

Ultrasound Uses in Pediatric Trauma

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Disclosures

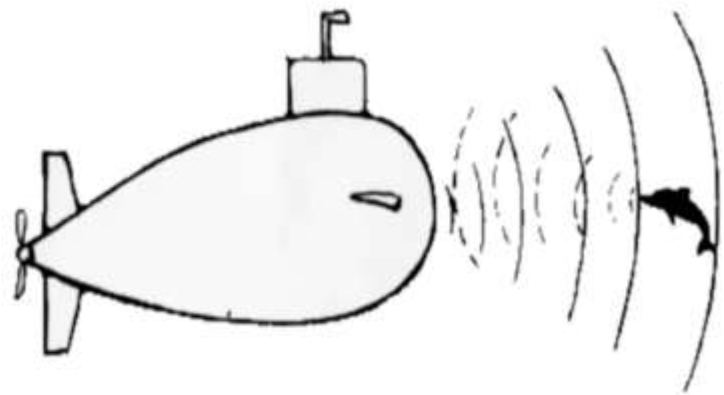
- No relevant financial relationships to disclose

Objectives

- Introduce the basic principles of ultrasound and contrast-enhanced ultrasound (CEUS)
- Compare the CT scan, FAST exam and CEUS exam in the evaluation of children with blunt abdominal trauma (BAT)
- Discuss the sensitivity and specificity of FAST and CEUS in detecting pediatric abdominal trauma

Basics of Ultrasound

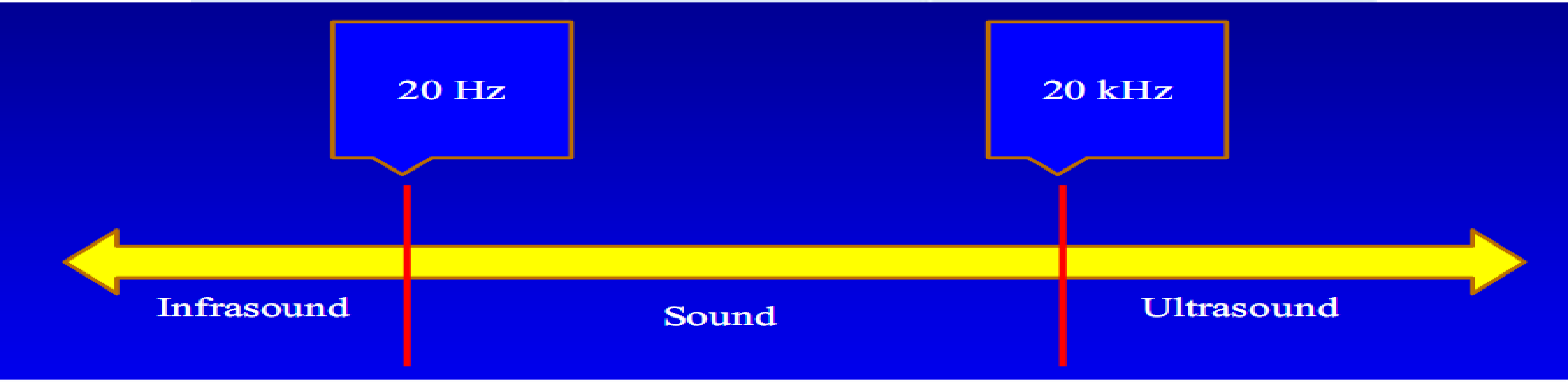
50 Million years ago



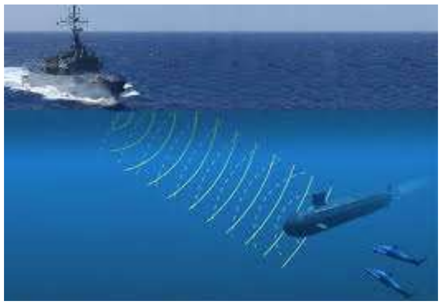
World War I

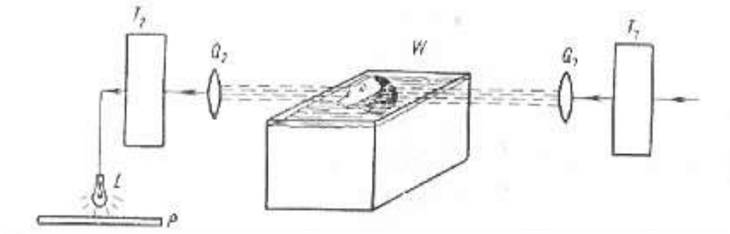
Basics of Ultrasound

Frequency Range (Hertz)	Designation	Examples
0-16 Hz	Infrasound	Seismic waves
16Hz-20KHz	Audible Sound	Speech, music
20KHz-10GHz	Ultrasound	Dolphins, medicine
1MHz-20MHz	Medical Ultrasound	Ultrasound Imaging
!0GHz-10TH	Hyper sound	Acoustic Microscopy



Ultrasound: Some Historical Context





1794
Spallazani discovered ‘non-audible’ sound

1877
Pierre Curie discovered piezo-electric effect

1912
Destruction caused by U-boats in WWI provides drive for development of SONAR

1917
Langevin produced ultrasound device using piezoelectrics

1942
Dussik investigates ultrasound transmission of the brain

1950s
Pulsed ultrasound developed at multiple institutions enabling ‘B Mode’ imaging

1980s
Real time ultrasound possible

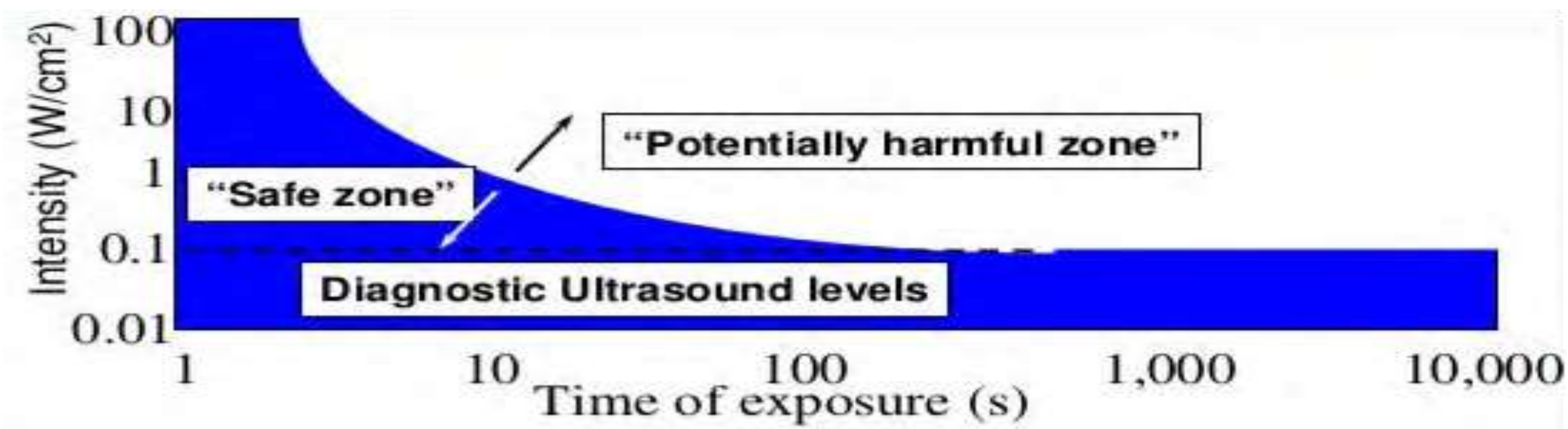
1990s
3D and 4D ultrasound emerge

1990s

Today

Ultrasound Safety

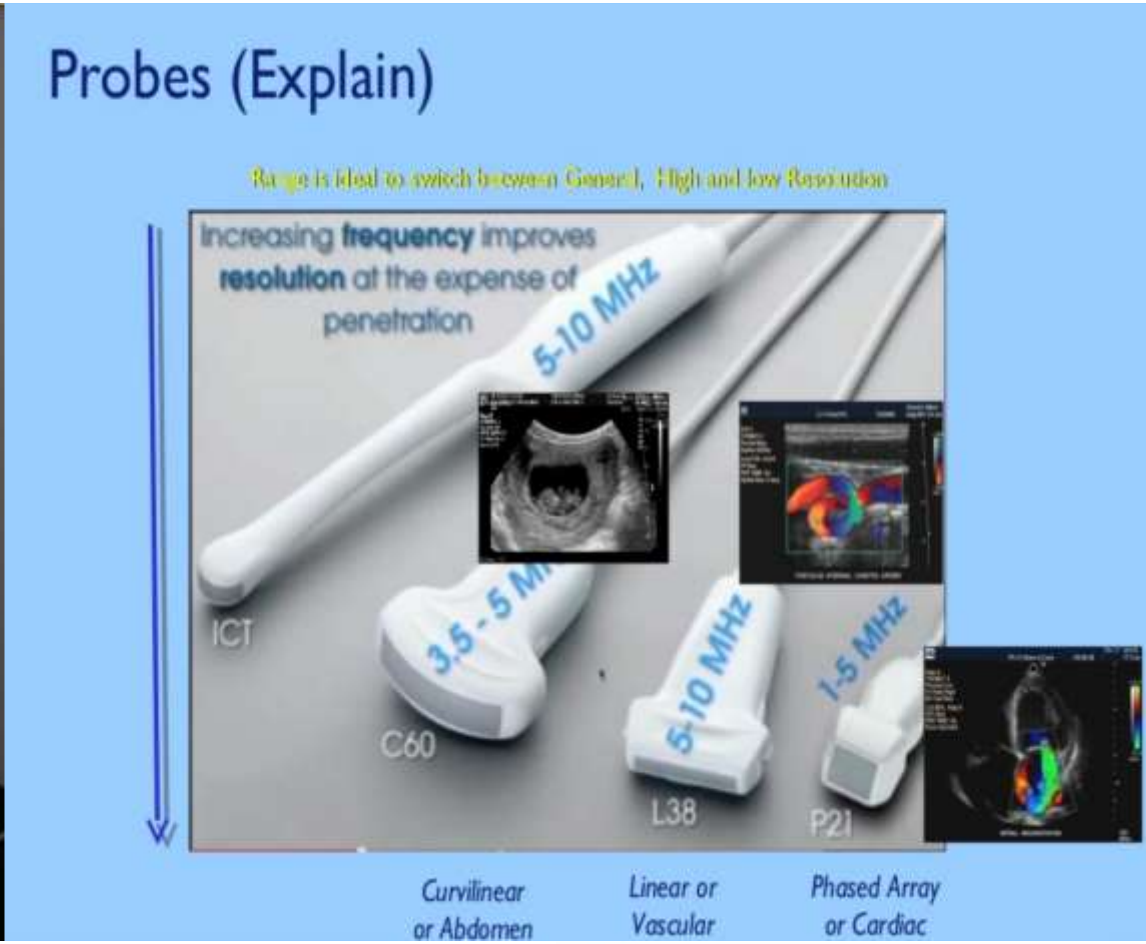
- ➢ High intensity ultrasound causes heating
- ➢ Could damage body tissues
- ➢ Low intensity ultrasound is always used for diagnostics ultrasound



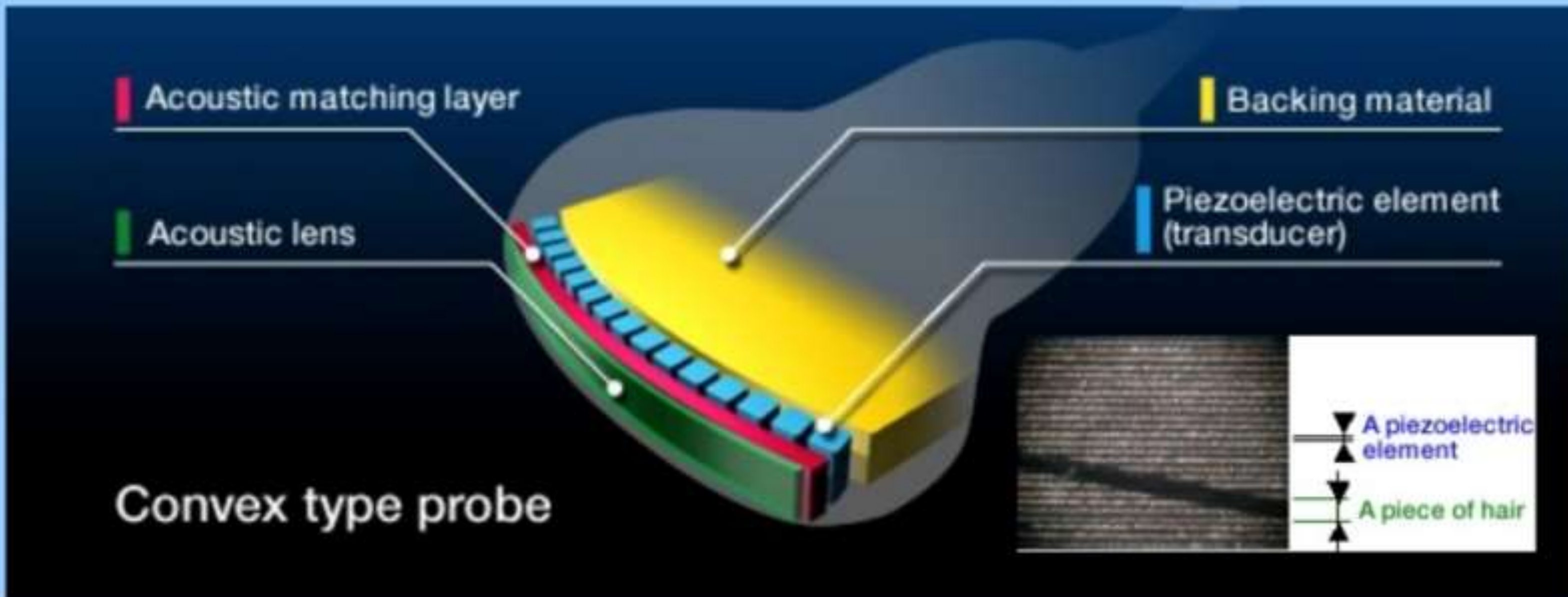
Basics of Ultrasound

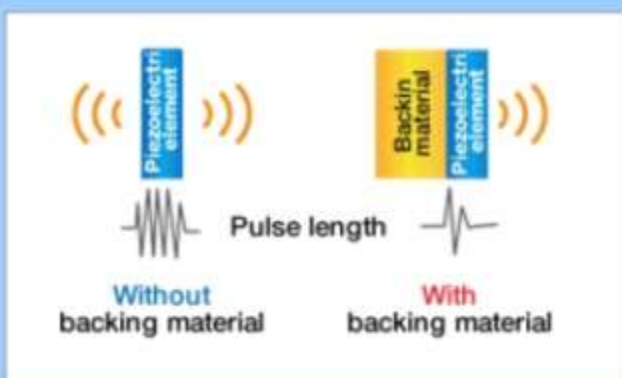
- **Sound is a mechanical wave**
  Created by a vibrating object
  Propagated through a medium
- **Sound is a pressure wave**
  Consists of repeating pattern of high and low pressure regions
- **Sound is a longitudinal wave**
  Motion of particles is in a direction parallel to direction of energy transport

