Relationship between Cardiac Imaging Data and Simultaneous Physiological Measurements

Wenfeng Duan[1], Dingchang Zheng[1], Christopher Eggett[2], Philip Langley[1], Alan Murray[1]

[1] Institute of Cellular Medicine, Newcastle University, Newcastle upon Tyne, UK
[2] Cardiac Services Department, Freeman Hospital, Newcastle upon Tyne, UK

Abstract

This study aimed to quantitatively link cardiac imaging and simultaneous physiological measurements.

Cardiac valve movement and valve blood flow were examined by M-mode and Doppler echocardiography simultaneously with cardiac electrical activity, thoracic impedance and peripheral pulse. The timing sequence of cardiovascular events through the cardiac cycle was reconstructed, and the relationships between valve movement/blood flow and physiological measurements were investigated. Data from one subject were studied.

The timing of mitral and aortic flow was quantified as starting within 19 ms of the valves opening, and ending within 13 ms of the valves closing, except at the end of ventricular relaxation when mitral flow stopped 39 ms after valve closure. Mitral peak flow always occurred after the valve was fully open.

Thoracic impedance stared to fall soon after aortic flow onset (12 ± 16 ms), while the minimum impedance occurred 107 ms (± 20 ms) before the flow stopped, with impedance taking account of both left ventricular volume and aortic blood volume. Similarly, left ventricular ejection produced a longer effect on peripheral pulse (from foot to the notch, 390 ± 13 ms).

In conclusion, with simultaneously recorded cardiac images and physiological signals, we have analyzed the cardiovascular timing sequence through the cardiac cycle and linked echocardiograms to thoracic impedance and peripheral pulse.

1. Introduction

Clinicians usually assess the heart with only the tools which they have expertise. There are studies linking ECG and echocardiography [1], and ECG and pulse [2], but to the best of our knowledge there is little research linking a range of different investigation modalities.

Cardiac imaging provides useful information about heart function. M-mode echocardiography is one of the most effective ways to examine the motion of valves [3],

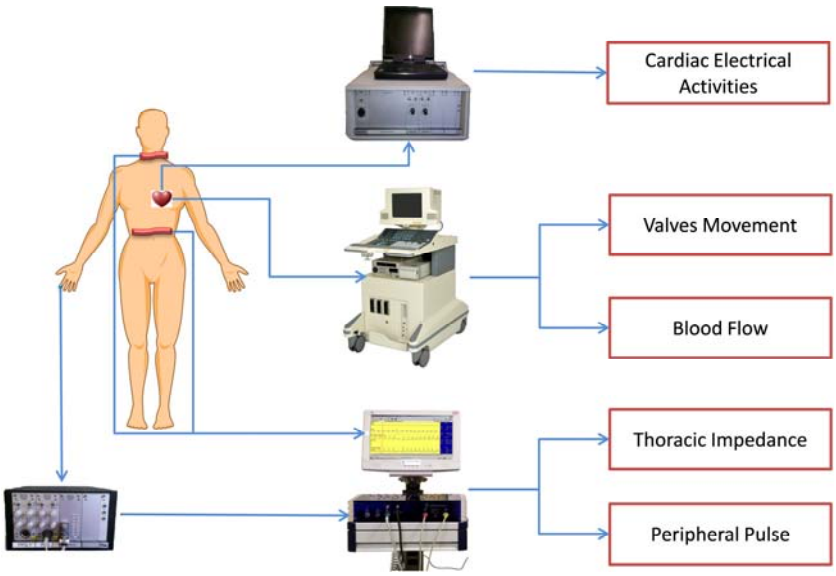

Figure 1. Schematic representation of measurement system.

while Doppler echocardiography is an important non-invasive technique to record blood flow velocity [4]. Other non-invasive physiological measurements, such as thoracic impedance, impedance cardiography and photo-plethysmography have potential to provide additional clinical information [2, 5, 6], but are rarely studied together with echocardiography.

The study aimed to link cardiac imaging and simultaneous physiological measurements in terms of the timing sequence through the cardiac cycle.

2. Methods

2.1. Subjects

Healthy subjects with no history or symptoms of cardiovascular disease were studied after obtaining informed consent.

2.2. Data collection and signal synchronization

Data were collected simultaneously from following systems (Figure 1):

- Twelve-lead ECG
- Philips echocardiograph HDI 5000
- Impedance cardiograph TaskForce 3040i
- Photoplethysmograph

M-mode echocardiography was used to record the movements of mitral and aortic valves, and Doppler echocardiography for blood flow through these valves.

