3D and Other New Technique in Musculoskeletal Ultrasound

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Advances in Musculoskeletal US
- Power Doppler Imaging
- Contrast Agents
- US in Fracture Healing
- Extended-field-of-view
- 3D US

Power Doppler Imaging (PDI)
- Method of displaying color using the amplitude of the Doppler signal
- It is a measure of the density of the scatterers within flowing blood
- (vs. Conventional color Doppler imaging which uses mean Doppler frequency shift)

Characteristics of PDI
- PDI increases “flow sensitivity”
- Improvement of 10 to 15 dB in sensitivity
- Result of increased display dynamic range (by sacrificing part of the available information i.e. velocity and directionality) and increased temporal averaging

PDI vs. CDI
- Uses amplitude of the Doppler signal
- Non-directional
- No aliasing
- Less angle dependent
- uses mean Doppler frequency shift
- Directional
- Aliasing
- Angle dependent
PDI in Reflex Sympathetic Dystrophy (RSD)

- Ability of Power Doppler Imaging to show increased blood flow in patients with RSD of the lower extremity
- PDI performed in 30 patients and 26 asymptomatic control subjects
- Obtained bilateral PDI of the soft tissues of the dorsum of the foot bilaterally, at the level of the talar dome

Images evaluation scale

- 1 = no flow or minimal flow
- 2 = mild flow
- 3 = moderate flow
- 4 = marked flow
Results

- More PD flow was seen in the patients with RSD than in the control subjects ($p < 0.005$)
- Side to side asymmetry was seen in patients but was not statistically significant ($p < 0.20$)
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PDI other examples

- Tendon - tendinitis, tear. E.g. ATT
- Muscles - mass etc.
  - Hemangioma
  - Myositis

Achilles Tendon

CONTRAST AGENTS IN MUSCULOSKELETAL IMAGING
1967 Gramiak R, and Shah PM, visualized clouds of echo signal passing through the heart when performing echocardiography during injection of indocyanin green at cardiac catheterization.

Kremkau and Meltzer indicated mechanism of contrast effect was produced by injection of gas bubbles.

IV contrast echo: to assess valvular regurgitation and intracardiac shunting, detect patent foramen ovale (replaced by color Doppler).

**Indocyanine Green Dye**

**Air / Gas limitation**

- bubbles too large
- left side of heart could not be opacified
- bubbles would have to be 6 µm in diameter
- however surface tension of room air microbubble at 6 µm diameter is such that they persist as bubbles in blood for approximately one-tenth of a second prior to dissolving

**Microbubbles - Size**

- Microbubble: 2–8 µm
- RBC: 6–8 µm

**Determinants**

\[ T = \frac{r^2 \cdot p}{2D \cdot C_s} \]

- \( r \) = radius of the bubble
- \( p \) = density of the gas
- \( D \) = diffusivity of the gas
- \( C_s \) = concentration of the saturation
Maneuvers to prolong bubble persistence

- increase size
- increase density
- decrease diffusion
- decrease solubility

Practicality

- Gas size may not exceed 6-8µm without embolisation.
- Utilize gas with an increase density, decrease diffusivity, and a low concentration of saturation.
- Fluorocarbons have been most suitable.
  - Higher density,
  - Decrease diffusivity
  - Lower concentration of saturation than room air.
  - Well tolerated by humans.

Contrast Agents with perfluorocarbons

- Optison (FSO69)
- Echogen (QW3000)
- Imaget (AF0150)
- Definity (MRX115 / DMP 115)
- SonoVue (BR1)
- PESDA

Air-Based Ultrasound Contrast Agents

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Mean Diameter</th>
<th>Shell composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallinkrodt</td>
<td>4.3 µm</td>
<td>Denatured albumin</td>
</tr>
<tr>
<td>Schering AG</td>
<td>2-4 µm</td>
<td>Palmitic acid stabilized galactose carrier</td>
</tr>
<tr>
<td>Schering AG</td>
<td>1-2 µm</td>
<td>Cyanocrylate</td>
</tr>
<tr>
<td>Andaris</td>
<td>3.2 µm</td>
<td>Denatured albumin</td>
</tr>
</tbody>
</table>

Ideal contrast agent

- Non-toxic
- Injected intravenously
- Capable of traversing the pulmonary, cardiac, and capillary circulation
- Stable for recirculation
Mechanism of contrast agents

- Contrast agents significantly enhance the backscattered echo-signals (ranges from 8.5 to 23 dB), and provide improved signal-to-noise ratio.
- Results in Doppler signal acquisition from deeper and smaller vessels, in which the number of RBCs, their flow velocity, or both is insufficient to otherwise allow adequate detection of flow.

E.g.