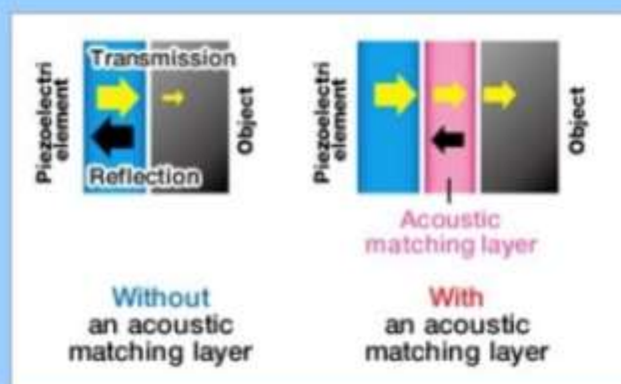
Basics of Ultrasound



Ultrasound - Internals







Beam focused by the acoustic lens

Interactions of Ultrasound with Tissue

- Most transducers send out waves only approximately 1% of the time, then the ultrasound system processes the returning signals into images that are displayed on the ultrasound monitor
- Acoustic impedance determines the amount of sound waves transmitted and reflected by tissues
- Reflection occurs when the ultrasound beam hits two tissues (areas) having different acoustic impedance
- Large differences in impedances inhibit useful information
  - Acoustic impedance : Z=dv
    d: density, v : sound velocity

Propagation Velocity

Material	Speed (m/s)	Acoustic impedance (g/cm^2 s)
Water (20°C)	1480	1.48×10^5
Blood	1570	1.61×10^5
Bone	3500	7.80×10^5
Fat	1450	1.38×10^5
Liver	1550	1.65×10^5
Muscle	1580	1.70×10^5
Polythene	2000	1.84×10^5
Air	330	0.0004×10^5
Soft tissue (average)	1540	1.63×10^5

Frequency vs. Resolution

- The frequency also affects the QUALITY of the ultrasound image
  - The **HIGHER** the frequency, the **BETTER** the resolution
- The **LOWER** the frequency, the **LESS** the resolution
- A 10 MHz transducer has very good resolution, but cannot penetrate very deep into the body
- A 3 MHz transducer can penetrate deep into the body, but the resolution is not as good as the 10 MHz

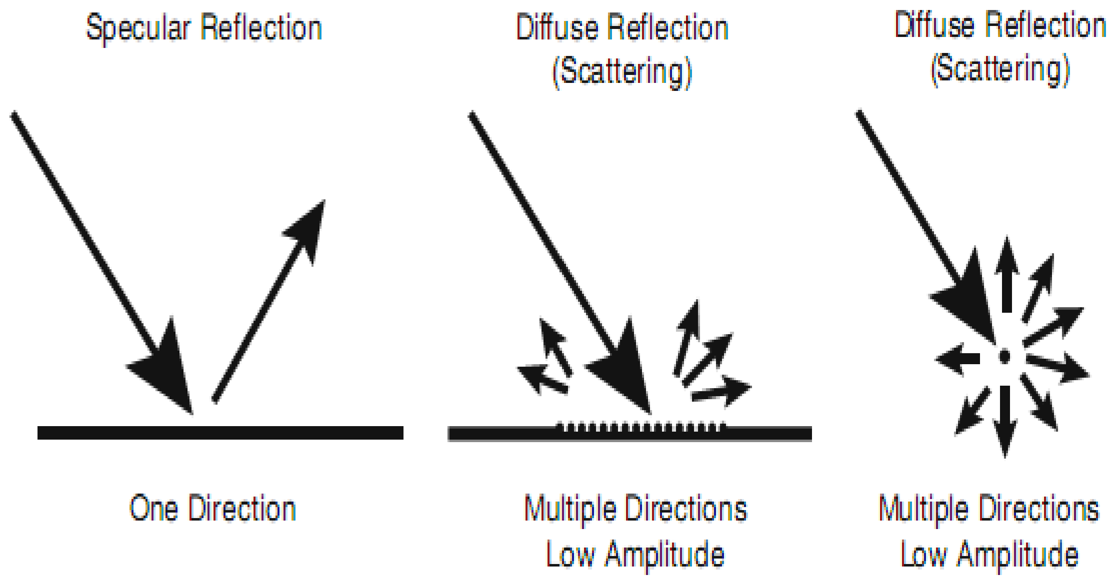
Low Frequency
3 MHz

High Frequency
10 MHz

Interactions of Ultrasound with Tissue

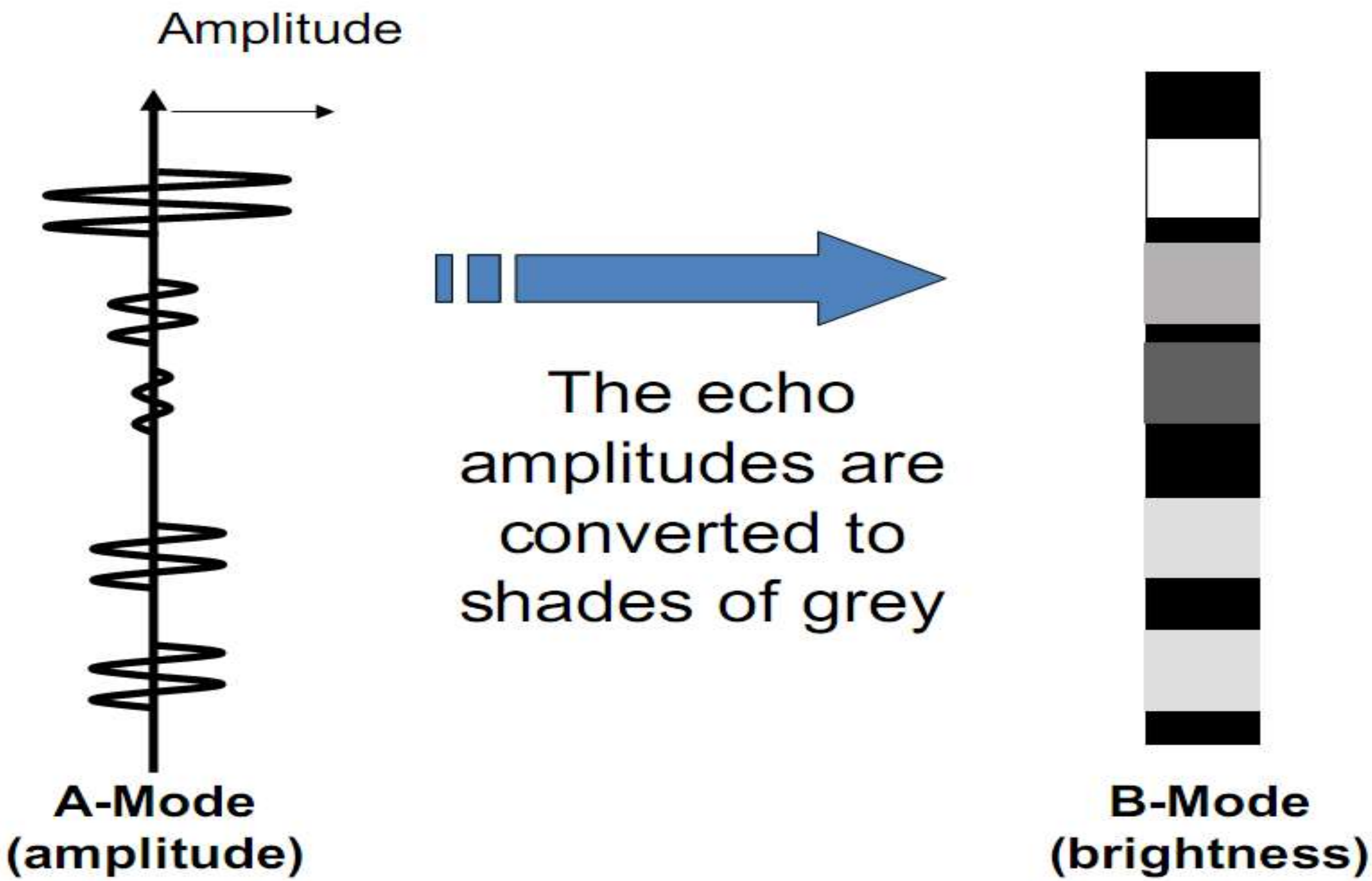
Ultrasound waves interact with tissue in these basic manners

- ➢ Reflection
- ➢ Refraction
- ➢ Scattering
- ➢ Transmission
- ➢ Attenuation

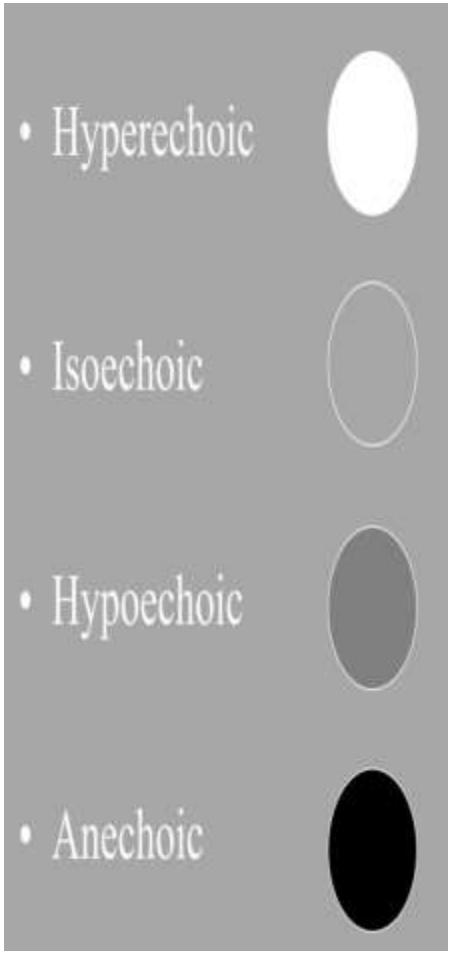


– The ultrasound image is formed from reflected echoes

Echoes from ONE Pulse

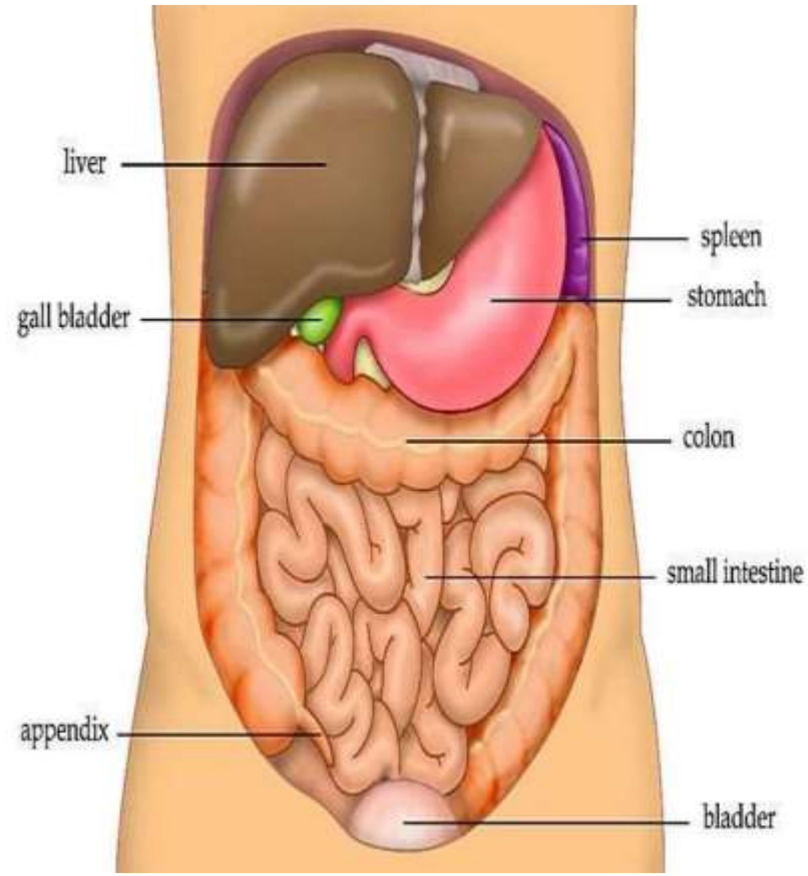


Echogenicity



Common Abdominal Injuries

- Hepatic lacerations
- Splenic rupture
- Renal injury
- Pancreatic injury
- Gastric rupture
- Bladder rupture
- Mesenteric artery tears
- Great vessel tears
- Diaphragmatic rupture
- Retroperitoneal hematoma



Pediatric Blunt Abdominal Injuries

Abdominal trauma constitutes 10-15% of the injuries in pediatric trauma patients

- Blunt 90%
- Penetrating 10%
- Spleen 37%
- Kidney 27%
- Liver 18%
- Pancreas 2%

What Makes Pediatric Patients Different?

