid and synovitis, and possibly gas, which appears hyperechoic with comet-tail artifact



Septic arthritis

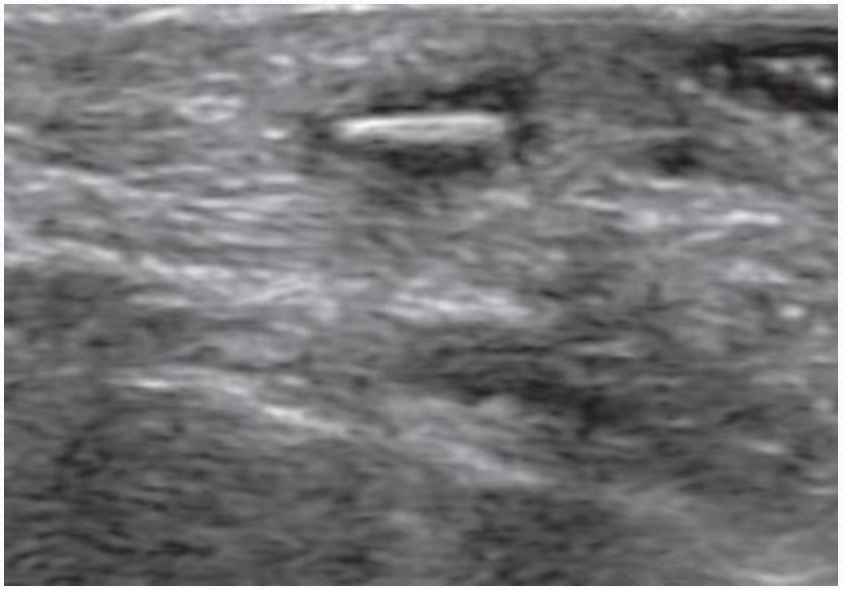
- septic arthritis is suspected when there is fluid distention of a joint recess, which may range from anechoic to hyperechoic, with possible hypoechoic or isoechoic synovial hypertrophy
- If distention of a joint recess is not anechoic, the possibility of complex fluid versus synovial hypertrophy must be considered.

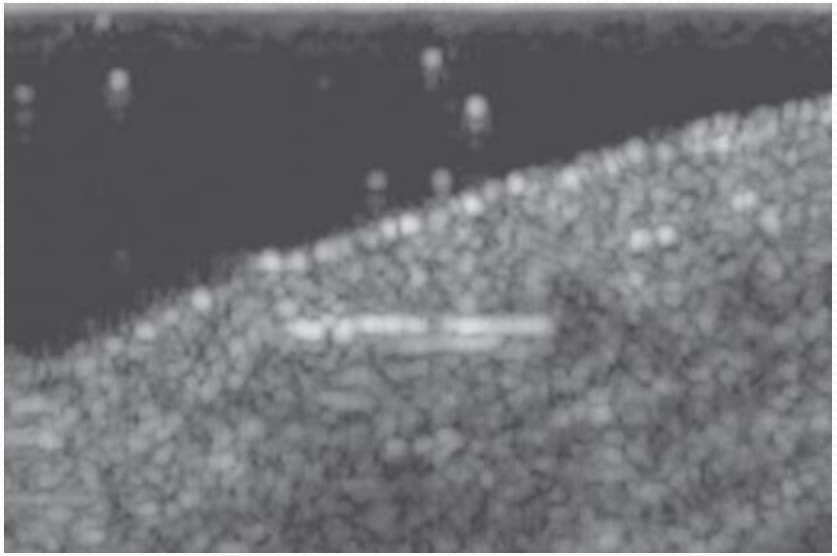


- The echogenicity of fluid or the presence of flow on color or power Doppler imaging cannot predict the presence of infection, and therefore ultrasound-guided percutaneous fluid aspiration should be considered

