US IMAGING QUANTIFICATION:
ERROR - SOURCES & MITIGATION

Brian S Garra
Office of Science & Engineering Laboratories, FDA
Eliterad Radiology Services

CONFLICTS OF INTEREST

None

The mention of commercial products, their sources, or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products by the Department of Health and Human Services

GOALS

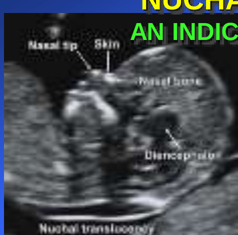
- Review the Gamut of Ultrasound Imaging Measurements and Quantification
- Discuss Errors in US Measurement / Quantification
- Outline Approaches to Mitigation of Errors

MEASUREMENT & ULTRASOUND

- US is the Oldest Cross-Sectional Imaging Modality
  - Breast Cancer at 15MHz: Reed & Wild 1951
- Measurements/Quantification Dominate US Like No Other Modality
  - Early BISTABLE US: Provided Only Boundaries – Only Size / Position Information
  - Focus on OB and Fetal Measurements – thousands of papers

NUCHAL LUCENCY

AN INDICATOR FOR T-21



Sheila Miller, Posted on: 29 October 2015
Categories: NHS Fetal Anomaly Screening Programme, Screening Quality Assurance Service

CRL (mm)	Expected nuchal translucency (mm)		
	5th percentile	50th percentile	95th percentile
40	0.31	1.22	2.14
45	0.40	1.32	2.24
50	0.50	1.42	2.34
55	0.60	1.52	2.44
60	0.70	1.62	2.54
65	0.80	1.72	2.64
70	0.90	1.82	2.73
75	0.99	1.91	2.82
80	1.09	2.01	2.92
85	1.19	2.11	3.02

GRAYSCALE US MEASUREMENT

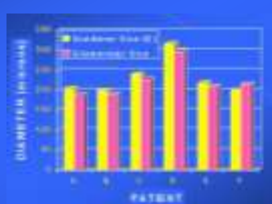
- 1975-1985: 4-6 bits - Better ID of Organs/Path But Mostly Still Size and Location
- 1985-1995: Quantification of Echogenicity (Brightness) Appears
  - Never Widely Used Due to Operator Dependence
  - Machine Settings Not Reproducible
- 1977 Real–Time US: Shifted Focus of US to Movement Evaluation Away From Single Image Quantification

US TISSUE CHARACTERIZATION

- 1980 – 1990: The "Tissue Characterization" Era
- Realization: Quantification/Quantitative Imaging Provides Tissue Type & Path Information
- Research Systems Used RF Data – non Real Time
- Parameters: Attenuation; Integrated Backscatter; Sound Speed; Spectral Features (Zero Intercept, Mid-Band Fit, Spectral Slope, Scatterer Concentration/Size, Statistical Features)
- Most Efforts Were Successful

TISSUE CHARACTERIZATION

CHRONIC HEPATITIS vs GAUCHERS
STATISTICAL SCATTERING FEATURES
Mean Scatterer Spacing, Variance of Specular
Specular-Diffuse Backscatter Ratio



GLOMERULAR SIZE vs SCATTERER SIZE

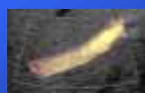
THE COLLAPSE OF TISSUE CHARACTERIZATION INITIATIVE

- Clinical Machines Never Became Available
  - On Board Computing Power Insufficient
  - Many Analog Components With Stability Issues
  - Preoccupation With RT Only Implementations
- Disillusionment of Clinical Community
  - Assumed Larger Scale Clinical Studies Had Failed

DOPPLER ULTRASOUND
THE OTHER MAIN TYPE OF QUANTITATIVE US

- Non Imaging Doppler Flowmeters – late 1950s
- Spectral Doppler (PW) - Mid 1960s
- Color Doppler Imaging - Early 1980s
- Power Doppler – Late 1980s



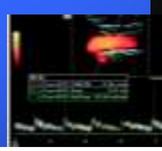



DOPPLER FLOW MEASUREMENTS

- Velocity (after angle correction)
- Doppler Ratios (Resistive & Pulsatility Indices). No angle correction needed.
- Volume Blood Flow


Velocity

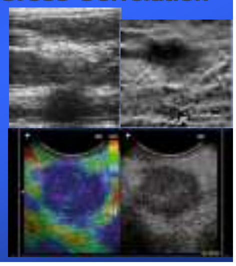

Resistive Index


Volume Flow

DOPPLER TISSUE MOTION EVALUATION
MYOCARDIAL VELOCITY, STRAIN, STRAIN RATE

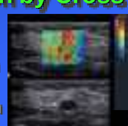
TISSUE ELASTICITY QUANTIFICATION
Tissue Motion Detection by Cross-Correlation

Strain Elastography
- Tissue Position Tracked Before & After Small Compression
- Change in Position vs. Depth = Strain
- Strain → Elastic Modulus if Applied Pressure is Known

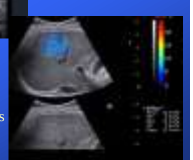


TISSUE ELASTICITY QUANTIFICATION
Tissue Motion Detection by Cross-Correlation

Shear Wave Elastography
- Shear Waves Generated in Tissue by Mechanical Vibrator or Acoustic "push pulse"
- Shear Waves Tracked by Changes in Tissue Position
- Elastic Modulus Computed From Shear Wave Propagation Speed. $E = V^2 \rho D$



