Basics of UltraSound in Regional Anesthesia

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Disclosure

- As co-inventor of the Human Patient Simulator mannequin, I receive a fraction of the royalties that the University of Florida collects from the licensee CAE/METI.

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- As co-inventor of the TMS cooling football pads, I receive a fraction of the royalties that the University of Florida collects from the licensee.

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Outline

• Basics of US in RA – Training needs assessment
• Mixed reality simulation (mixed simulation)
• A new mixed simulator for training in Fundamentals of UltraSound Imaging, Interpretation and Guidance (FUSIIG)
Basics of UltraSound in RA

• Cross-sectional literacy, the foundation for UGRA
  – “Reading” cross-sections
  – “Writing” cross-sections
• Spatial ability
• Hand-eye coordination
• Knowledge of anatomy
• Artifacts
Cross-Sectional Literacy: the 2 Rs

• “Reading”: inferring, envisioning, visualizing, identifying a 3D object and its surroundings from a series of derived 2D cross-sections

• “wRiting”: insonate, obtain a desired 2D cross-section (view) from a 3D shape and its surroundings

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Fundamentals: Cross-sectional literacy

Problem 6

From Santa Barbara Solids Test rev 1210
Fundamentals: Cross-sectional literacy

Problem 7

(a)  (b)  (c)  (d)

From Santa Barbara Solids Test rev 1210
Fundamentals: Cross-sectional literacy

Problem 8

From Santa Barbara Solids Test rev 1210
Fundamentals: Cross-sectional literacy

Problem 9

(a)  (b)  (c)  (d)

From Santa Barbara Solids Test rev 1210
Fundamentals: Cross-sectional literacy

Problem 15

From Santa Barbara Solids Test rev 1210
Fundamentals: Cross-sectional literacy

From Santa Barbara Solids Test rev 1210
Egocentric error

• D is an egocentric error: Inability to transfer from one’s perspective to the probe’s perspective

• To get the correct cross-section, users must be able to abandon their egocentric (own) perspective and transpose their perspective as if they were at the US probe
Why simulation?

• Safe environment for
  – Hands-on experiential learning and deliberate practice to achieve mastery
  – Encounter rare conditions, pathologies, anomalies
  – Controlled repeatable environment for formative or summative assessment
  – Can include tracking and recording of all relevant parameters
  – NOT for being like the real thing; BUT for acquiring skills

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Mapping the skills triangle to the simulation triangle

Skills Triangle
- Affective (Interacting)
- Psychomotor (Doing)
- Cognitive (Thinking)

Simulation Triangle
- Biologic Simulation (Human Actors)
- Physical Simulation (Mannequins, Part Task Trainers)
- Virtual Simulation (CBTs, Virtual Anatomy)


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Simulation Technology Synergies: Breaking the Silos

The Simulation Triangle

- **Human Simulation**
  (Standardized Patients - SP)

- **Hybrid Simulation**

- **Augmented SP**

- **Physical Simulation**
  (Mannequins, Part Task Trainers)

- **Virtual Simulation**
  (Screen-based, abstract, conceptual, avatars)

- **Mixed Simulation**

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Simulation Triangle Synergies

- Hybrid Simulation (Human-Physical): Draped human actor wearing physically simulated body parts or moulage, e.g., for childbirth, combat casualty care
Hybrid Simulation (Human Actor/Birthing Simulator)

http://www.samuelmerritt.edu/images/hssc/hybrid_simulation_640x480.jpg

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Simulation Triangle Synergies

• Augmented Standardized Patients (Human–Virtual): Human actor using hidden controls or wearing hidden magnets that trigger appropriate playback of virtual normal/abnormal heart and lung sounds
Augmented Standardized Patients
(Human Actor/Virtual Sounds)


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Simulation Triangle Synergies

- Mixed Simulators (Physical-Virtual): A simulator with collocated physical and virtual components
Mixed reality and the reality-virtuality continuum (Milgram and Kishino, 1994)
What is mixed reality?

• An environment where physical and virtual elements are present and precisely registered (placed at the right position and orientation) relative to each other

• Example: Black line sweeping the pool during Olympic swimming events on TV is virtual (does not exist) and is precisely overlaid on video representation of the physical pool; also yellow first down line
Mixed Simulation Output AND Input (User Intervention)


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What is mixed simulation?