Data were collected for 15 s on each subject during normal respiration with subjects lying on a measurement couch. Lead I ECG was recorded to all systems, with a preceding blank period to ensure that the same 15 s was saved for each system. Because of small sampling rate differences, data were resampled to a common 1 kHz for all the physiological signals. The sampling rate for the images was 200 Hz. Figure 2 shows the synchronized signals from one subject.

2.3. Timing features extraction

Following de-noising procedures, an interactive MATLAB program was developed to obtain the following timing features (figure 2):

- ECG P-QRS-T waves
- valve movement (open, maximum and close)
- blood flow through valve (start, peak and end)
- impedance waveform (start, minimum and end)
- pulse waveform (foot, notch and two peaks).

All timing features were obtained beat by beat from the 15 s recordings.

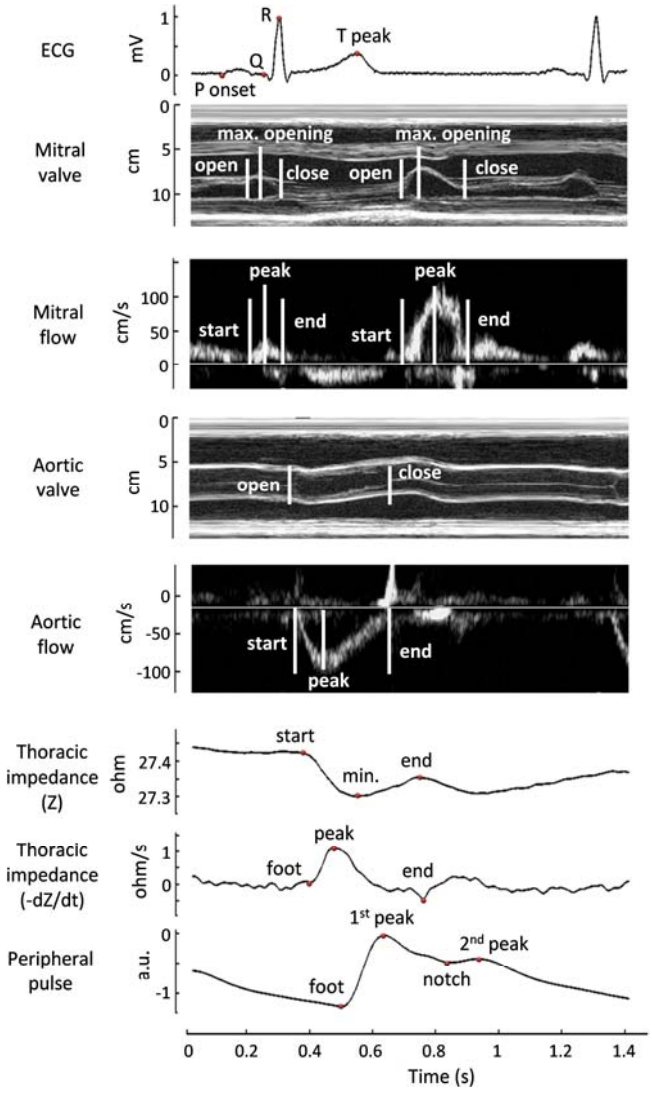

Figure 2. Example of synchronized signals. The extracted features are also identified on the signals.

2.4. Data and statistical analysis

Data from one example subject were analyzed. Times were measured with reference to ECG R peak to reconstruct the sequence of atrial contraction, ventricular contraction and ventricular relaxation phases.

Dynamic relationships between valve movements and flow were quantified. Relationship between aortic flow and thoracic impedance and pulse were investigated. Mean±SDs were calculated across all beats from the 15 s recordings.

3. Results

3.1. Summary of timing measurements

Figure 3 shows timing data from all measurements,

giving the sequence of the three phases of atrial contraction, ventricular contraction and relaxation.

3.2. Dynamic relation between valve movement and blood flow

Table 1 and figure 3 show the timing between valve movement and changes in blood flow for the three phases of atrial contraction, ventricular contraction and relaxation. As expected flow is detected after the valves start to open (between 9 and 19 ms), and peak flow occurs following maximum valve opening (around 30 ms). However, it can be noted that the mitral flow ends after the valve closure (39 ms) at the end of ventricular relaxation in contrast with atrial and ventricular contraction (7 to 13 ms), probably because the valve is not fully closed at the end of ventricular relaxation.

