Advances in Ultrasound Imaging

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The Future of Ultrasound

- Advances in US technology include
  - Miniaturized ultrasound scanners
  - Volume US (3D and 4D US)
  - US Elastography
  - US Contrast agents
  - Computer Assisted Diagnosis (CAD)
  - Robotics
- In the future there will be continued advances in these and other technologies which in turn will expand the utilization of the modality

Compact ultrasound scanners:
Smaller, more powerful, less expensive and easier to use

Compact US scanners:
- Enhanced delivery of services
  - Easy portability between service settings (private offices, nursing homes, etc)
    - Bed-side / portables
    - Emergency transport (trauma)
- US systems are being “imbedded” into other medical devices

Stethoscope of the future?
- Fits in a lab coat pocket
- Very light weight
- Inexpensive
- Probes that attach to a laptop computer

Three-Dimensional US technology:
A time line
- Free-hand acquisition using 2D transducers
  - Poor spatial resolution
- Mechanical transducers with mechanized stepping motors
  - Improved spatial resolution
  - Slow reconstruction times
- Electronic arrays
  - Color flow capable
  - True real-time 3D (4D US)
**Electronic Real-time Bi-Plane Imaging**
- Real-time bi-plane imaging
- See two 2D views simultaneously
- More diagnostic information
- Monitor and guide interventional procedures

**Electronic Real-time 3DUS (4DUS)**
- Advances in computer processing and transducer technology have resulted in faster reconstruction of US data
- Normal anatomy
- Left atrial myxoma
- Gain new perspectives on spatial anatomy and pathology
- Visualization of complex anatomic features
- Assessment of regional and global function (echocardiography)

**Electronic Real-Time 3D US: Silicon Ultrasound**
Charged membranes in micromachined silicon
- Transmitted Ultrasound
- Received Ultrasound

*This product is under development by Siemens Medical Systems and is a works-in-progress.*

**Electronic Real-time 3D US**
- Accelerates transformation from 2D to 3D imaging
- Massively parallel image formation enhances real-time volume imaging resulting in higher 4D image quality

*This product is under development by Siemens Medical Systems and is a works-in-progress.*

**Potential Vascular US screening tool:**
- A Prototype Electronic 4D Vascular US System
- 6 MHz matrix array transducer with 1008 elements
- Frame rates of up to 25 volumes per second
- Permits rapid acquisition of blood flow data
- Provides semi-automated velocity and volume flow measurements

*Note the difference in pulsatility between the external and internal carotid arteries*

DISPLAY OPTIONS

- Multi-slice display
- 4D display

Flow velocity estimations
Flow volume estimations

The Future of Ultrasound: Increased use of Elastography

- Based on properties of tissue structure and organization - the strain modulus
- Potential applications
  - Enhance sonographic characterization of tumors
  - Identify variations in tissue stiffness

Elastography: Thyroid tumors

- Benign tumor
- Malignant tumor

Degree of tissue stiffness is indicated on color scale
*Courtesy of Dr. Nobuhiro Fukunari

Elastography: Prostate

- CTVS tumor (implanted in canine prostate). Elastography characterizes the tumor as being harder than normal prostate tissue

Elastography: Tennis elbow

- Hypoechoic area on grayscale US
- Asymptomatic elbow
- Symptomatic elbow

- Elastography indicates "soft" tissue area c/w mucoid degeneration
Transient Shear Wave Elastography

Step 1
Shear wave generation by local excitation

Step 2
Plane wave insonification with 3-6 kHz FR

Step 3
Processing

Total duration: 20 ms

Courtesy of SuperSonic Imagine

Quantitative Elastography

FibroScan
E > 170 kPa in the periphery
E < 36 kPa in the center

Elastography: Hepatic applications *

- Hepatic fibrosis in patients co-infected with HIV and hepatitis C (HCV) can be accurately assessed using elastography
- FibroScan; Echosens, Paris
- 72 HIV-infected patients with chronic HCV infection
- The findings were 96% specific with an 88% positive predictive value for diagnosing cirrhosis

"FibroScan is the best noninvasive method for the evaluation of liver fibrosis and cirrhosis and for the evaluation of the severity of cirrhosis." Dr. Victor de Ledinghen

Ultrasound Contrast Agents

- Improved diagnoses
  - Tumor characterization
- Enhanced tumor staging
- Treatment guidance
  - RFA, cryoablation, HIFU
- Serial monitoring of treatment effectiveness
  - Antiangiogenesis, chemotherapy, etc
- Therapeutic contrast agents
  - Enhanced drug delivery, thrombolysis, gene therapy, etc

Delayed imaging with a tissue-specific agent

Enhanced detection of multicentric HCC
Liver lesion characterization:
- **Focal nodular hyperplasia (FNH)**
- **Hemangioma**
- **Hepatocellular carcinoma**

The Use of US to Assess Treatment Effectiveness

- **Pre-contrast**
- **Post-contrast**

Liver metastases post chemoembolization

US evaluation of angiogenesis and anti-angiogenesis therapy

- **Normal Testis**
- **CTVS Tumor**

*Micro Flow Imaging*

  - Five high power flash pulses (MI > 1.3) destroy microbubbles
  - Five seconds of low power pulses (MI < 0.1) demonstrate contrast replenishment
  - A composite image depicting vascular architecture and blood flow is constructed through maximum intensity capture of temporal data in consecutive low power images

Contrast-enhanced US:

**Evaluation of angiogenesis and anti-angiogenesis therapy**

Improved detection of necrotic region in tumor
**Contrast-enhanced 3D US:**

*Improved visualization of vascular architecture*

*Normal renal vascularity*

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**Staging Cancer with “Lymphosonography”**

