Echocardiography
(cardiac ultrasound)

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Overview

- The clinical need
- Ultrasound physics – why do ultrasound images look the way they do?
- 3D echocardiographic image analysis
- The role of 3D echocardiography in multi-modality cardiac imaging
- Ultrasound to assess myocardial tissue health
- Summary
Functional Cardiac Image Analysis

Automated Quantification for Diagnosis (QUAMUS, 2002)

Multi-modality Registration for Diagnosis and Therapy Assessment

Fetal cardiology – quantifying healthy functional growth

Fusion 3D Echocardiography
• **Tissue perfusion**

- Segmental wall motion
- Segmental thickening
- Thickening: \((\text{SWT} - \text{DWT})/\text{SWT} \times 100\%\)
What is biomedical ultrasound?

The name:

- “ultra” – beyond, on the other side of, extreme [Oxford Dictionary]
- “sound” – sensation caused in ear by vibration of surrounding air [Oxford Dictionary]

Hence

“Ultra”+”sound” = sound with frequency greater than 20,000 cycles/second (20kHz)
Data acquisition
The US image formation pipeline

Fig. 5. Simplified model of the ultrasound scanner, with frame grabber connected to the video output.

- RF Signal
- Envelope of RF Signal
- Scan-converted Image
An apical long axis acquisition
(courtesy C Szmigielski, H Becher)

- Field of view
- Frame-rate
- Signal dropout (border definition)
- Speckle
- Signal attenuation increases with depth
- Signal is affected by attenuation path (BMI and lungs)
- And etc.....

Modulus of the detected backscatter US signal

Real-time

Interfaces

Signal dropout

Attenuation

Speckle

Variable resolution/sampling
Ultrasound Frequencies - examples

**Adult heart (left ventricle)**
- 10cm length
- 70 beats/min
- 3-5MHz probe
- 25-120Hz sampling rate

**Mouse heart (left ventricle)**
- “Smartie” size (1cm)
- 400-600 beats/min
- 15MHz probe
- 184-400Hz sampling rate
- More of a “snow storm” (speckle noise)
Real-time 3D Echocardiography

Commercially available since 2003
Significant excitement in echo community
Gives 3D in real-time (40Hz)
Matrix-array vs linear array technology
Limited field of view

? Role in heart disease diagnosis/patient management
Averaging versus wavelet-based fusion

Aligned Single-view Images

Fused Multiview (Wavelet)

Fused Multiview (Averaging)

(Kashif Rajpoot, 2008)
4D Fusion Echocardiography (Scientific Highlights, ASE 2009)

Contrast to noise ratio (CNR) Cardiac Phantom

Contrast to noise ratio (CNR) Participants

Endocardial border definition

Visualization grading scale:
- Good
- Intermediate
- Poor
- Out of sector

Before Fusion (RT3DE) (%): 29.9, 36.9, 30.3

After Fusion (4DFE) (%): 3.9, 0.4

CNR RT3DE: 10.26 ± 6.54
CNR 4DFE: 22.15 ± 13.46

p < 0.001
MR-Echocardiography Fusion (image alignment)

Data is acquired on different machines at different times.

This leads to:

- Different image appearance
- Different temporal sampling

A non-rigid registration solution is required…..

(Zhang, Brady, Noble, MICCAI 2008, IPMI 2007, PMB 2011)
Non-rigid image alignment is based on image phase not intensity.

A poly-affine transformation estimated using an iterative algorithm.

(Zhang & Noble, IPMI 2007)
Again, the potential clinical value is that alignment can provide new information for clinical decision-making.
Characterising tissue health

1. Speckle tracking

Figure 1. Processing and Presentation of 2DS

(A) Tracking quality (TQ) approval screen; segments with adequate tracking are assigned a green V mark (TQ <3). (B) Strain profiles from each apical view. Average segmental values in each segment are used to generate a parametric ("bull's eye") display of the entire left ventricle. 2CH = 2-chamber; 4CH = 4-chamber; ANT = anterior; APLAX = apical long-axis; AVC = atroventricular canal; INF = inferior; LAT = lateral; POST = posterior; SEPT = septal.
Ultrasound Contrast agents

- Encapsulated gas bubbles
  - <10μm diameter (mean 2μm)

- Stable during cardiac + pulmonary passage
  - i.v. injection

- Blood pool agents
  - Duration 5 to 20 mins

- Safe - non-toxic ingredients
• Bubble response $\propto$ transmit power
Contrast Ultrasound Perfusion Imaging
(myocardial contrast echocardiography)

Patient at Rest

Patient at Stress

Quantification of contrast agent entering myocardium

Manual ROI analysis is tedious

You are sampling a spatio-temporal process so the analysis method should reflect this.
From Motion Models to Models of Tissue Health

• Spatio-temporal analysis of contrast ultrasound perfusion images to determine uptake curves at same time as segment areas of similar uptake

• Employ Bayesian Factor Analysis (Rowe 2000) set in a Markov Random Field Framework

\[(y_i | \mu, \Lambda, f_i) = \mu + \Lambda f_i + \epsilon_i\]

\[y_i = A(1 - e^{-\beta t})\]

(Williams & Noble, MICCAI 2004)
Fig. 3. Frames (a) 1, (b) 10 and (c) 20 along with (d) the classification result (White = normal, Gray = abnormal, black = cavity) for a stress 2-chamber view of an abnormal patient with occlusion in all three main coronary arteries. The associated normalised intensity curves is shown in (e), while (f) shows the diagnosis from the computer algorithm (note the error made in anterior wall) and (g) the clinician’s diagnosis (error in whole myocardium) (0 = Normal, 1 = Abnormal). This dataset was graded as 'poor', but is shown here as an example of the strength as well as weakness of the computer algorithm.
41 apical stress echo datasets

22 (12 normal/10 stenosis) patients
(9 high, 8 medium, 5 low quality)

BFI=blood flow index, BFRI=blood flow reserve index

<table>
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<th>Clinician</th>
<th>BFI</th>
<th>BFRI</th>
<th>BFI × BFRI</th>
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<tr>
<td>Sensitivity (%)</td>
<td>49.37</td>
<td>55.91</td>
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<td>Specificity (%)</td>
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<td>67.02</td>
<td>76.92</td>
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Table 3. Evaluation percentages for All Datasets

Coronary angiograms as the reference. >50% stenosis=abnormality

Diagnosis by automated algorithm better than experienced reader and leads to measurement of extent of ischaemia not just detection
Summary

• Echocardiography is the most widely used imaging modality in clinical cardiology.
• As a research tool it has a role in diagnosis, interventional and potentially therapeutic research in the future.
• It can be used to assess global/regional motion in 3D of a heart.
• It can be used for characterising myocardial tissue health.
• Advances in medical image analysis underpin many of the current advances in 3D echocardiography.
• 3D echocardiography is already cheaper than its competitors and costs of 3D transducers will come down.

How far are we off from 3Decho on a smartphone?
Thank you for your attention