3.3. Relationship between aortic flow and thoracic impedance

Figures 3 and 4 show that thoracic impedance starts to fall soon after aortic flow starts (12 ms delay) and reaches a minimum at 258 ms (± 22 ms) between aortic flow peak (134 ± 6 ms) and end (365 ± 7 ms).

Table 1. Time difference between valve movement and corresponding flow conditions.

Time Difference (ms)	Atrial contraction Mitral	Ventricular contraction Aortic	Ventricular relaxation Mitral
Valve opens to Flow starts	10 ± 7	9 ± 5	19 ± 7
Valve max. opening to Flow peak	30 ± 7	N/A	31 ± 11
Flow ends to Valve closes	7 ± 5	13 ± 5	-39 ± 7

3.4. Aortic valve opening duration and intervals on pulse and impedance

Figure 5 shows the left ventricular ejection time (aortic valve opening duration, 347 ± 13 ms). The ejection produced a longer effect on both the pulse (from foot to the notch, 390 ± 13 ms) and impedance (from start to the end, 457 ± 17 ms).

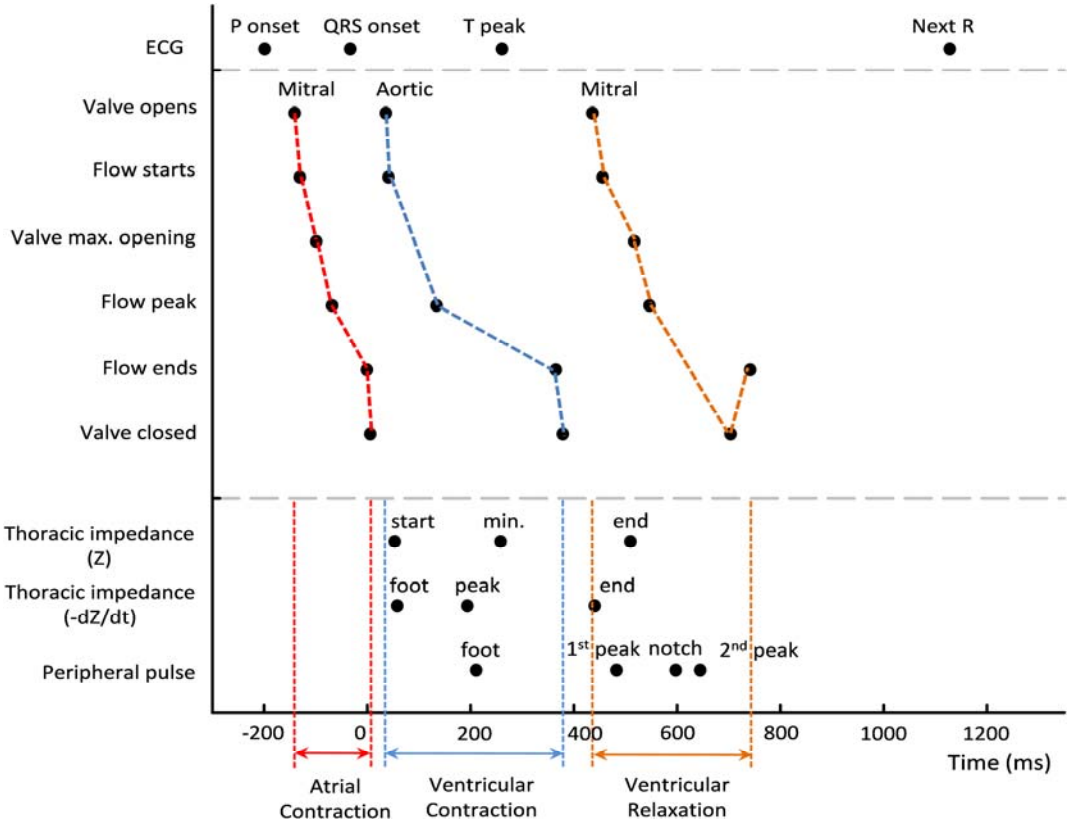

Figure 3. Times from cardiac imaging and physiological measurements. The black circles denote the mean values of measurements from the example subject. Time sequence of valve movements and their flows during atrial contraction, ventricular contraction and ventricular relaxation phases are connected.