- Ribcage compliant leads to transmission of force to liver and spleen
- Abdominal organs are relatively larger
- Abdominal muscles are poorly developed
- Better vasoconstrictive response
- Solid organ bleeding tends to stop
- Large BSA leads to Hypothermia
- Difficult to identify if patient in pain
  - Kids cry due to pain
  - Kids cry because doctors are scary
  - Kids cry because parents are not holding them

Abdominal CT for Pediatric Trauma

- Advantages
  - Gold standard for diagnosis of IAI
  - IV contract needed but no oral contrast
  - Excellent sensitivity for solid organ injuries
  - 97% accurate for bowel injury

Advances in CT result in high resolution, huge reduction of radiation exposure

- ☛ Good sensitivity (85-95%) for GI injuries
- ☛ Limited (~50%) sensitivity for pancreatic injuries

– Abdominal CT is recommended for the evaluation of hemodynamically stable patients associated neurologic injury, or multiple extra-abdominal injuries

CT Scan and the Pediatric Trauma Patient—Are We Overdoing It?

By Stephen J. Fenton, Kris W. Hansen, Rebecka L. Meyers, Daniel J. Vargo, Keith S. White, Sean D. Firth, and Eric R. Scaife
Salt Lake City, Utah

- 897 patients that had an abdominal CT
- Only 2% required exploratory laparotomy
- Only 5% of those that had CT's interpreted as abnormal required exploration

- *Fenton， JPS 39（12）,1877-1881, 2004*

Abdominal CT Scan – Risks

- Sedation: patient must be still for the CT, potential complications from sedation
- Transfer outside the ED
- Charges for abdominal CT …….
- Radiation exposure
- Epidemiological data suggests that 10-50 mSv for an acute exposure is sufficient to increase the risk of cancer

Linet et al. Pediatric Radiology, 2009. 39.
Frush. Pediatric Radiology, 2011. 41(2).

Radiation Doses

- CT head 2.5mSv
- CT chest 8mSv
- CT abdomen 10mSv
- CT pelvis 10mSv
- chest radiograph PA 0.02mSv
- abdomen radiograph AP 0.7mSv
- pelvis radiograph AP 0.7 mSv

It is estimated that 1:1000 children might die as a result of a radiation induced tumor

ALARA=As Low As Reasonably Achievable

Cost of CT Scan

- CT Head $2301
- C Cervical Spine $2739
- CT Chest $4161
- CT Abd/Pelvis $987
- Charge for a "Pan Scan:" ***$10,188***

The Bottom Line is….

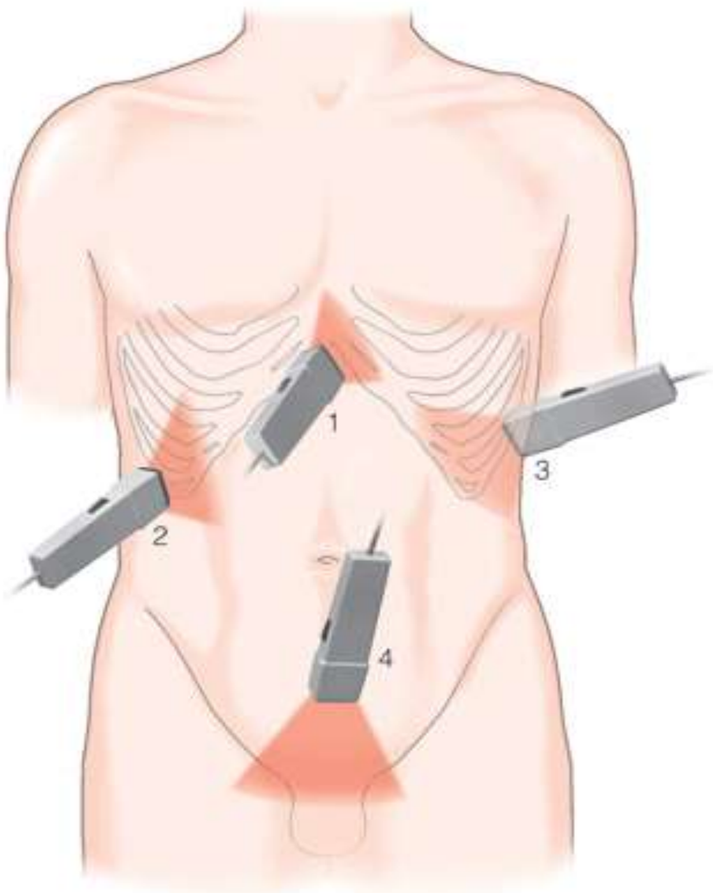
- The possibility for traumatic injury must dictate the need for radiation-based medical imaging as the risk from exposure to ionizing radiation associated with radiological examinations is low
- Nevertheless, it is still advisable to avoid such exposure where possible

<u>ALARA</u>=<u>A</u>s <u>L</u>ow <u>A</u>s <u>R</u>easonably <u>A</u>chievable

Focused Abdominal Sonography for Trauma

- Perform during
  - Resuscitation
  - Physical exam
  - Stabilization

FAST and eFAST

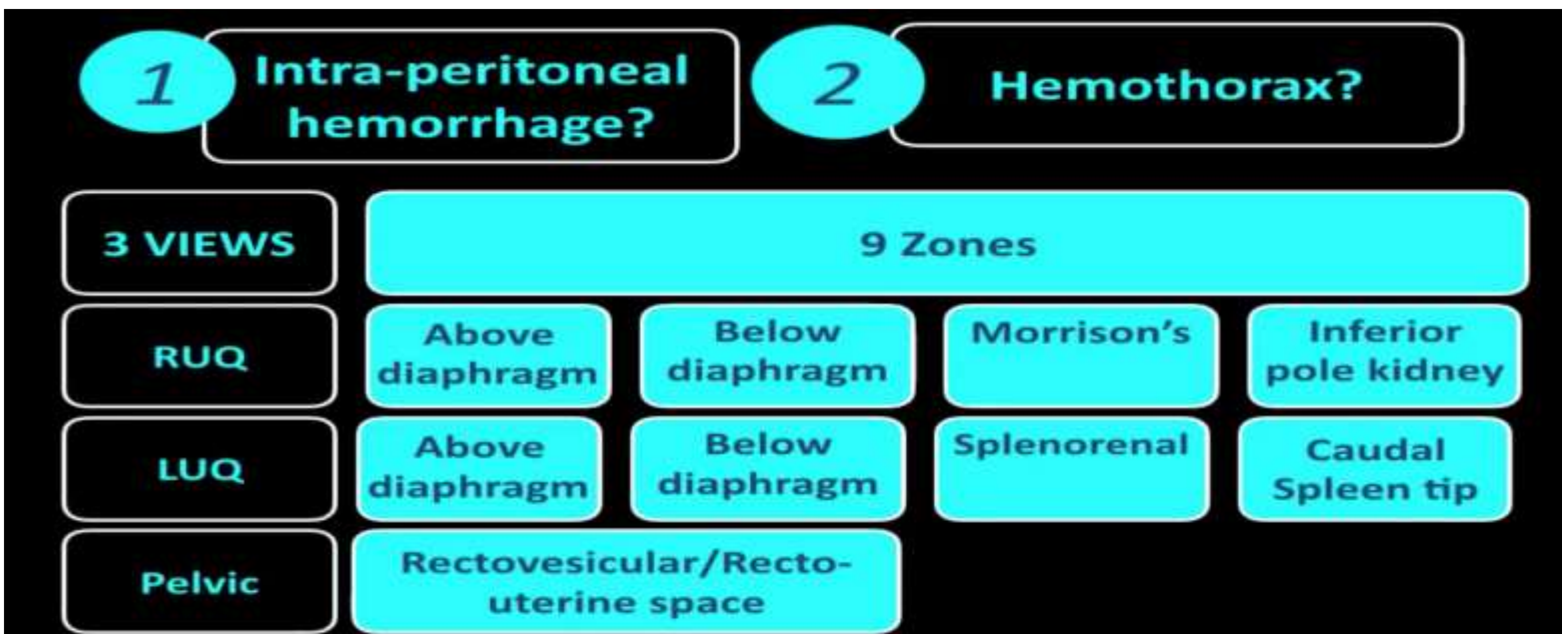


- Four standard views
  - Pericardial
    - Subxiphoid (parasternal if cannot obtain subxiphoid view)
  - Perihepatic
  - Perisplenic
  - Pelvic