Foreign body

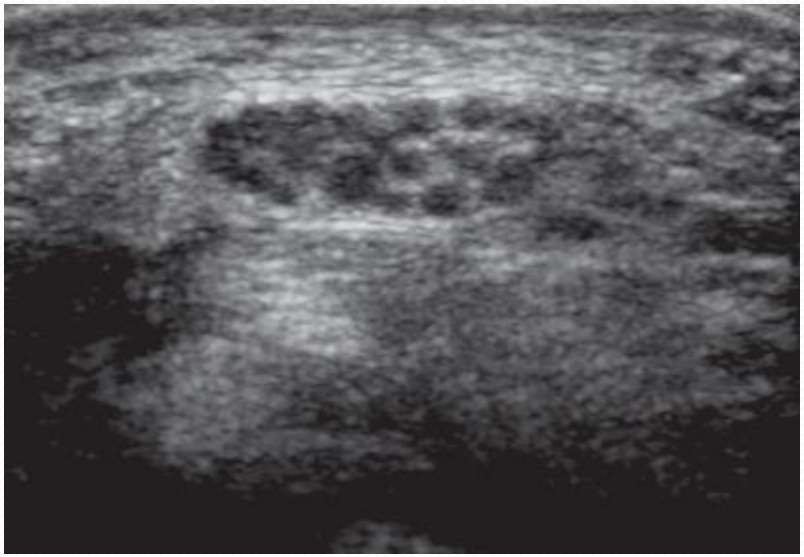
- initially hyperechoic
- A hypoechoic halo with possible hyperemia may be present, representing hemorrhage, granulation tissue, or abscess





Peripheral nerve entrapment

- Common sonographic features of each of these conditions are hypoechoic enlargement of the involved nerve at and proximal to the entrapment site with possible compression distally.



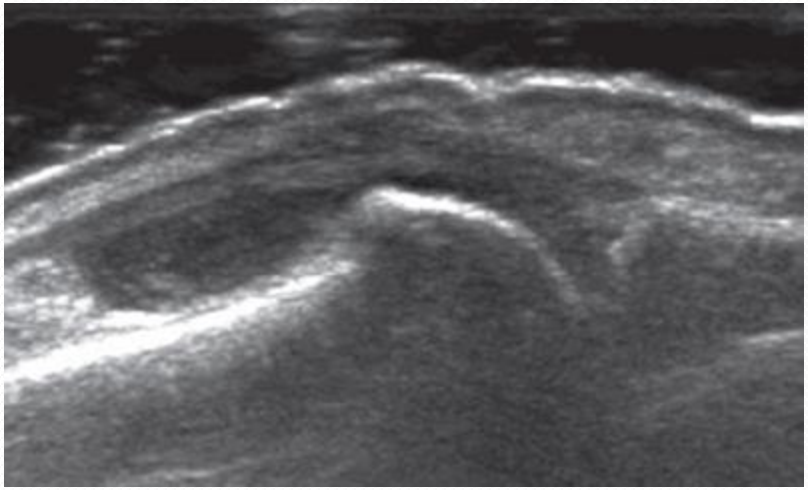
Rheumatoid arthritis

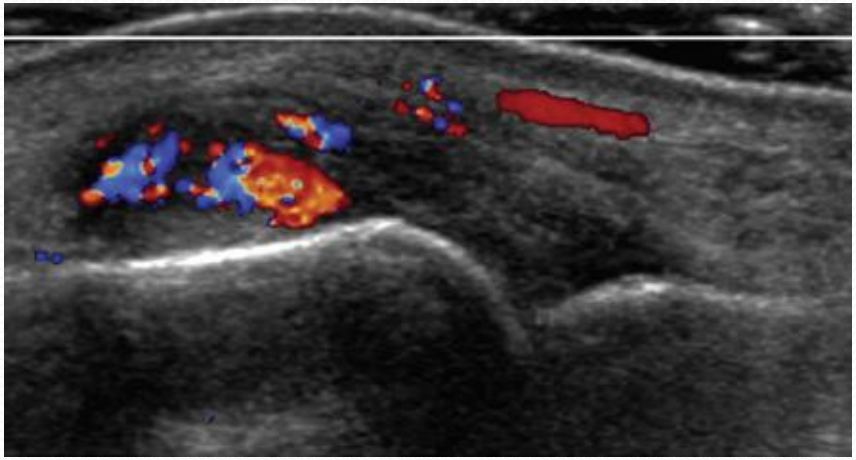
- Ultrasound can be used for early diagnosis, assessment of response to therapy, and can guide injections or aspirations.
- Synovial hypertrophy appears as hypoechoic

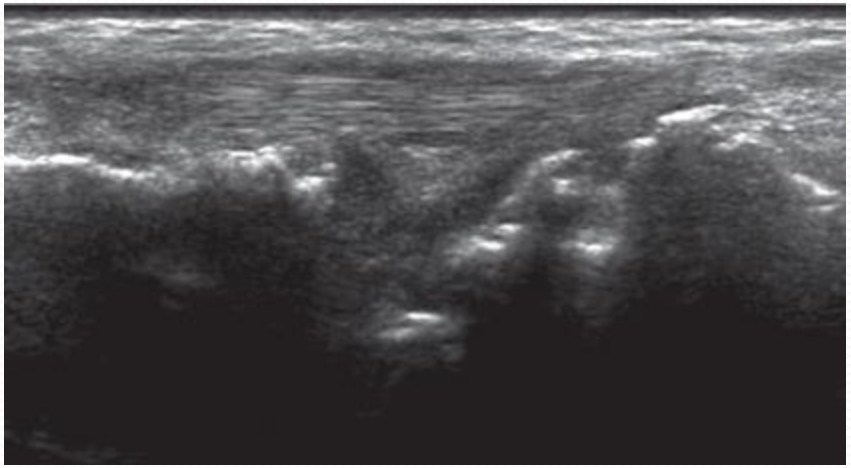
or, less commonly, isoechoic or hyperechoic relative to subdermal fat, poorly compressible tissue within a joint or a joint recess.