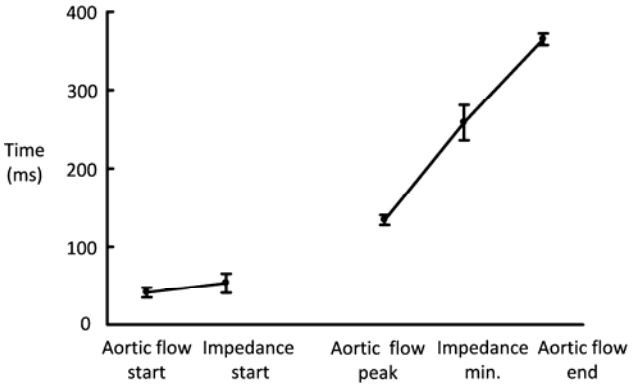

Figure 4. Relationship between aortic flow and thoracic impedance (Z). Impedance starts to fall after the aortic flow starts, but its minimum occurs before the aortic flow ends. Mean and SDs were calculated from all beats from the 15 s recordings.

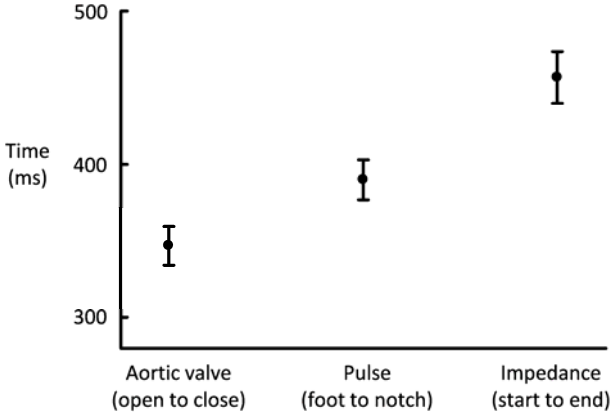

Figure 5. Comparison between aortic value opening duration and intervals on pulse (from foot to the notch) and impedance (from start falling to end). Both the pulse and impedance intervals are significantly longer than the aortic value opening duration.

4. Discussion and conclusion

To the best of our knowledge, this is the first study to simultaneously record and investigate the synchronous timing relationships between cardiac mechanical events from echocardiography and several physiological measurement systems.

Our results demonstrated the feasibility of obtaining simultaneous recordings from multiple physiological measurement devices and imaging. Each subject was connected to 16 sensors to obtain the recordings. The challenge of synchronisation of the measurements from multiple systems was achieved by a single ECG reference signal. We also demonstrated the expected timing sequence of mechanical functions, which are initialized by electrical activity and associated changes in thoracic impedance and peripheral pulse. Furthermore, the dynamic relations between valve movement and blood flow were examined during atrial contraction, ventricular contraction and relaxation phases. This detected a delay between mitral flow end and mitral valve closure at the end of ventricular relaxation, which is probably because of the incomplete closure of the valve.

The investigation of the relationship between aortic flow and thoracic impedance (figure 4) confirmed that the distribution of blood in the aorta makes a significant contribution to thoracic impedance changes [4]. Both impedance and pulse intervals were significantly longer than the aortic valve opening duration because pulse and impedance reflect conditions of the overall cardiovascular system.

In conclusion, with simultaneously recorded cardiac images and physiological signals, we have demonstrated cardiovascular timing sequence information through the cardiac cycle, and linked echocardiogram data to thoracic impedance and peripheral pulse measurements.

References

[1] Stewart RA, Young AA, Anderson C, Teo KK, Jennings G, Cowan BR. Relationship between QRS duration and left ventricular mass and volume in patients at high cardiovascular risk. Heart 2011; 21: 1766-70.

[2] Allen J. Photoplethysmography and its application in clinical physiological measurement. Physiological Measurement 2007; 28: R1-39.

[3] Feigenbaum H. Role of M-mode technique in today's echocardiography. Journal of the American Society of Echocardiography 2010; 23: 240-57.

[4] Quiñones MA, Otto CM, Stoddard M, Waggoner A, Zoghbi WA. Recommendations for quantification of Doppler echocardiography: a report from the Doppler Quantification Task Force of the Nomenclature and Standards Committee of the American Society of Echocardiography. Journal of the American Society of Echocardiography 2002; 15: 167-84.

[5] Patterson RP. Fundamentals of impedance cardiography. IEEE Engineering in Medicine and Biology Magazine 1989; 8:35-8.

[6] Lababidi Z, Ehmke DA, Durnin RE, Leaverton PE, Lauer RM. The first derivative thoracic impedance cardiogram. Circulation 1970; 41:651-8.

Address for correspondence.

Wenfeng Duan
Institute of Cellular Medicine
Newcastle University
Newcastle upon Tyne
NE2 4HH, UK
w.duan@ncl.ac.uk