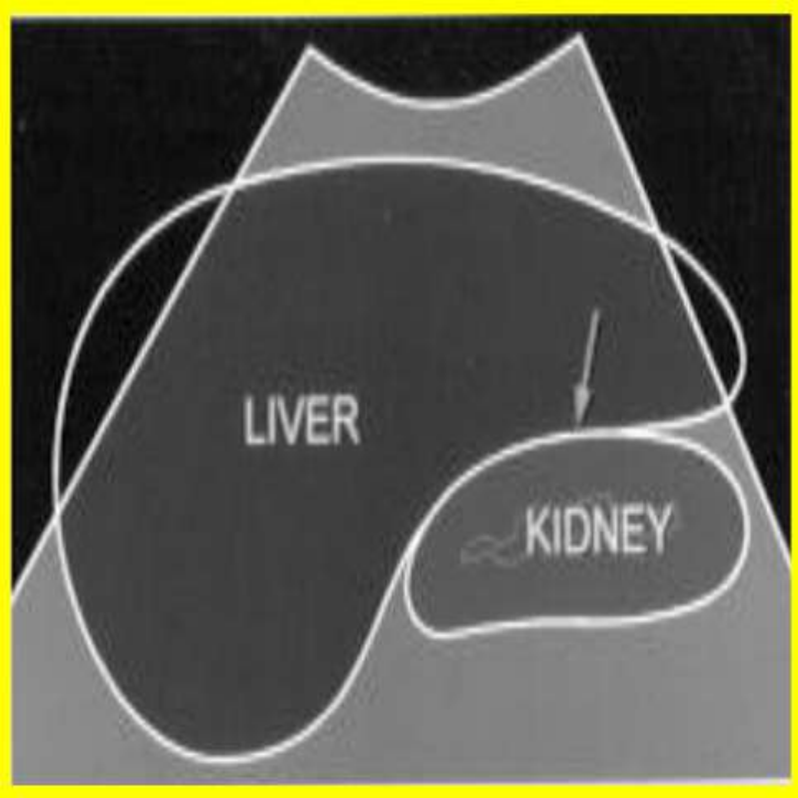
- 3.5 MHz curvilinear transducer

Time to Complete Scan

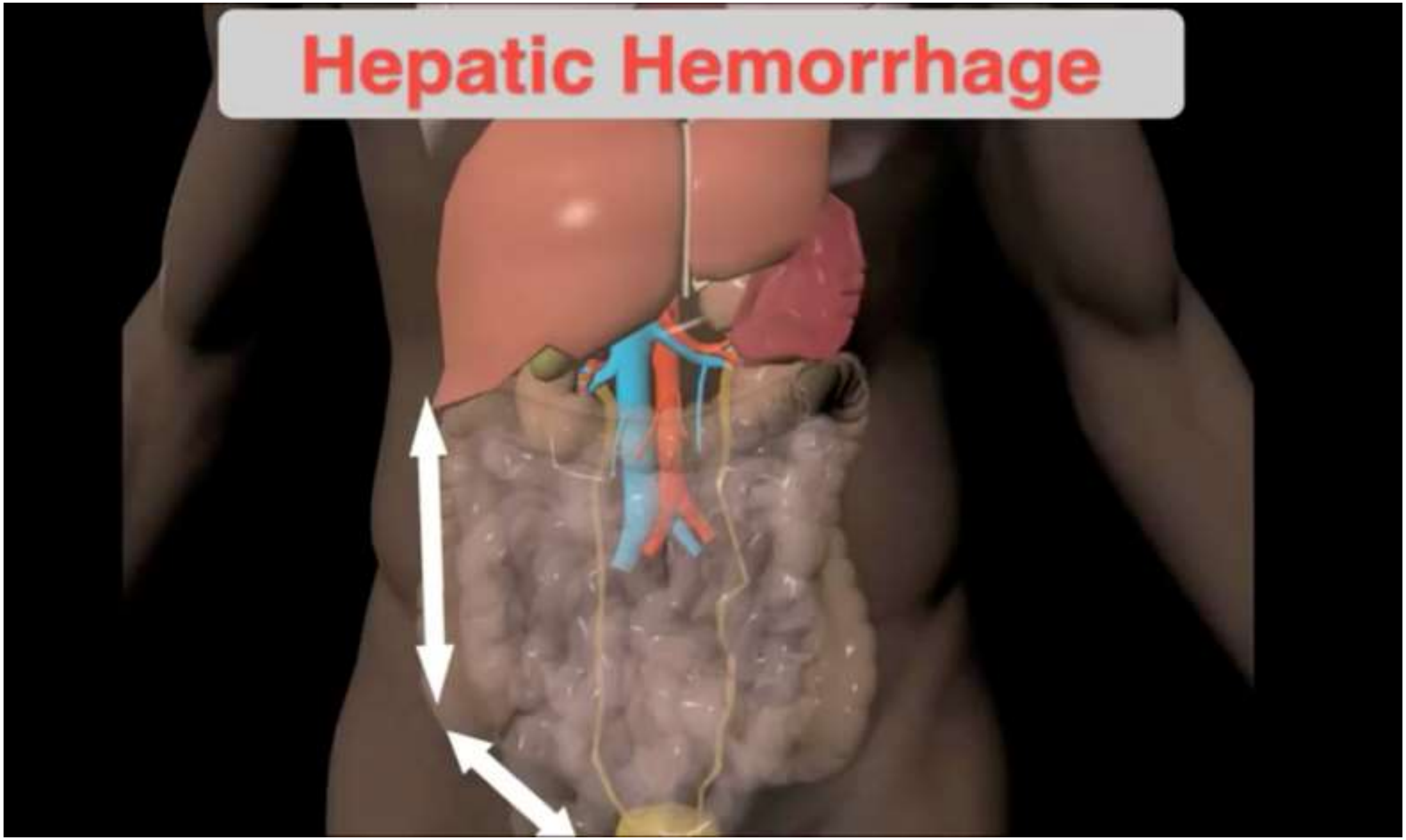
- Each view: 30-60 seconds
- Number of views dependent on clinical question and findings on initial views
- Total exam time usually < 3-5 minutes



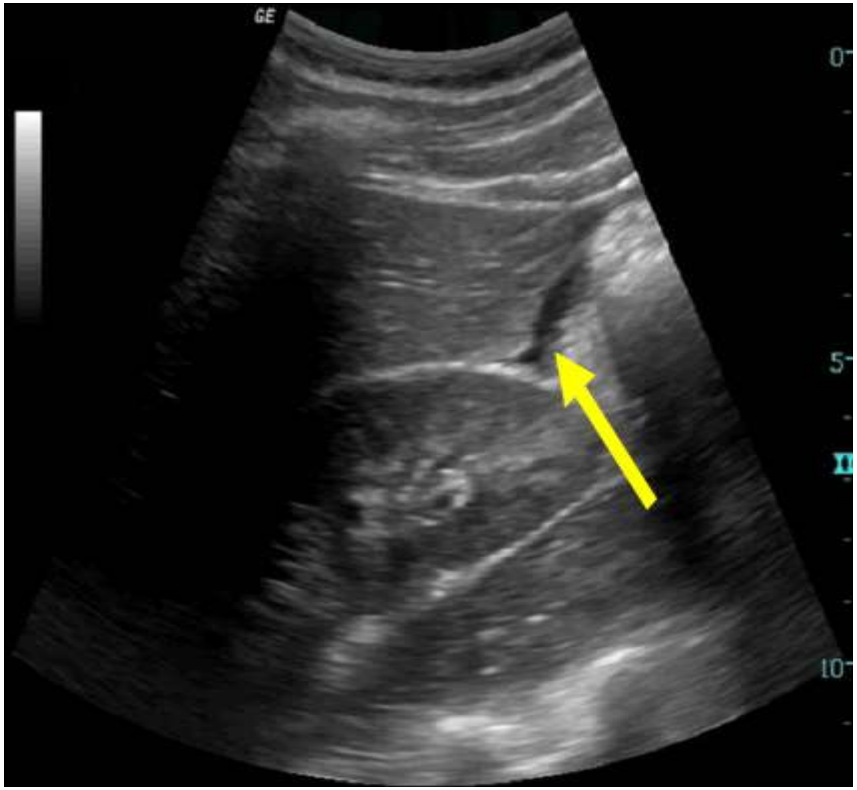
Scanning Techniques (RUQ)



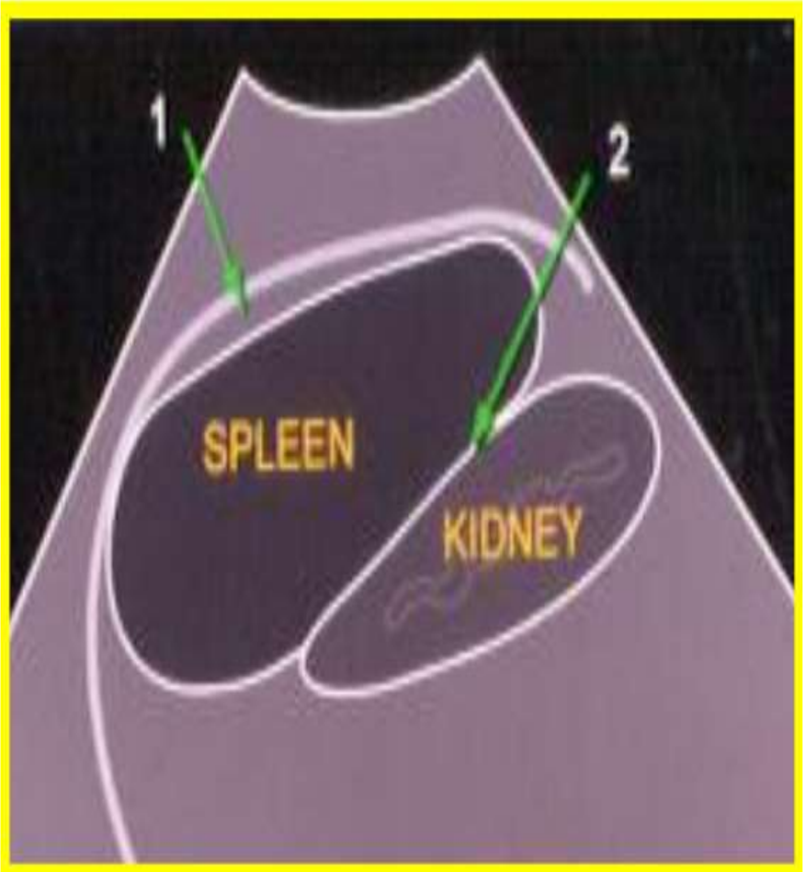
Scanning Techniques



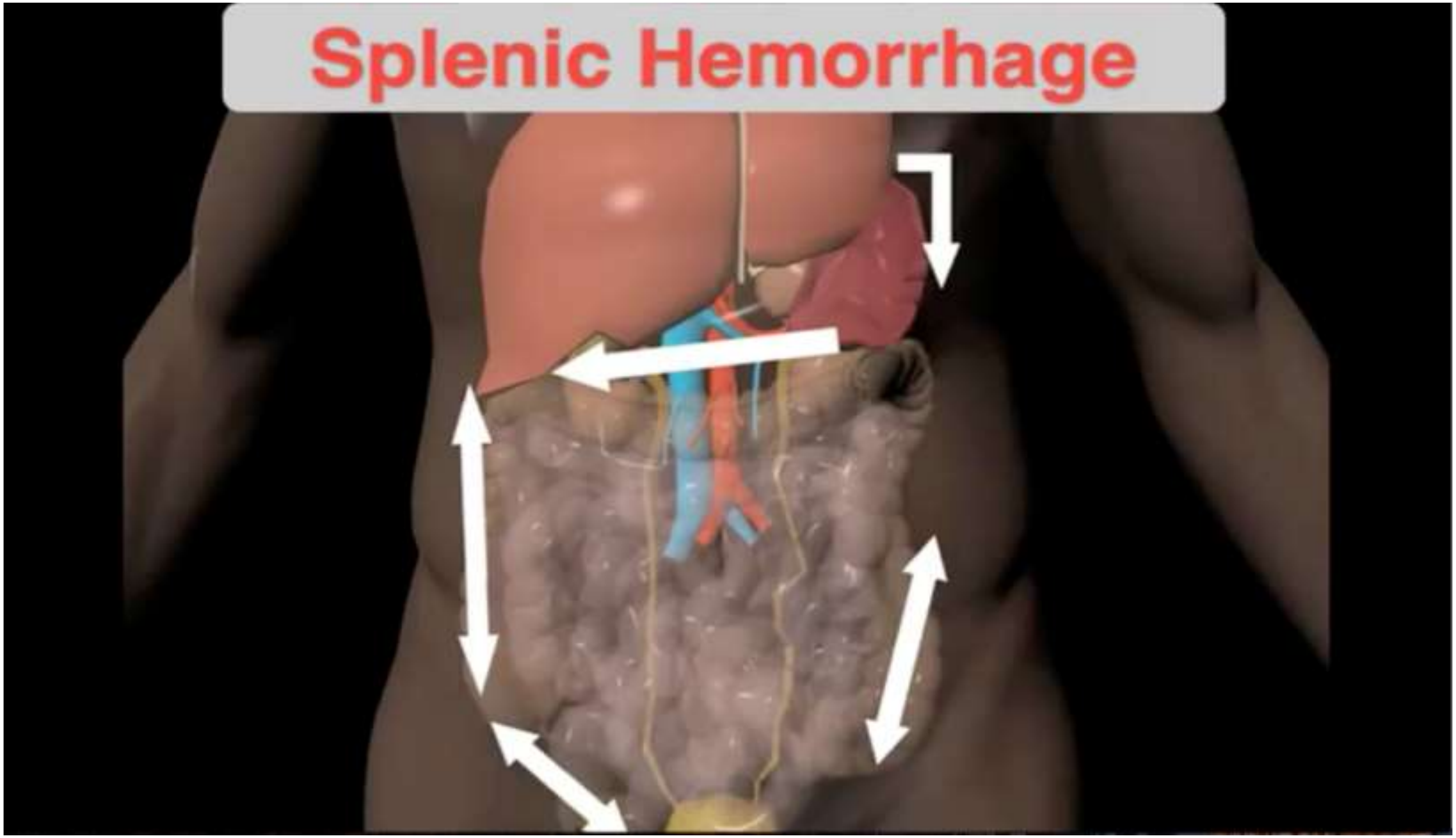
Free Fluid in Morison's Pouch



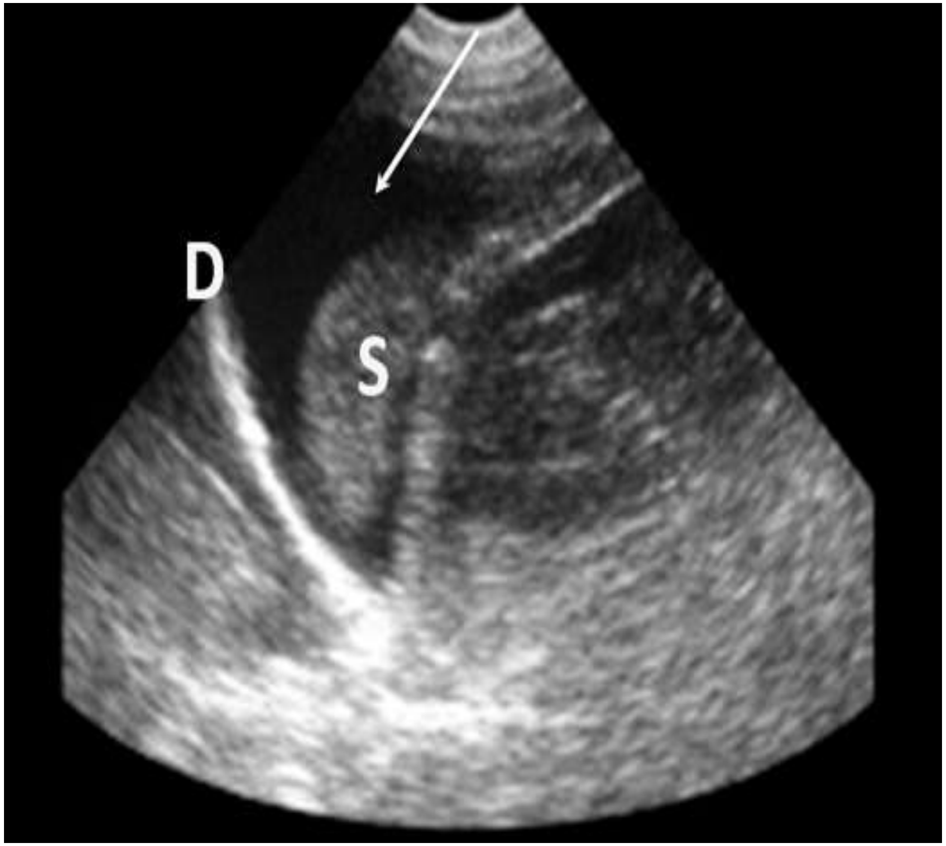
Scanning Techniques (LUQ)



