Introduction

- Coronary heart disease: the vessels that supply oxygen-carrying blood to the heart, become narrowed and unable to carry a normal amount of blood.
  - The heart does not receive sufficient oxygen.
  - Heart attack and death.
- Coronary heart disease is the leading cause of death in the United States, responsible for nearly 460,000 deaths each year.
- Cardiac imaging: more accurate diagnostics.

Overview

Cardiac imaging modalities:
1. Magnetic Resonance Imaging (MRI)
2. Magnetic Resonance (MR) velocity mapping
3. Computed Tomography (CT)
4. Ultrasound imaging
5. Doppler imaging
6. Tissue Doppler Imaging (TDI)

MRI

- Developed in the early 1970’s.
- Spin of protons: small magnetic field.
- Huge magnetic fields applied:
  - Align protons
  - Magnetization of the body.
- Radio waves directed to the heart: nuclei of atoms give off energy.
- Energy detected and translated into an image.

MRI (Continued)

- Temporal resolution < 100ms.
- In-plane spatial resolution: 0.7-1mm or better.
- Different configurations: appearance of the image (resolution, SNR, tissue contrast).
- Two main configurations:
  - Black blood imaging (high tissue contrast, slow: ~13 seconds for one slice).
  - Bright blood imaging (very fast: real time).

MRI (Continued)

- Standard reference: cardiac anatomy.

High resolution representation of cardiac and thoracic anatomy in black blood imaging.
LV = Left Ventricle
LA = Left Atrium
Ao = Aorta
Spatial resolution: 0.7x0.7mm
Acq. time: 12 seconds.
MRI (Continued)
Assessment of the heart function
- Gold standard: cardiac output (amount of blood pumped out by each ventricle in one minute)
- Bright blood imaging:
  - movie series of the heart chambers in 3D
  - better quantification of the heart chambers volumes

MRI (Continued)
- State-of-the-art technique
- Allows more accurate diagnostics
- Very expensive (1 to 3 million dollars for the latest scans)
- Respiratory movements: artifacts
  - can require a short breath hold

MR velocity mapping
- Particular use of MRI
- Magnetic field gradient: phase shift of proton spins
- Magnetic field inhomogeneity:
  - 2 acquisitions with different velocity sensitivities
  - Subtraction of the phase-contrast images
  - Phase-difference map proportional to the velocities

MR velocity mapping (Continued)
- Application: mapping of blood velocity distribution downstream of aortic valve prostheses
- Shear stress: random time-dependent fluid mechanical stress that acts tangentially on the surface of an element in the blood
- Prosthetic heart valve: late complications due to elevated levels of turbulent shear stress
- MR velocity mapping can assess the complexity of flow fields without surgery

MR velocity mapping (Continued)
Mapping of blood velocity distribution downstream of aortic valve prostheses (typical case):
- In-plane resolution: 1mm x 1mm
- Temporal resolution: 30 msec
- Section thickness: 5mm
- Acquisition time: 8 seconds per image

Computed Tomography (CT)
- Invented in the early 1970's
- Refined version of X-ray machines
- X-ray tube: rotates around the body
  - sends beams from all directions to a specific level of the body (slice)
- Sensors: amount of radiation absorbed by different tissues
- Cross-sectional images

Kozerke (2001)
Color-encoded axial flow velocity images measured downstream of the valve in five consecutive heart phases. Values are given in centimeters per second. A=anterior, P=posterior, R=right.
CT (continued)

- Can provide image of the full heart volume (15x15x15cm)
- 1.25mm slice thickness
- Acquisition time ~ 18 seconds
- Multislice CT (MSCT)
  - decreases the acquisition time
  - acquisition of 4, 8 or 16 slices simultaneously
- High resolution slices: 0.5x0.5x0.5mm spatial resolution for the visualization of coronary arteries

Applications:
- Visualization of coronary arteries
- Quantification of coronary calcium
- High resolution assessment of morphological detail of the heart’s chambers (including the cardiac valves)
- Accurate measurement of functional parameters of the heart such as wall thickening, diastolic and systolic volumes

Example:
This 3D spiral CT view is looking down on top of the left ventricle. It shows a normal coronary artery (black arrow) and side branches.