• A simulated 3D environment where physical and virtual 3D **models** are precisely registered (placed at the right position and orientation) and/or tracked relative to each other
  – Some objects may have both physical and virtual models
  – Other objects may only exist virtually or physically
  – Visual augmentation (3D color real-time visualization) can be provided

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Example of a Mixed Simulator of Regional Anesthesia

- Video of Thoracic Regional Anesthesia

Mixed Simulator

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Why mixed simulation?

- UGRA mainly focused on cognitive and psychomotor skills that map well to virtual and physical simulation respectively.
- Mixed simulation combines virtual and physical models seamlessly and thus is ideal for UGRA training.
Mapping the skills triangle to the simulation triangle

Skills Triangle
- Affective (Interacting)
- Psychomotor (Doing)
- Cognitive (Thinking)

Simulation Triangle
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With skin on
Packed and ready to travel! Note TSA note
Characteristics

• Virtual 3D shapes with no physical counterpart embedded in gel
  – Simple 3D objects (single, attached, nested)
  – For novices, reality gets in the way of learning; the seductive details hypothesis
  – Then more complex objects
• Tracked US probe (6 DoF, sub-mm resolution)
• Tracked needle (6 DoF, sub-mm resolution)
• No real US; air in prior needle tracks OK
• Performance recorded and automatically graded by objective scoring algorithm
• Turnkey; sets up in 7 minutes with untrained personnel

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What can be learned/practiced
US views

LAX
SAX
Oblique

Usually try to image nerves in a short axis view.

1. Short axis view 2. Long axis view
Angle of incidence

- The angle at which US waves impinge the surface of the structure
- If angle of incidence is perpendicular or close to perpendicular, more US waves will be reflected back to transducer and less will be “scattered” away resulting in a better image
- Angle of incidence with the anatomical structure or with the needle can be improved by manipulating the US probe or using a slightly different needle approach

Slide courtesy of Dr. Ihnatsenka
Changing the angle of incidence of insonation wave to needle

In order to improve needle visualization one can change the US probe position (from 1 to 2) and the needling approach (from 1 to 2 to 3) to optimize the angle of the incidence of US waves and the needle

Slide courtesy of Dr. Ihnatsenka
Changing the angle of incidence with anatomical structure

• By probe manipulation (tilting or rotating it) we can change the direction of US beam relative to the structure of the interest in order to obtain a true short axis view (perpendicular incidence)

• Knowledge of the 3D applied anatomy (direction of the nerve in the 3D space for example) helps to predict needed probe manipulation

Slide courtesy of Dr. Ihnatsenka
Anisotropy

- Anisotropy is a property of the tissue to change the reflection with mild changes in angle of incidence.
- It creates the phenomena “now you see me; now you don’t” during probe toggling (tilting).
- Tendons are more anisotropic than peripheral nerves.

Slide courtesy of Dr. Ihnatsenka
Now you see it; now you don’t… BUT it’s still there

Slide courtesy of Dr. Ihnatsenka
Probe orientation

• **Probe orientation (sidedness)** is important
  – we can easily change the orientation of the probe by turning it around (it is much more time-consuming to invert actual image on ultrasound screen)

• To avoid confusion, one must determine which side of the probe corresponds to which side of the ultrasound screen
  – All transducers have a physical tactile orientation marker corresponding to a marker on the screen
  – We must also determine which side of the screen represents the specific side of the body

Slide courtesy of Dr. Ihnatsenka
Artifacts

• Artifact means that we see something on the screen that does not exist or we do not see on the screen something that exists

• Some artifacts are related to the physics of US (reverberation artifact, mirror image artifact or acoustic enhancement artifact)

• Some artifacts are not fully understood and quite complex
PART overview

When discussing US probe manipulation the “PART” mnemonic (Pressure, Alignment, Rotation, Tilt) is handy to keep in mind.

Slide courtesy of Dr. Ihnatsenka
Mold for gelatin

Pins that keep the bologna cube suspended in the middle of the mold while gelatine is liquid

Bologna cube with tunnel and the pebble

Gelatin cube with bologna cube inside after gelatin is hardened and mold and pins are removed

Slide courtesy of Dr. Ihnatsenka
PART (pressure)

Correct pressure application considerably improves image quality.

Pressure must be applied evenly (most of the time) in order to get the correct direction of the scan, especially when a curvilinear probe is used.