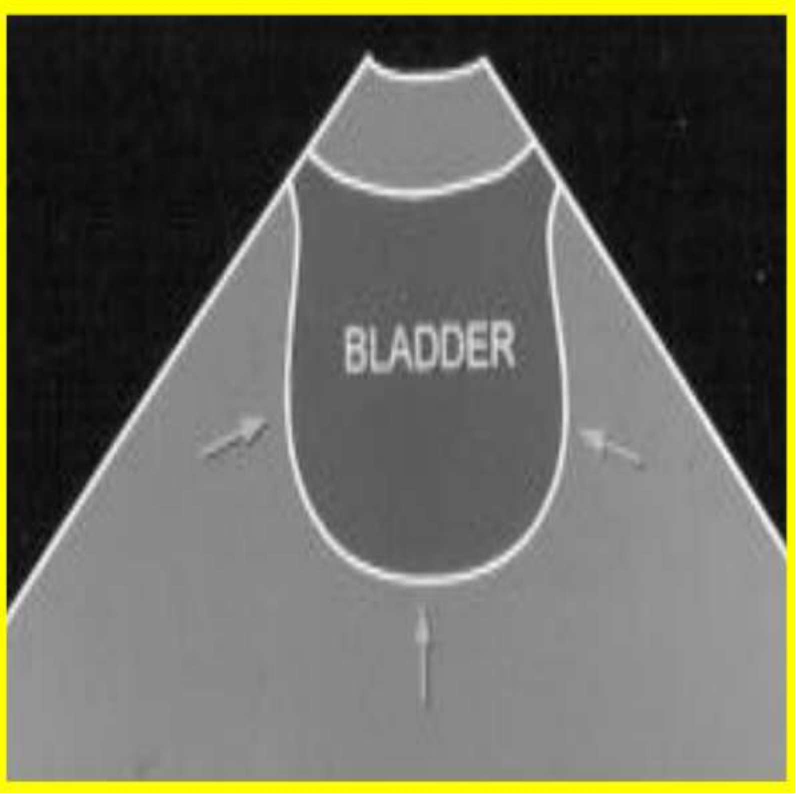
Scanning Techniques



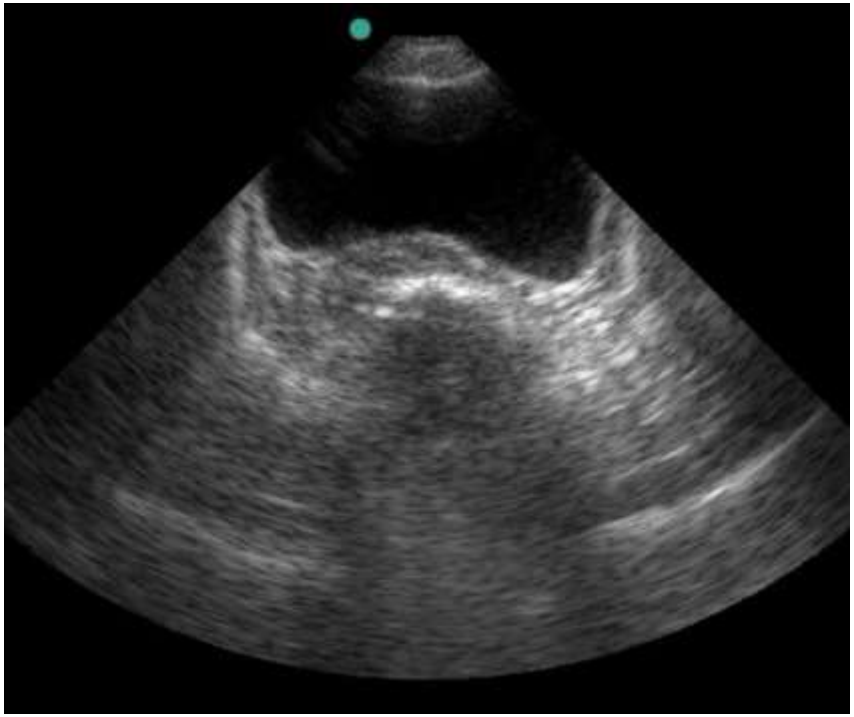
Splenic& Hepatic Trauma



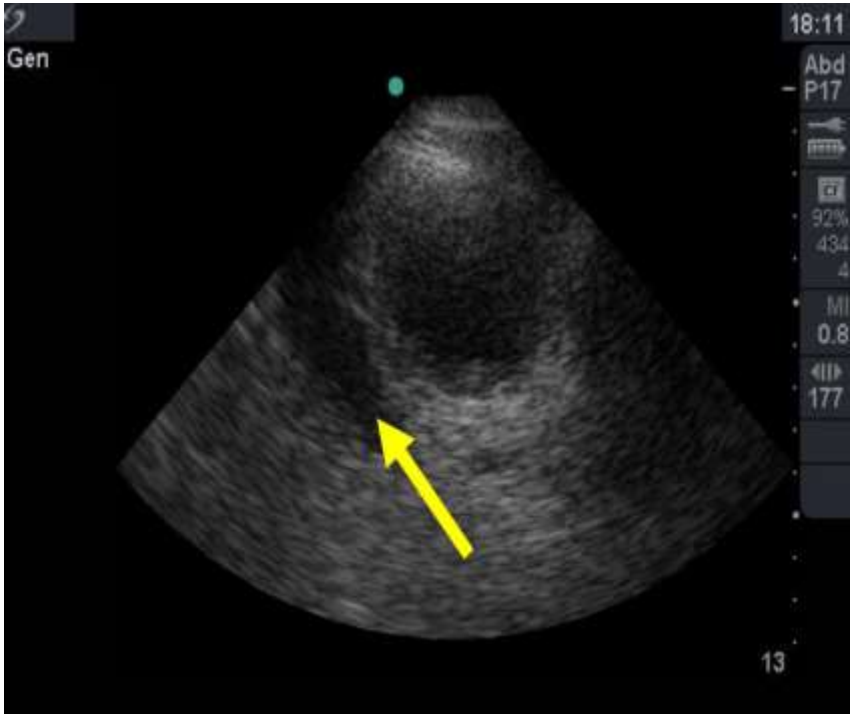
Scanning Techniques (Pelvic View)



Fluid in Pelvis



Transverse pelvic view: normal



Transverse pelvic view: positive FF (arrowed)

Clinical Experience with FAST

- Intraperitoneal fluid
  - Sensitivity 82-98%, specificity 88-100%
- Morison's pouch alone 36-82% sensitivity
- The sensitivity depends on
  - Source of hemorrhage
  - Rate of hemorrhage
  - Patient position
  - Prior abdominal surgeries
- Can detect as little as 250cc of free fluid
- FAST can be performed in children but the threshold for operative intervention in pediatric blunt abdominal trauma is higher than for adults

Clinical Experience

- Solid organ disruption
  - 40% sensitivity for all organs
  - 33-94% for splenic injury
- Hollow viscus injury
  - Sensitivity 57%
- Retroperitoneal injury
  - Sensitivity for identification of hemorrhage <60%
- FAST = specific, not sensitive
- FAST = a rule-in test for large volume hemorrhage, should not be used as a rule-out strategy

Use of focused abdominal sonography for trauma at pediatric and adult trauma centers: a survey

Eric R. Scaife[a,*], Stephen J. Fenton[b], Kris W. Hansen[a], Ryan R. Metzger[a]