CT (continued)

- State-of-the-art technology
- Very expensive (more than 2 million dollars for the latest models)
- High resolution
- Good overall image quality of the entire heart but possibility of artifacts in the data
- Candidate objects for examination must be small enough to be accommodated by the handling system of the CT equipment available to the user and radiometrically translucent at the X-ray energies employed by that particular system

Ultrasound imaging

- Ultrasound introduced to the medical world in the 1960’s
- Piezo-electric crystal (transducer):
  - placed against the skin of the patient near the region of interest (heart)
  - stream of high frequencies sound waves (2MHz) which penetrate into the body
  - detects sound waves as they echo back from the internal structures of the organ
- Different tissues reflect these sound waves differently:
  - signature measured and transformed into an image in real time
- Also called echocardiography

Ultrasound imaging (Continued)

- High lateral resolution up to 0.3mm
- Discrimination between structures along the direction of the beams of ultrasound
- Higher the frequencies = better the axial resolution
- However high frequencies:
  - are attenuated more quickly
  - have less penetration
Ultrasound imaging (Continued)

Applications:
- Visualization of most valve diseases (stenosis or regurgitation)
- Detection of ischaemic heart disease (ischaemia results in regional defects in myocardial contraction and mass. An injured myocardium is unable to thicken during systole.
- Visualization of primary heart tumors
- Characterization of pericardial effusion which is an abnormal collections of fluid inside the pericardial (the sac that covers the heart)

Ultrasound imaging (Continued)

Example:
- The Echocardiography Laboratory of the University of Medicine and Dentistry of New Jersey

Pericardial effusion

Doppler imaging

Applications:
- Most common technique used for the detection and evaluation of severity of valvular regurgitation
- Characterization of aortic stenosis
- Detection of muscular hypertrophy
- Aneurysms
- Pericardial effusion

Several kinds of Doppler imaging:
- Continuous Doppler (transmits a continuous ultrasound stream in a single direction and simultaneously receives the echoes continuously)
- Pulsed Doppler (the stream is discontinuous)
- Color Doppler (displays a color representation of Doppler shifts over a moving ultrasound image)
Doppler Imaging (Continued)

Example:

Four-chamber view in real-time (left) and color Doppler. During diastole, flow is visualized entering from both the right and left atria (RA, LA) into the right and left ventricles (RV, LV) and the flows are separated by the interatrial and interventricular septum.

Tissue Doppler Imaging (TDI)

- Variation of conventional Doppler imaging
- Allows measurement of velocities of myocardial tissue (low velocity in conjunction with high amplitude) at certain points
- Standard Doppler imaging: high frequencies, low amplitude
- TDI: low frequencies, high amplitude signals to identify wall motion

TDI (Continued)

Applications:

- Assessment of diastolic function by evaluating annular displacements during diastole
- Help determine when a transplanted heart will fail
- Assessment of regional systolic ventricular wall motion in patients with coronary artery diseases

Example:

During systole (left), the walls of the LV move towards the apex (coded in red), while during diastole (right), they move up towards the base (coded in blue).

Conclusion

- Each cardiac modality has its own advantages and disadvantages
- MRI: expensive, accurate diagnostics, can detect heart attack in emergency room patients with chest pain more accurately and faster than traditional method but is limited for the detection of coronary artery disease
- Ultrasound: cheap, easy to use, real time, high resolution but less accurate than MRI
- Doppler imaging: limitations in the evaluation of the right ventricular morphology and function while MRI provides more accurate visualization of the right ventricle
- The modality of choice in evaluating the degree of mitral stenosis.
- MRI velocity mapping and TDI are promising techniques but need more development.
- Improvements possible in all the cardiac imaging modalities

References

- L. Wexler. Modern imaging of acquired heart disease
- K. Goodon. Cardiac MRI and Echocardiography: a comparative analysis