Synovial hypertrophy may also involve other synovial spaces, such as a bursa or tendon sheath

- Flow may be seen on color or power Doppler imaging, depending on the inflammatory activity of the synovitis
- Erosions appear as discontinuity of the bone cortex seen in two orthogonal planes as seen with ultrasound Such erosions begin in the marginal regions of a joint, where the bone cortex is not covered with hyaline cartilage and is directly exposed to joint inflammation



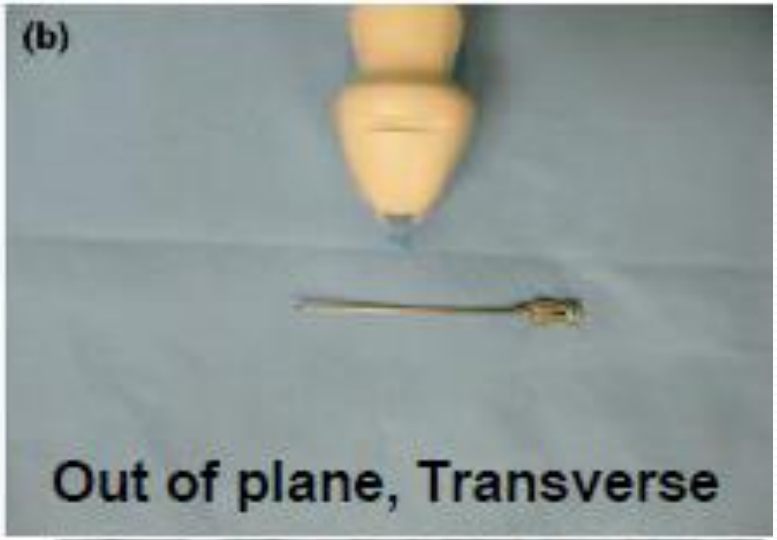


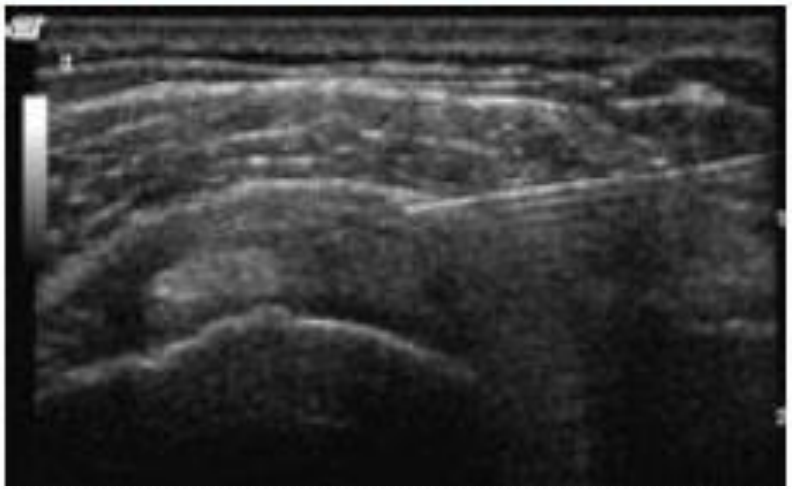


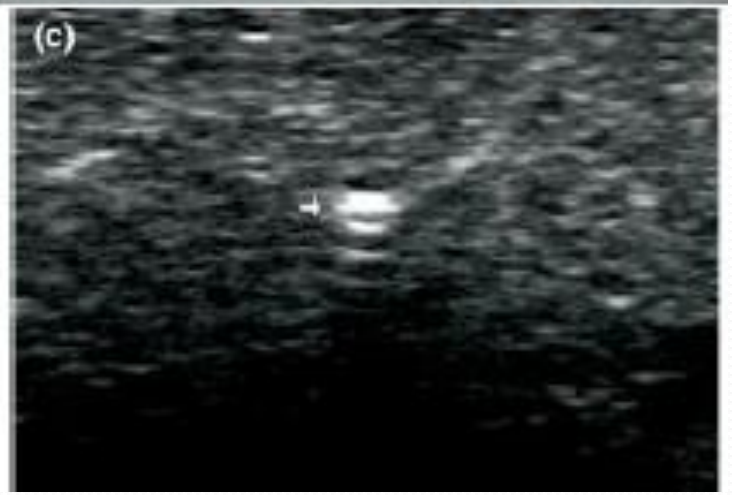
Injection Considerations

- Approach
- Room Arrangement
- Needle approach
- Sterile technique
- Needle visualization techniques