[a]*Division of Pediatric Surgery, Primary Children's Medical Center, Salt Lake City, Utah 84113, USA*
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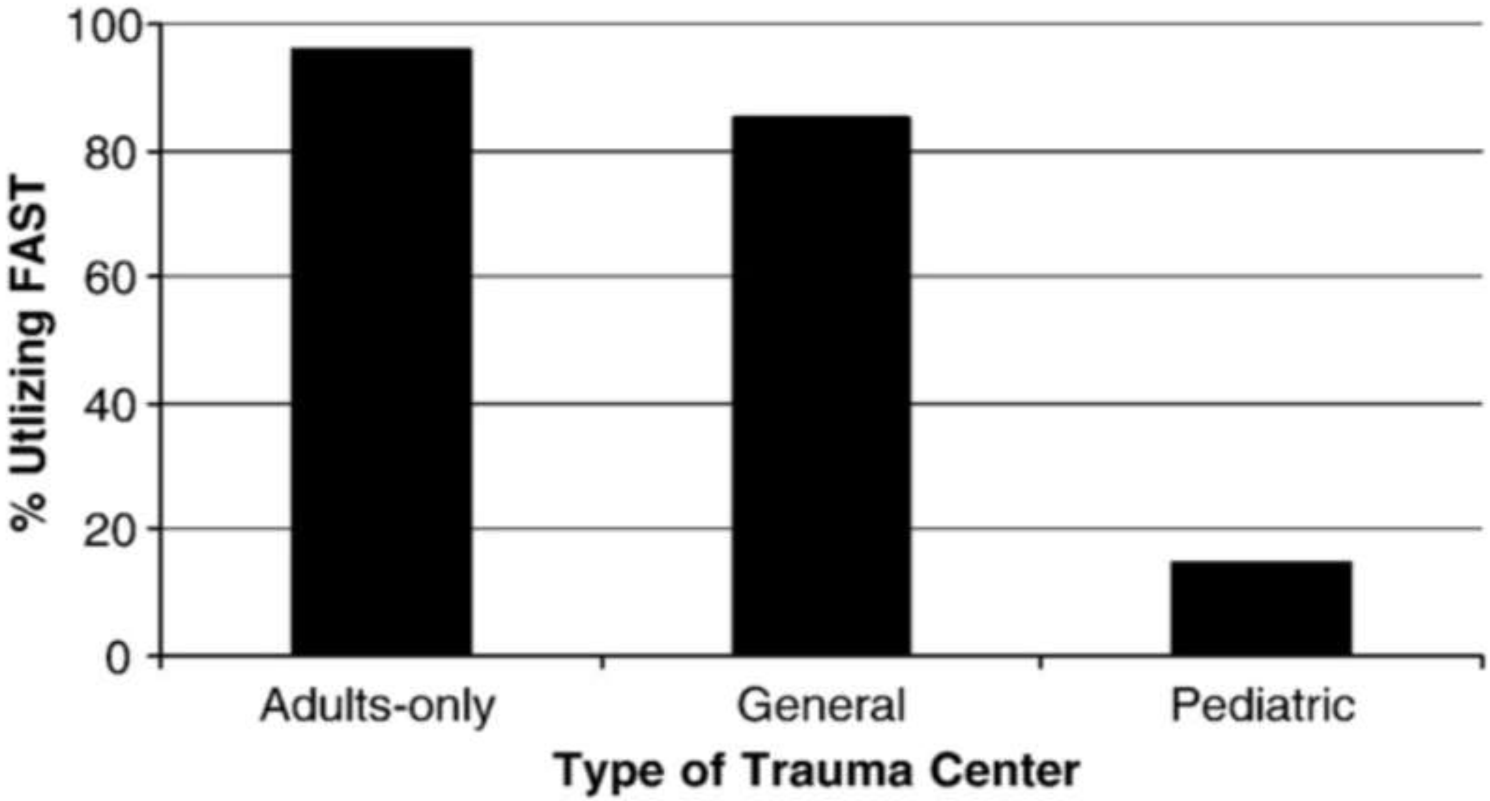
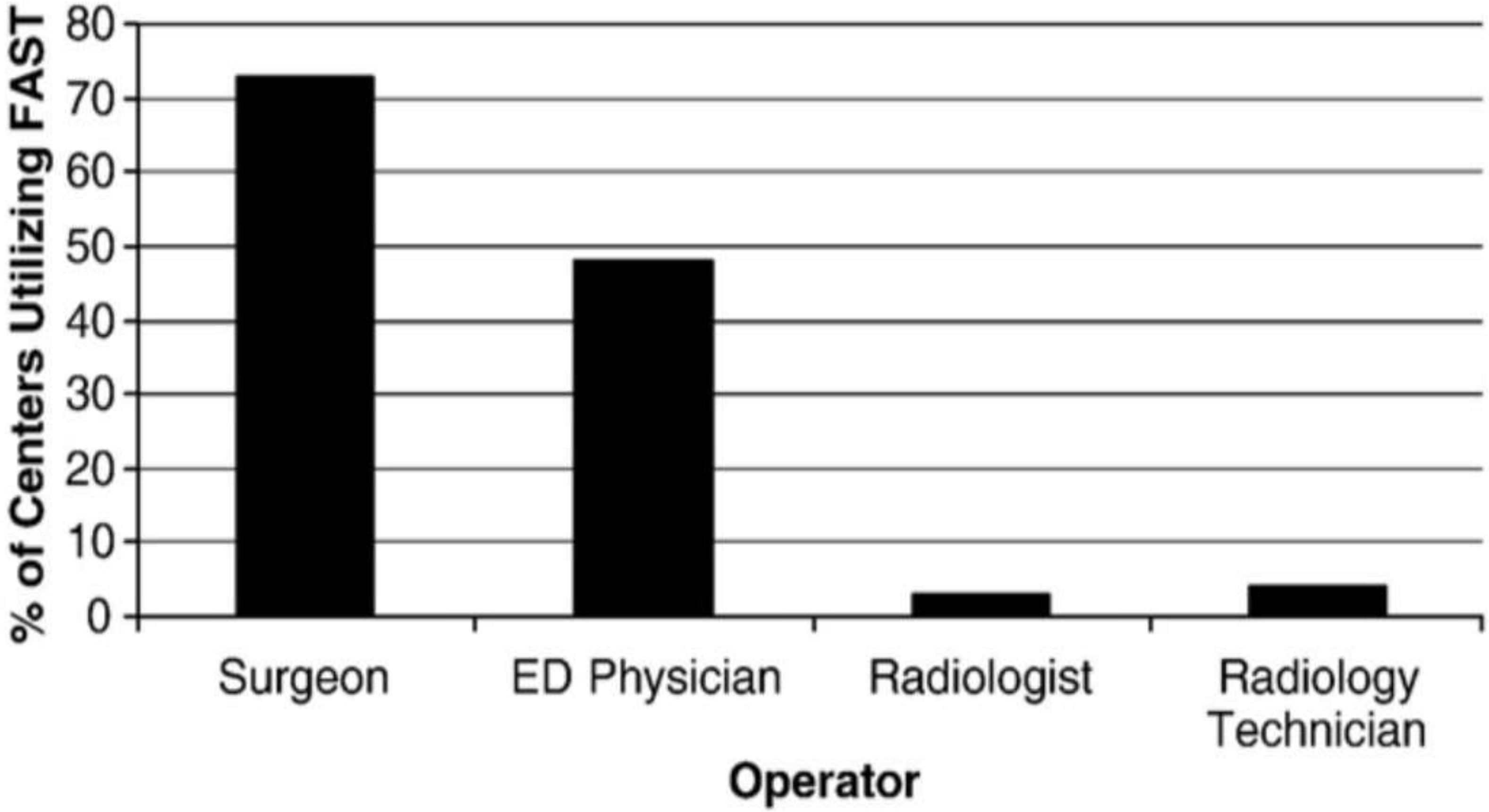
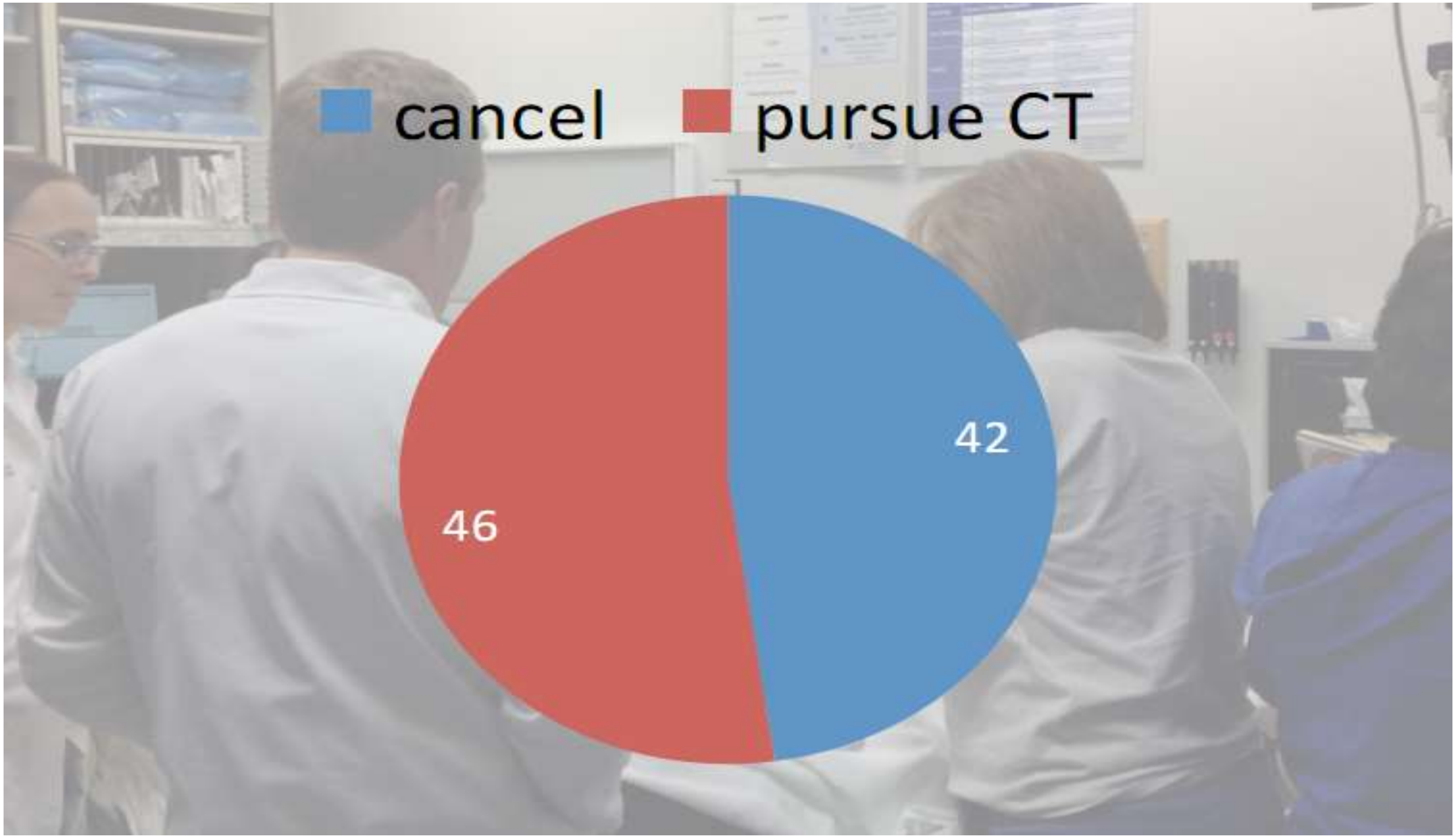
Received 7 October 2008; revised 16 January 2009; accepted 18 January 2009



Individual Performing FAST



Would the surgeon elect to cancel the CT after the FAST?



<u>A</u>LARA=<u>A</u>s <u>L</u>ow <u>A</u>s <u>R</u>easonably <u>A</u>chievable

FAST

☆ Advantages:

- Rapid ID of Intraperitoneal Haemorrhage
- Non Invasive
- Portable
- Rapid (5min FAST)
- Widespread (US) therefore not rely on Radiologists
- Serial examinations possible
- No side effects

FAST- Principles

- Intraperitoneal fluid may be
  - Blood
  - Preexisting ascites
  - Urine
  - Intestinal contents

FAST-Current Status

- FAST has become an accepted tool to assess the adult trauma patient
- It has become the study of choice to rule out hemoperitoneum or cardiac tamponade in the unstable adult trauma patient
- It's acceptance in pediatric trauma has not been as widespread

FAST in Pediatric Abdominal Trauma

- Less fluid may mean less sensitivity
- Less volume leads to less experience and comfort with the procedure
- Estimated as high as 40% of pediatric abdominal trauma is solid organ injury without intra-abdominal fluid
- Children are rarely unstable from hemorrhagic shock
- SO WHY FAST?

WHY FAST in Pediatric Trauma?

- 700% increase in the number of CT scans the past decade
- 11% of all CT scans performed on children
- Appendicitis and trauma the 2 most cited areas of abuse
- Children’s cells more rapidly dividing and more sensitive than adults

Current Opinion in Pediatrics 2008, 20:243–247

ORIGINAL ARTICLE

Complete ultrasonography of trauma in screening blunt abdominal trauma patients is equivalent to computed tomographic scanning while reducing radiation exposure and cost

Zia A. Dehqanzada, MD, Quinn Meisinger, MD, Jay Doucet, MD, Alan Smith, MPH, PhD, Giovanna Casola, MD, *and* **Raul Coimbra, MD, PhD,** *San Diego, California*

J Trauma Acute Care Surg 199-205

- Blunt abdominal trauma (BAT) has heightened concerns for increased radiation exposure and costs
- Complete ultrasonography of trauma (CUST) is equivalent to routine computed tomography of the abdomen and pelvis(CTAP) for BAT screening and leads to an average of 42% less radiation exposure and more than $591,000 savings per year (J Trauma Acute Care Surg. 2015;79: 199-205)

FAST

- Disadvantages:
  - Operator dependant
  - Patient dependent (obese, constipated: attenuation)
  - Can’t differentiate blood from ascites
  - Brain can hardly be imaged with ultrasound
  - Limited ability to detect free fluid in some injured children
  - Low sensitive to patients with mesenteric, diaphragmatic, or hollow viscous injury and isolated penetrating injury
  - High (31%) false-negative rate in detecting hemoperitoneum in the presence of pelvic fracture

Introduction of CEUS

- Contrast-enhanced ultrasound (CEUS) is an essential modality in imaging abdominal solid organs
- CEUS is of great value in assessment of mild-to-moderate blunt abdominal trauma, although its use is still off-label in the United States
- CEUS may improve the sensitivity and specificity of US in the diagnosis of blunt abdominal injury in children, thereby obviating the need for CT

Safety: Black Box Warning

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Cardiac Imaging

Safety and Efficacy of Commercially Available Ultrasound Contrast Agents for Rest and Stress Echocardiography

A Multicenter Experience

Melda S. Dolan, MD,* Simil S. Gala, MD,* Saritha Dodla, MD,† Sahar S. Abdelmoneim, MD,‡ Feng Xie, MD,† David Cloutier, MS,† Michelle Bierig, MPH, RDCS, RDMS,* Sharon L. Mulvagh, MD, FACC, FRCP,‡ Thomas R. Porter, MD, FACC, FASE,† Arthur J. Labovitz, MD, FACC, FACP, FCCP, FASE*

St. Louis, Missouri; Omaha, Nebraska; and Rochester, Minnesota

1997: FDA Approval of contrast agents
2007: Black Box Warning
2008: Retrospective multicenter study

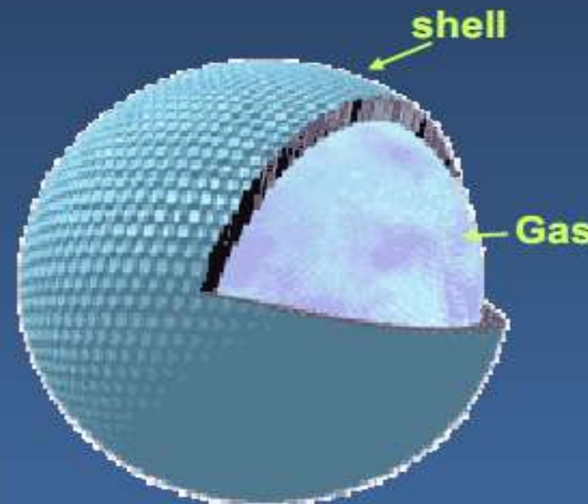
Conclusions

This study examined, in a large multicenter experience, the safety and incremental value of contrast use in the clinical practice of stress echocardiography. The risks of both short-term and long-term events, defined as nonfatal MI and death, after contrast administration are very low and are no different than in patients not receiving contrast during stress echocardiography. Contrast use in patients with suboptimal images improves feasibility and accuracy of stress echocardiography testing. Failure to use contrast agents in patients with suboptimal images may result in a misdiagnosis and/or additional alternative imaging tech-