- Melanoma
- Fracture studies
USE OF US IN TREATMENT OF FRACTURE HEALING

Fracture healing requires
- immobilization of entire body parts
- prolonged inactivity
- prolonged suspension or restriction of normal work and recreational activities

callus formation cannot be induced by
- pharmacologic
- hormonal
- biological
- alimentary means

Surgery
- 3 pairs of dogs (six) were studied.
- subcutaneous dissection of the midshaft of the ulna allowed symmetrical osteotomies to be made with a reciprocation saw

Ultrasound treatment
- one dog in each pair was treated and other used as control
- therapeutic ultrasonic device SAFHS (sonicated accelerated fracture healing system. Exogen, West Caldwell, NJ) was used
- fracture site was subjected to 1.5 MHz low-intensity US (30mW/cm²) for 20 minutes daily

SAFHS
Sonicated Accelerated Fracture Healing System
Ultrasound Imaging

- US examinations were performed daily for up to eight weeks.
- Ultrasound machine with 10 or 12 MHz transducer was used (Diasonics, Santa Clara, CA).
- B-mode US was performed to evaluate the fracture site. Power Doppler was used to assess flow patterns at the fracture site as well as in the surrounding soft tissue.

Ultrasound Imaging

- Ultrasound contrast agent, Optison (FSO69, Molecular Biosystems Inc. San Diego, CA) was administered intravenously before and after treatment. Dose was 0.2ml/kg.
- Temperature changes at the fracture site were monitored during treatment in one pair of dogs for 4 days.
Temperature Changes

<table>
<thead>
<tr>
<th>Days</th>
<th>Treated</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.65</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>4</td>
<td>1.7</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>0.8625</td>
<td>0.325</td>
</tr>
</tbody>
</table>

Results

- Power Doppler showed an increase in flow around the fracture site in the treated dog compared to the control dog.
- Increase started 2-3 days following the beginning of treatment.
- Most significant increase was seen in the first two weeks.

Conclusion

- Power Doppler showed increased vascularity around the fracture site in treated dogs both pre and post contrast administration.
- The most significant increase in vascularity was seen in the first two weeks.
Limitation of current US

- Limited field of view (compared with MRI and CT)
  - Linear probe 4-6cm
  - Curved probe sector angle of 60-120 degrees

Probe motion measured by position sensing device

- Articulated-arms used in static B-mode scanners
- Magnetic position sensors

Disadvantages are:
  - Scan less flexible because device must be attached to the probe and must be moved with the probe
  - Increase system cost
  - Some are sensitive to external interference, such as surrounding metal objects

EFOV Technique

- EFOV imaging uses image registration between sequentially acquired image frames for motion estimation and constructs a large panoramic image in real-time
- To run in real time, the image processing board uses multiple fast, digital, image-processing chips and an advanced parallel processing architecture and is capable of executing up to 4 billion operations per second
- “Panoramic view”, Siescape™

EFOV US image

- Extended-field-of-view image
- No loss of resolution
- No external sensor or articulated arm
- Geometric measurement accuracy up to a 60cm scan distance has been verified in phantoms (within +/- 5%)

Cases

- Patellar ligament
- Achilles - Normal and Abscess
- Thigh - lipoma, abscess
- PTT tear
**Advantages**

- Complete depiction of large masses
- Fluid collections (appreciate muscular anatomy and soft tissue planes)
- Clearer display of relationship of masses to adjacent structures
- Compare abnormal to adjacent normal area
- Greater measurement reproducibility at follow-up scanning
- Communicating findings to the referring physicians

**Limitations**

- Large-scale underlying tissue motion
  - Rapid fetal movement
  - Heavy respiration
  - (small-scale tissue motion artifact such fetal heart beat and arterial pulsation are corrected by fuzzy-logic technique)
- Probe off-plane motion
  - Measurement should not be obtained
What is 3D US?

- 3D US consists of obtaining a series of 2D image slices and then combining them to form a volume of data.

Means of obtaining a 3D volume

- 2D transducer
  - sweep manually or
  - with mechanical device
- Dedicated 3D transducer

Obtaining 3D Volume

- Scan area of interest, similar to 2D scan
- Select area of interest, angle and depth
- Choose the scanning plane i.e. area of interest preferably facing the transducer
- Choose sweep speed
Ways of using the data

- Multiplanar Imaging
- Volume Reconstruction
  - transparent
  - surface
- Volumetric measurements

Video

Supraspinatus – Large Tear

Supraspinatus – Large Tear

Supraspinatus – Small Tear
Supraspinatus – Undersurface Tear

Advantages of 3D US

- Fast image acquisition
- Simultaneous display of sectional image in all three planes
- Obtain planes normally not possible
- Scroll the image in different planes

Supraspinatus – Biceps Tear

Undersurface Tear

Advantages of 3D US

- Better appreciation of surface contours
- Global perspective of the anatomy
- Rotate the reconstructed image
- Volumetric measurements possible

Thank You