Effect of the uneven pressure on the US probe

Slide courtesy of Dr. Ihnatsenka
Probe rotation to achieve true axial view of curving vessel
Needle Punctures Blue

Problem 6

Place the needle in the blue vessel in this area:

Do not puncture the orange vessel

5.7 cm
Slide courtesy of Dr. Ihnatsenka
Problem 1

Resolve this cross section
2 cm deep
Slide probe along long axis of cone while maintaining SAX view (perfect circle). Stop when top of circle is 2 cm deep.
Problem 2

Place the needle on the tip of the cone
Tilt and Slide

Slide courtesy of Dr. Ihnatsenka
By tilting the probe from position 1 to position 2 we obtained the true axial short axis view of the artery and the nerve (shape of the artery and the nerve got more round; image of the nerve got more clear secondary to more favorable angle of incidence) By closely watching the changing US image while sliding the probe from position 2 to position 3 we can see that nerve is branching and both artery and the nerve are moving more superficially.
Slide probe along long axis of cone while maintaining SAX view (perfect circle). Stop when circle becomes a point, rotate probe 90 degrees to long axis view and guide needle in plane.
Alignment, probe rotation, in-plane needling: Circle becomes a point indicating insonation plane is at tip of cone.
In plane needle approach; maintain length of needle, esp. needle tip, in insonation plane while advancing...
Problem 3: Obtain a hexagonal cross-section from a regular 3D shape. What is the shape?
A regular cube!
Problem 4: Attached objects (from Santa Barbara Solids Test)
Problem Number 5: “Easier”

Needle Punctures Blue

Problem 5

Place the needle in the blue vessel in this area:
Structures are more anatomical with varying diameters with blue as target and orange as no go area – in plane needling
Structures are more anatomical with varying diameters with blue as target and orange as no go area – in plane needling.
Problem 6: Harder

Needle Punctures Blue

Problem 6

Place the needle in the blue vessel in this area:

Do not puncture the orange vessel

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Out of plane approach tips

When performing out of plane approach, some tilting of the transducer while advancing the needle may help to track the tip of the needle.

Out of plane needling with mild tilting of the probe in order to follow the tip of the needle during needle advancement.

Slide courtesy of Dr. Ihnatsenka
Geometry for out of plane approach?

Slide courtesy of Dr. Ihnatsenka
Short axis view of vessels, out of plane needle approach
US probes

Left: low frequency 2-5 MHz curved 60 mm

Right: high frequency 10-12 MHz linear 38 mm

Slide courtesy of Dr. Ihnatsenka
Ultrasound wave frequency, image resolution and penetration

- **High frequency probes** (10-15 MHz)
- **Mid range frequency probes** (5-10 MHz)
  provide better resolution but have less penetration. They are perfect for US of superficial structures (no deeper than 3-4 cm for high frequency probe and 5-6 cm for mid range probe)
- **Low frequency probe** (2-5 MHz)
  Used for deep structures (subgluteal sciatic nerve for example) Low frequency probes can reach up to 12 cm deep but the quality of the image is substantially lower
Curved array probes

- *Curvilinear probes* generate a wedge shape US beam and a corresponding image on the screen. The image width of deeper structures is wider than the footprint of the probe.
- Slightly unnatural image with the curvature of normally straight structures may be difficult to perceive.
- Rolling of the probe affects the US beam direction. It could be desirable to look around the corner but also could be disadvantageous when one tries to look straight forward.
- The curvilinear probe gives a broader view.
- It may help to visualize the needle that is advanced in plane better because of more favorable angle of incidence.

Slide courtesy of Dr. Ihnatsenka
Straight array probe

- Straight probes produce a straight US beam and image where the image width is equal to the size of the transducer footprint all the way from the surface to the deeper structures.
Curved probe vs. straight probe

Curved array low frequency US probe versus straight array high frequency US probe (subgluteal sciatic image)

1) sciatic nerve 2) gluteus maximus 3) quadratus femoris 4) femur

Note the difference in the shape and the scope of the images, different resolution ("quality of the picture") and the depth.

Slide courtesy of Dr. Ihnatsenka
Interpretation and Guidance: the other 2 Rs

• “Recon” or “scout scan” to survey surroundings and pertinent anatomy
• Reasoning
Questions/Contact info

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