Basics of Contrast Agent

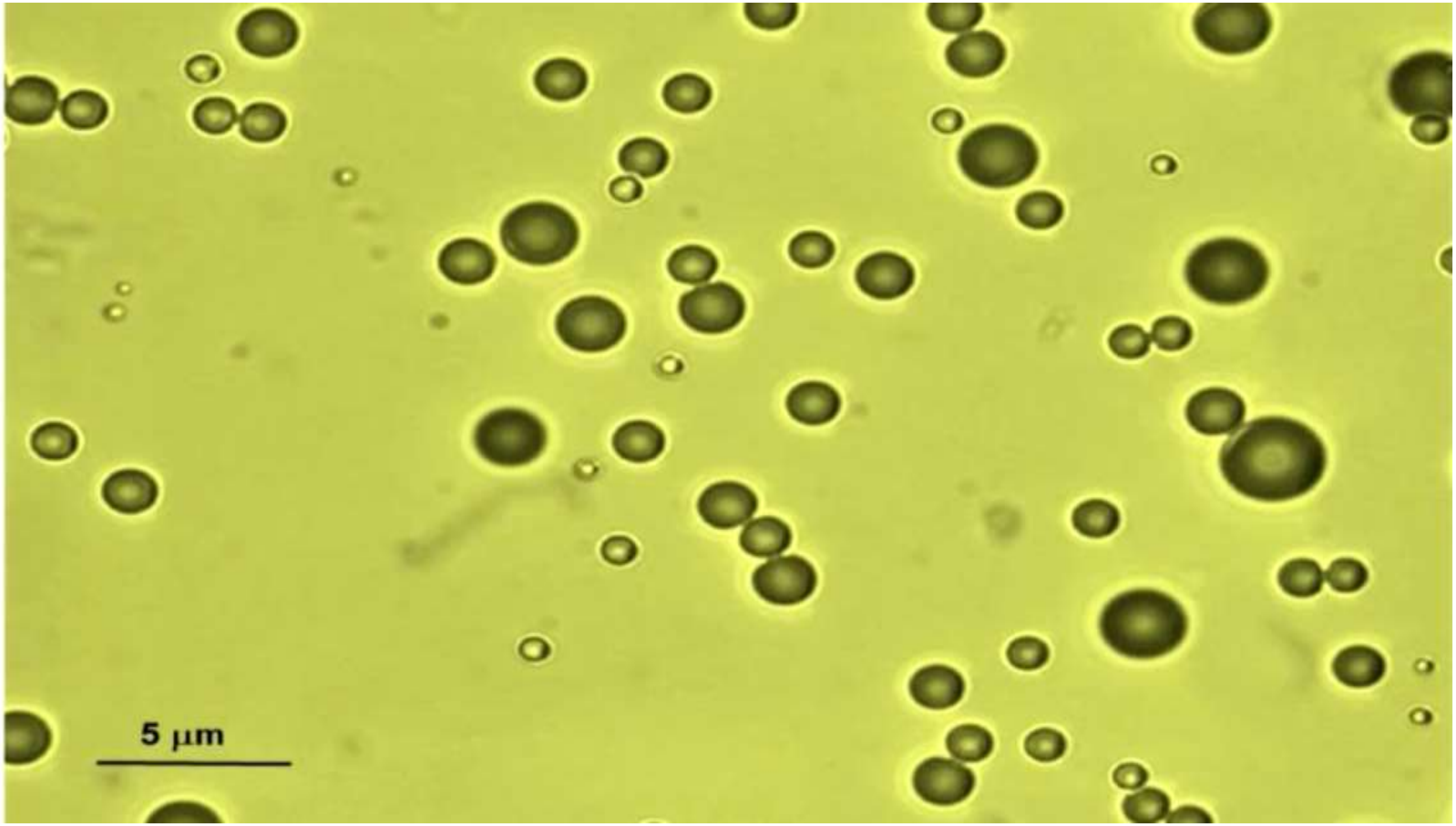
- UCA : Suspensions of **tiny gas microbubbles** for intravenous injection
- Cross the capillary bed

- Diameter 1-10 μm (Φ=3 μm)
- Persistence: minutes to hours
- Gas: air or high molecular weight gas
- Shell: albumin/lipid/polymer
- Shell thickness 5 - 500 nm
- Concentration 1-5 x 10^8 bubbles/ml
    - Sonovue Europe 2001
    - Definity USA & Europe (Luminity 2007)
    - Sonazoid Japan 2007

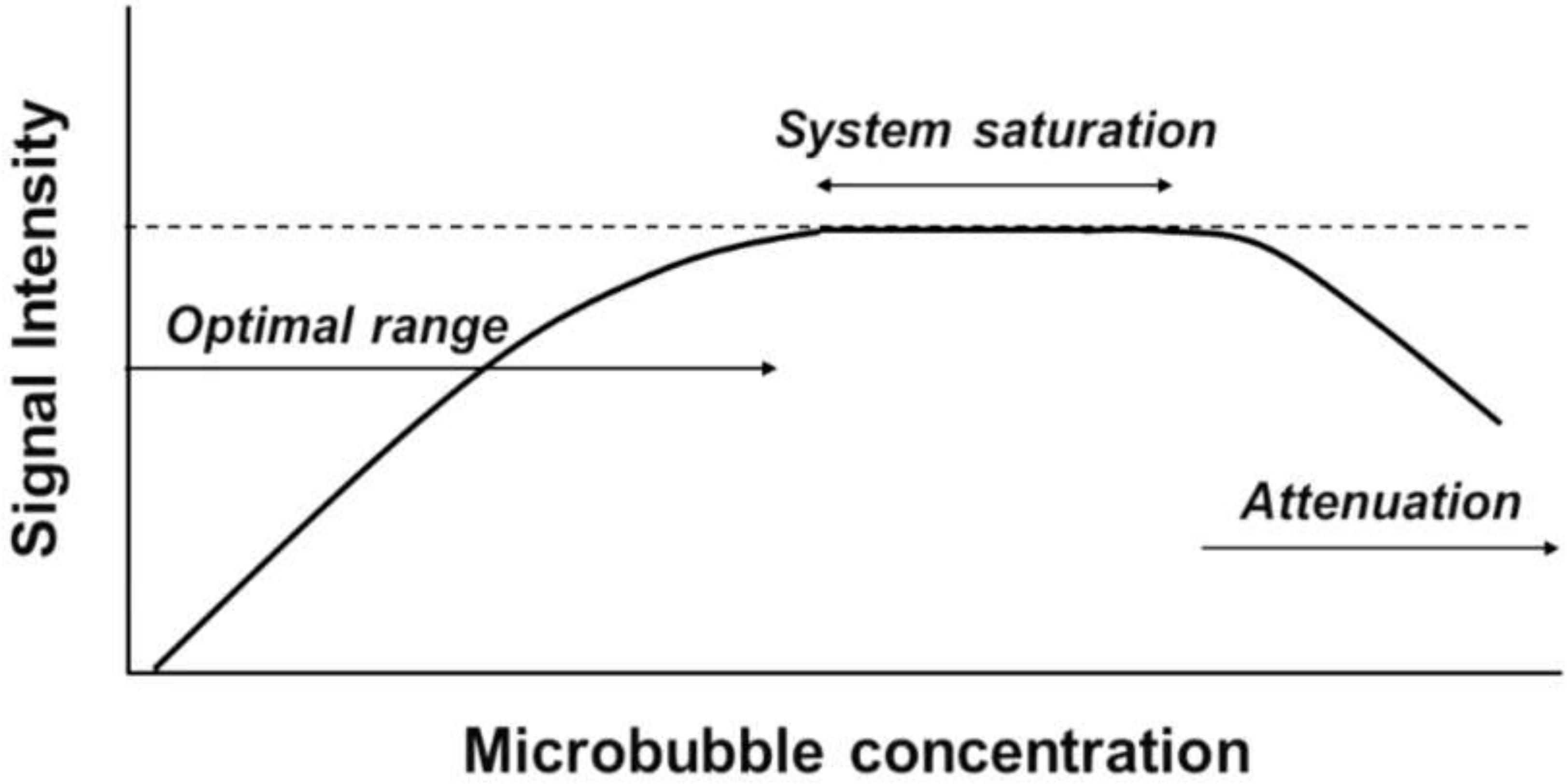


RBC
6–8 μm

Basics of Contrast Agent



Microbubble Concentration vs Signal



CEUS: Clinical Implications

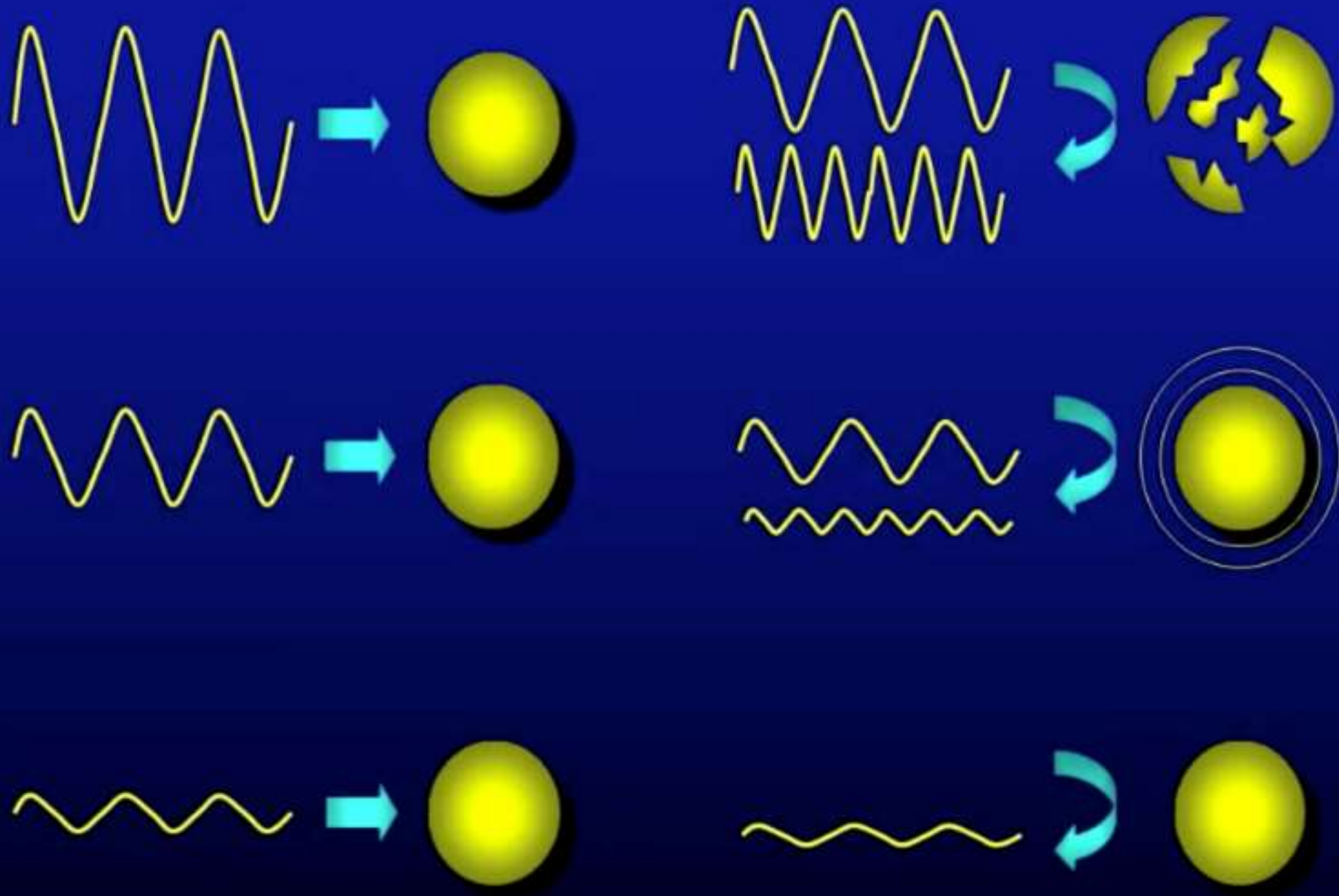
- CEUS is emerging as an important modality for imaging the abdominal organs injury, especially in patients with renal disease, contrast allergy, and contraindication to MRI
- It has 96% sensitivity and 99% specificity when compared with CT in detection of abdominal parenchymal lesions
- CEUS provides important and diagnostic information in real-time, often obviating the need for additional or follow-up imaging

Acoustic Power and Microbubble Responses

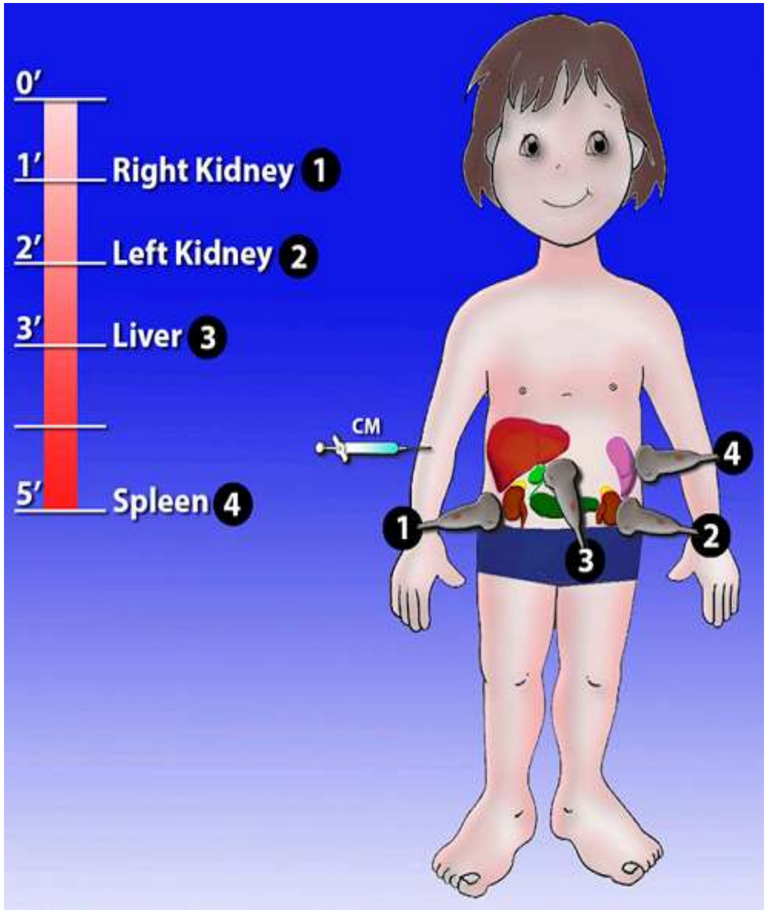
High Power
(MI>0.7)

Low Power
(MI 0.1-0.3)

Very Low Power
(MI <0.1)