Injection Approach





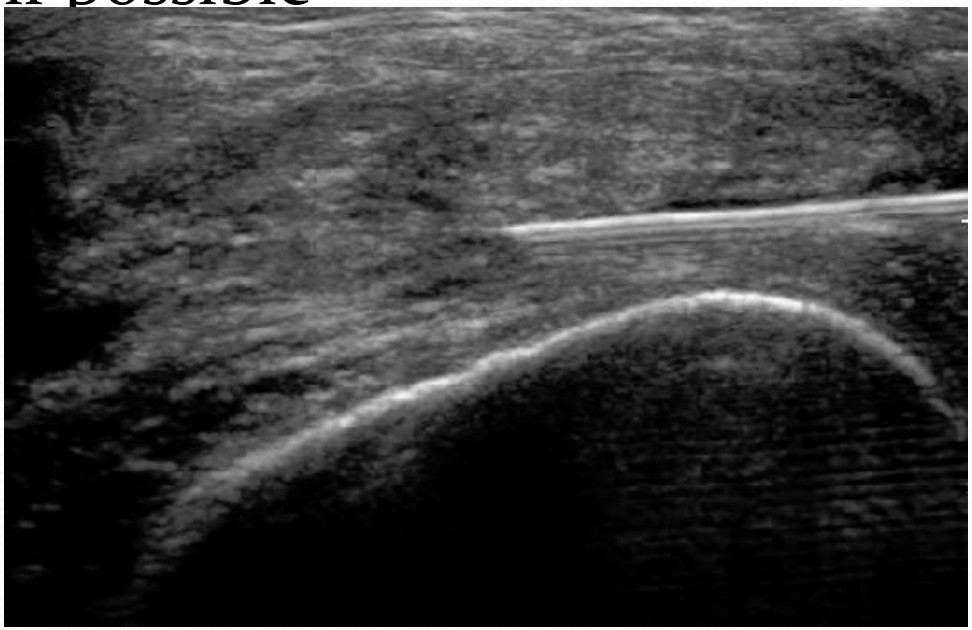


Room Arrangement

- Align transducer, patient and screen
- Consider posture
- Adjust lighting prior

Needle approach

- Pre-examine approach
- Check depth and insert appropriately
- Keep needle parallel to transducer
- Use in-plane approach if possible

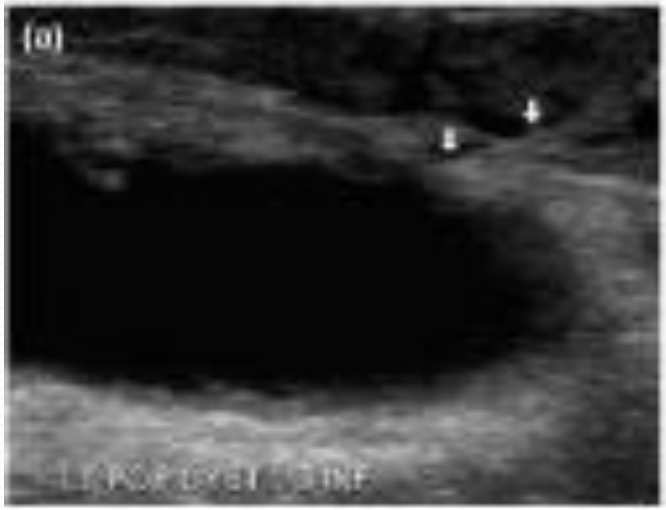


Sterile technique

- Sterile Gel
- Probe cover
- Draping as needed

Needle visualization

- Smaller needle (higher gauge) = more difficult
- Parallel to transducer
- Hydrodissection
- Jiggling
- Back-and-forth needle motion without advancement



Conclusions

- Ultrasound has many uses for physiatrists.
- There are many benefits and limitations of US.
- Basic understanding of US physics is important for image optimization.
- Various tissues can be identified due to their anatomic location, echotexture, and echogenicity.
- Always optimize your image first.
- Recognize common artifacts.
- Only use proper injection technique or defer the procedure.