Breast Cancer



Chronic Hepatitis

GENERAL SOURCES OF ERROR IN US MEASUREMENTS

- Vast Array of Potential Errors – General Ones Affect Most or All Measurements
- Sound Speed (SoS) Error: US Systems Assume 1540 m/s

TISSUE	SOUND SPEED	% ERROR
Fat	1450 m/s	5.8%
Water	1480	4.0
Liver	1550	0.6
Muscle	1580	2.6
Bone	4080	165

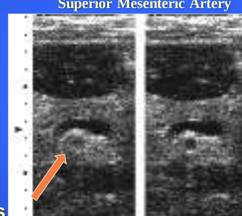
GENERAL SOURCES OF US ERROR
SOUND SPEED ERROR EFFECTS

- Sound Speed Error → Distance Error Affects
  - All Spatial Measurements
  - Displacement, Velocity, Acceleration
  - Placement of Regions of Interest
- Mixtures of Tissues With Different Sound Speeds Produce Wave front Distortions Affecting
  - Focusing, Beam Steering
  - Contrast
  - Penetration

SOUND SPEED ERROR MITIGATION

- Manual Change in Assumed Sound Speed
- Wave front Aberration Correction
  - Compare Expected Return Wave With Received
  - Check Arrival Times From Assumed Point Sources
  - Adjust Element Time Delays to Correct Deviations

Superior Mesenteric Artery



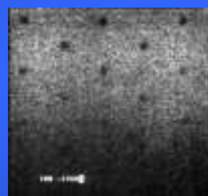
PRE POST

GENERAL SOURCES OF US ERROR
VOXEL - RESOLUTION ANISOTROPY

- Axial Resolution typically 5 – 10 times higher than lateral and elevational.
- Lateral and Elevational Resolution May Vary Considerably vs Depth
  - Measurement Accuracy Loss (↑ Bias & Variance)
  - Partial Volume Effects (lower contrast for small objects)

VOXEL – RESOLUTION ANISOTROPY

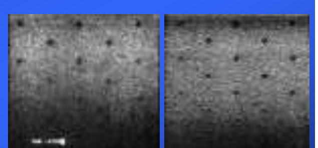
GALLSTONE MEASUREMENT



2mm Spherical Void Phantom
↓ Void Contrast Out of Focal Zone

VOXEL – RESOLUTION ANISOTROPY SOLUTIONS

- Measure in Axial Direction Only
- Finer Pitch Multi-Element Arrays (piezo, cMUT)
- 1.5 D and 2 D Arrays With Elevational Focusing



OPERATOR DEPENDENCE

- Large Number of Controls Available to Manipulate Image Quality
- “Image Artist” Mindset
- Time vs Image Quality Tradeoff
- These Problems Carry Over Into Image Quantification and Measurement

OPERATOR DEPENDENCE
CONTROL STRATEGIES

- Improved Training on Techniques to Control Bias and Variance
- Incentivization
- Improved and Increased Automation
- System Presets

OTHER SOURCES OF ERROR

- Spatial Measurement
  - Indistinct Organ/Lesion Margin, Irregular Margin
- Quantitative Backscatter Features
  - Non Reproducible Machine Settings
- Doppler
  - Angle correction, Diameter est, ROI Size -- Volume Flow
  - Gain, Compression, Focal Depth, Doppler Scale
- Tissue Elasticity
  - Compression Rate, Precompression, Patient Movement, Fasting State, Lateral Motion Correction (strain elasto)

MOST CAN BE SOLVED WITH GREATER AUTOMATION, BETTER TRAINING, BETTER FEEDBACK TO OPERATOR

US QUANTIFICATION
CLINICAL/RESEARCH TRENDS

- Increasing Focus on Measurement – Especially Non-Radiologists
- Skill Level Lower – Requires Greater Automation
- Greater Need for Quantification to Integrate With Other Objective/Numerical Output
- Manufacturers Recognize Trend – Producing Systems With More Measurement Capabilty

US QUANTIFICATION
REGULATORY TRENDS

- Greater Numbers of Submissions That Focus on Numerical Output
- CAD Type Submissions Often Produce Numerical "Score"
- Greater Accommodation of New Types of Measurement Using the "Tool Claim"
- Interest in Any Tools / Procedures That Increase Accuracy of Quantification

US QUANTIFICATION
QIBA

- Quantitative Imaging Biomarker Alliance
  - Industry, Academia, Clinical, Government
  - Formed to Promote Accuracy of Image Related Quantification
- Modality Specific Biomarker Committees Create Documents "Profiles" for a Quantifiable Biomarker
  - Contains Claims for Accuracy and Procedures for Achieving the Claim

US QIBA PROFILES

- Shear Wave Speed for Liver Fibrosis
  - Claim of Low Bias and Coefficient of Variation Across Users, Sites and US Systems
  - Profile Nearly Ready for Public Comment
- Quantitative Volume Blood Flow
  - Initial Focus on Renal Transplant Flow
  - In Phantom Testing Phase
- Contrast Ultrasound Quantification
  - In Parameter Selection / Phantom Design Phase

POSSIBLE NEW QIBA US BIOMARKERS

Spatial Measurements:
2D and 3D

Quantitative Backscatter
Features for Diagnosis

CONCLUSIONS

- Expanding Numbers and Applications for US Quantification
- Errors Relate to:
  - Erroneous Assumptions & Approximations
  - Training
  - Lack of System Automation
- Greater Need for Standard Tools to Assess New Types of Quantification
  - QIBA Provides One Such Tool

Thank You!