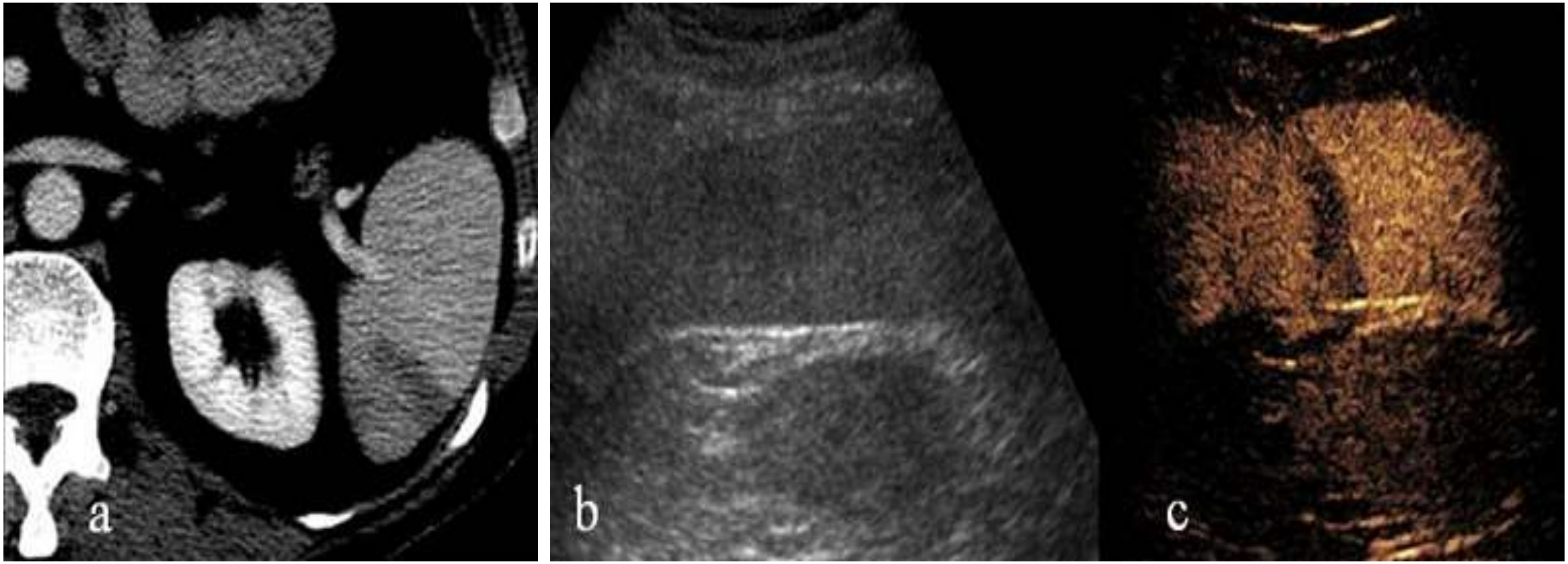


CEUS in Children



- Contrast-enhanced ultrasound (CEUS) employs a software operating at low mechanical index
- The contrast agent is administered an antecubital vein
- The arterial phase starts after 1-20s and proceeds up to 30-40s
- The venous and late phase lasts in the range of 2-6min
- The entire examination lasts for 4-6 min

Spleen Laceration

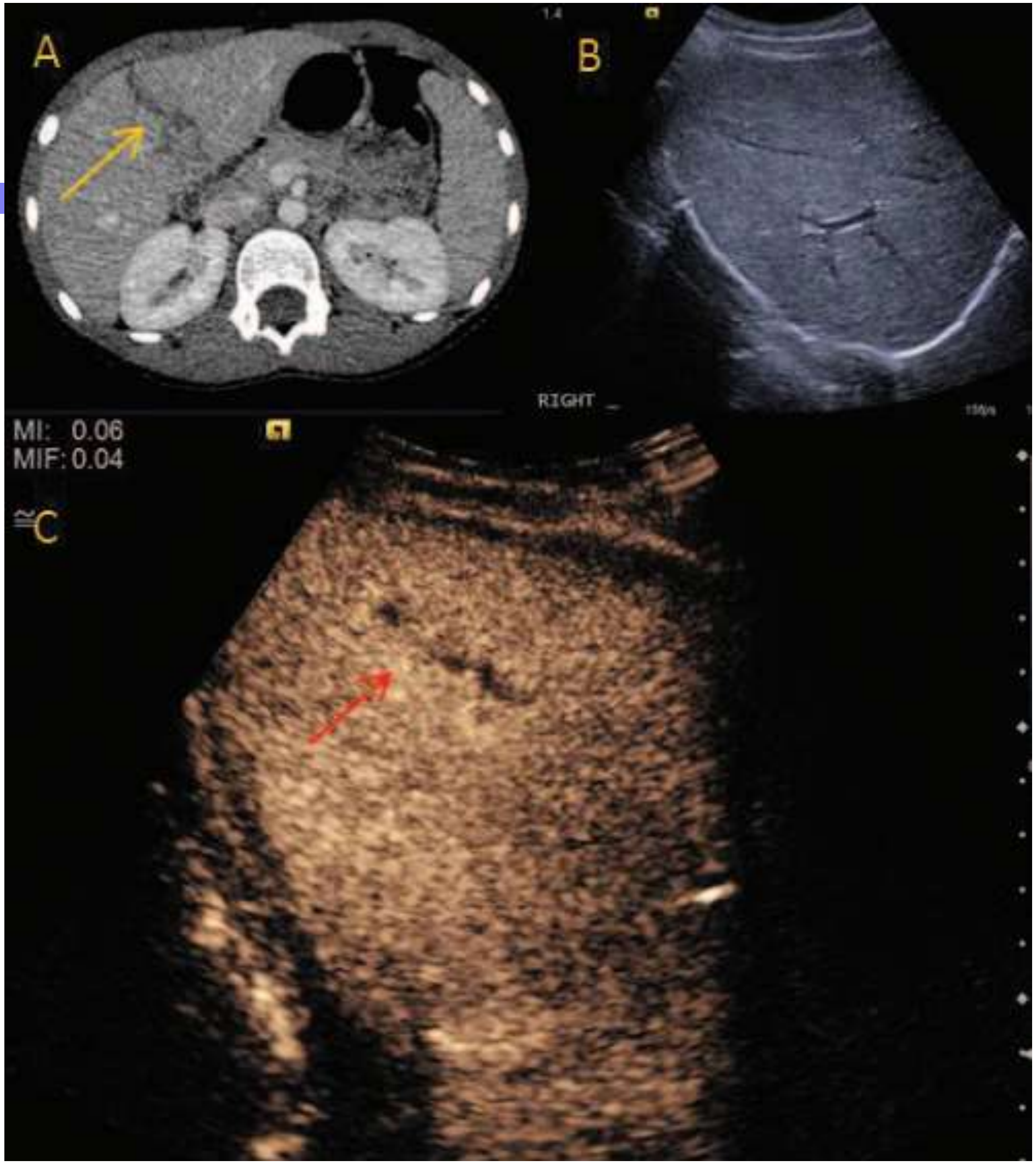


Spleen. Contrast-enhanced CT in venous phase (a), US-B-mode (b) and CEUS (c) in a 40 year- male patient with blunt abdominal trauma. CT shows a splenic hypodense parenchymal lacerative area (a) not recocognizable by US B-Mode examination (b). CEUS demonstrate splenic hypoechoic lesion corresponding to that of CT.

Grade III Splenic Injury

Liver Injury

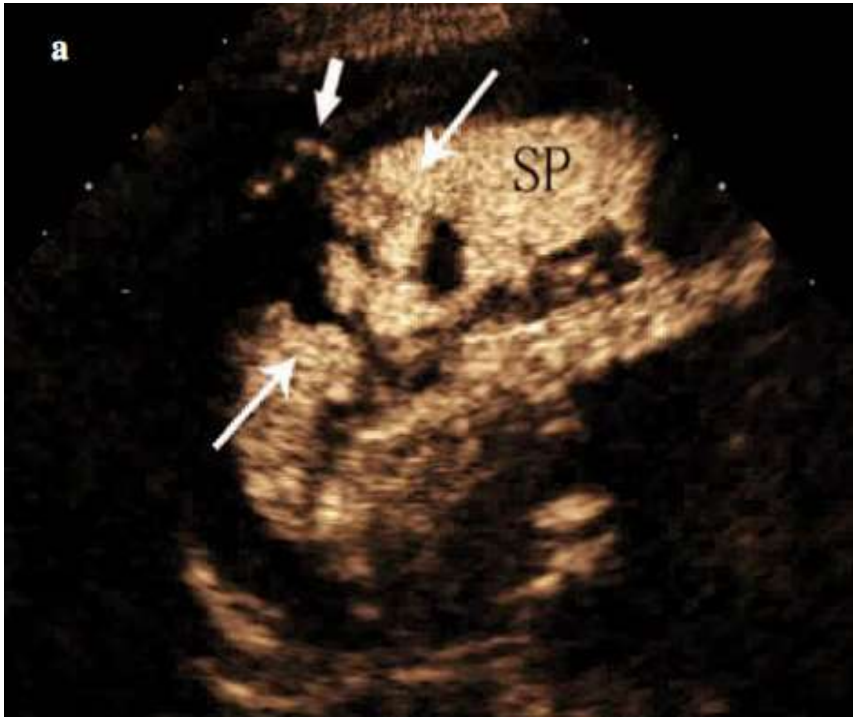
CT, B mode ultrasound and CEUS of a 10-year-old boy who sustained a handlebar injury after falling off his bike. (A) CT shows a 6cm liver laceration (yellow arrow) extending to the bifurcation of the portal vein consistent with a grade 3 injury. (B) B mode ultrasound shows homogenous echogenicity of the liver parenchyma. (C) CEUS demonstrates the liver laceration that was not seen on B mode ultrasound (red arrow)



上海交通大学医学院附属 新華醫院
Xin Hua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine

Active Bleeding of Spleen

a.The active hemorrhage appeared as an isolated, fountain-like, hyperechoic stripe (short arrow).



b.Gross specimen obtained in the same patient confirmed the origin of hemorrhage, as shown by contrast-enhanced ultrasound.

CEUS

➢ Advantages

– Timesaving
– Portability
– Safety of contrast agent
– Lack to ionizing radiation exposure
– Repeatability
– Particularly useful when high clinical suspicion but conventional US fails to show solid organ injury
– No interactions with thyroid gland
– None nephrotoxic

Limitations

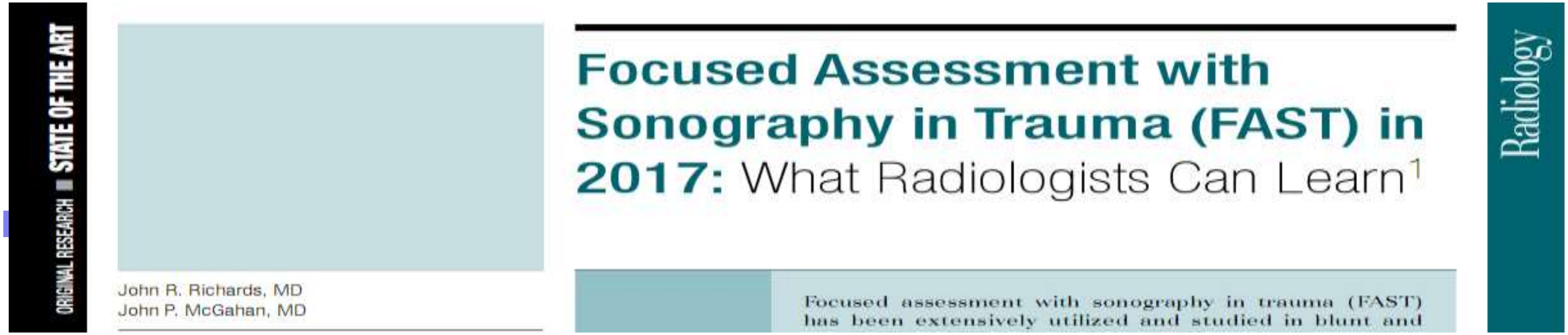
- Lacks the panoramic quality
- Requires rapid and skillful because a single CEUS examination is only 6–8 min
- Resonance frequencies of approx. 1-3 MHz
- Well suited for low frequency applications (1-8 MHz)
  - – Cardiac
  - – Abdominal
- Not well suited for high frequency imaging
- IT is not yet licensed for use in lactating or pregnant women

Adverse Effects

- Usually very mild
- Allergic reaction
  - ☛ Headache, dizziness
  - ☛ Flushing
  - ☛ Shortness of breath
  - ☛ Hyper- or hypotension

➢ ***Contraindications***

- *Known or suspected right-to-left or bi-directional cardiac shunts*
- *Prior hypersensitivity reactions*


ORIGINAL RESEARCH ■ STATE OF THE ART

Radiology

Focused Assessment with Sonography in Trauma (FAST) in 2017: What Radiologists Can Learn[1]

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Focused assessment with sonography in trauma (FAST) has been extensively utilized and studied in blunt and

- FAST is ideal in the field to make rapid triage of injured patients in multiple casualty incidents or battle field situations
- Press et al reported moderate accuracy for helicopter paramedics performing eFAST, with 46% sensitivity and 94.1% specificity for detection of hemoperitoneum and 18.7% sensitivity and 99.5% specificity for detection of pneumothorax
- Menichini et al showed the sensitivity of contrast-enhanced US approached CT in pediatric trauma patients

Conclusion

“ The most important preoperative objective in the management of the patient with trauma is to ascertain whether or not laparotomy is needed, and not the diagnosis of a specific organ injury”

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Questions?

Thanks !