- The combination of grayscale phase-inversion harmonic imaging with subcutaneous administration of a RES-specific US contrast agent

- Results in the ability to detect lymphatic channels (LCs) and sentinel lymph nodes (SLNs)

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**Lymphatic drainage into a normal SLN**

*Pre-contrast*

*Post-contrast*

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**Lymphosonography: Appearance of SLNs**

- Normal SLNs demonstrate uniformly increased echogenicity (i.e., contrast enhancement)
- SLNs with metastases demonstrate filling defects (i.e., non-uniform enhancement)

- SLNs as small as 4mm can be detected

- SLN with metastatic tumor deposits (T)

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**Comparison to Histology**

*Large SLN with >70% metastases*

*Small SLN with <10% metastases*

- Metastatic infiltration
- Normal parenchyma
- Metastatic infiltration

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**Therapeutic US contrast agents**

- A drug is encapsulated within the contrast microbubble, contained within the shell or attached to the shell

- US imaging is performed directed over the area of interest

- The acoustic energy ruptures the microbubble, releasing the drug targeting the desired location

- Potential applications include thrombolysis and tumors ablations
Contrast-enhanced detection of tumor angiogenesis (molecular US imaging)

- Microbubbles with targeted ligands attached to their shells attach to $\alpha_v \beta_3$ in vessels resulting in contrast-enhancement only in regions undergoing angiogenesis.

Computer assisted diagnosis (CAD) for characterization of breast masses

- Case-based and rule-based reasoning with physician in the loop during operation
- Breast Ultrasound CAD - BIRADS lexicon based
- Flexible CAD and protocol architecture applicable to many applications and modalities

Breast US CAD

- The sonographer confirms the lesion border and selects object of interest if multiple objects/areas are detected
- Level of Suspicion (LOS) to cancer calculated & passed to radiologist

BrUS CAD produces Level of Suspicion Score

- Provide objective computer analysis of mass on US
- Compare unknown mass to digital database of other masses with known findings and/or prior exam
- Compute the Level of Suspicion (LOS) score for unknown mass

Lesions with scores 2 and 3 represent the most challenging for diagnosis

Fusion of Imaging Modalities

- Co-registration imaging or “fusion-imaging” is used to enhance diagnosis, staging and treatment

US has been combined with mammography and MRI to improve characterization of breast masses
Improved needle guidance and brachytherapy
US has been combined with CT
MRI has been combined with HIFU for treatment of a variety of diseases

Fusion CAD system for breast cancer diagnosis

- CAD systems produce quantified results
- Integrated classifier is invoked
- Score is calculated and displayed to radiologist
- Based on variety of factors and complexity of the case radiologist may invoke the detailed information that illustrates how the score was obtained and other related information

Mammography CAD: Suspicious area found
MRI CAD: Suspicious area found
US CAD Follow-up: Lesion Segmented & quantified

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Fusion Imaging

- Fusion of real-time sonography with multi-slice CT (from a CT volume)

Courtesy of Hitachi Medical Systems

NaviSuite® CT-US Navigator for Interventions

(MedCom in cooperation with ESAOTE)

3DUS and CT Fusion imaging

(Resonant Medical Inc., Quebec, Canada)

Volume US image is superimposed over CT

Automated US breast scanner

- An automated breast US system with a 14.7 cm transducer automatically acquires 250 to 400 2D images

Automated Holographic Ultrasound*

- Prototype breast system
  - 2.7 MHz center frequency
  - 13.3 cm field of view
  - Patient prone
  - Breast in water bath

- Potential benefits include
  - Large field of view (similar to mammography)
  - Easier to correlate findings with mammography
  - Less operator dependent

Courtesy of Beverly E. Hashimoto, M.D., Virginia Mason Medical Center, Seattle, WA
Holographic US (HUS)

Robotics in Medicine
- Robotic surgery is gaining acceptance and its range of applications is expanding

Robotic Ultrasound

Tele-operated Echography using a Robotic Arm

TERESA (Sisters C-ESA prog 2002) ESTELE (Robosoft C-ESA-CNES 2006-08)
A Day in the Future…

7:00AM: Using a small US system at home a woman detects a breast mass and calls her physician

An appointment to have a mammogram and US is arranged

A Day in the Future…

8:00AM: The mammogram and US are performed

A Day in the Future…

9:00AM: The US demonstrates a mass which is confirmed by computer-aided diagnosis and elastography

A Day in the Future…

10:00AM: Contrast-enhanced US is used to characterize the mass

11:00AM: US-guided biopsy is obtained and cancer is confirmed using US microscopy

Sonogram

Specimen
A Day in the Future…

12:30PM: Staging is performed using lymphosonography to evaluate the tumor’s sentinel lymph nodes. Three normal-appearing SLNs are identified. There is no sonographic evidence of metastases in these nodes.

1:30PM: PET-CT scan demonstrates no evidence of distant metastases.

A Day in the Future…

2:30PM: A video conference between the patient’s physician, diagnosticians and therapists is conducted and a decision is made to destroy the tumor non-invasively using HIFU.

3:30PM: MRI-guided HIFU is performed.

A Day in the Future…

4:30PM: Contrast-enhanced US and elastography is performed and demonstrates no evidence of residual tumor.

5:30PM: The patient is discharged with instructions from her physician that she can return to normal activities by the next morning. She is scheduled to have a follow-up contrast-enhanced US examination in 6 months.

Conclusions

**The most advanced medical technology is useless without knowledgeable physicians and other healthcare providers that know how to use it.**

The best healthcare providers cannot work to their fullest capacities without the appropriate medical technology.

**The combination of technology and knowledge is greater than the sum of their parts.**

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Thank you for your attention!

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