

# The Relationship between the Occurrence of the U Wave and both the Electrical and Mechanical Timing Sequence

Wenfeng Duan, Dingchang Zheng, Philip Langley, Alan Murray

Newcastle University and Freeman Hospital, Newcastle upon Tyne, UK

## Abstract

*The genesis of the U wave in the ECG is still in doubt. This study aimed to investigate the relationship between the occurrence of the U wave and both the electrical and mechanical timing sequence in heart beats.*

*The M-mode echocardiography and 12-lead ECG were simultaneously recorded from 4 healthy subjects, with four repeat measurements in each. The ECG for both aortic valve (AV) and mitral valve (MV) were recorded from all four subjects. The timings of QQ interval, the peak and end of T wave, the peak and end of U wave, the AV and MV opening and closing were measured. The relationships between the QQ interval and the other timings were analysed.*

*The MV opening and AV closing preceded the end of T wave (also considered as the start of U wave for healthy subjects) by  $9 \pm 11\text{ms}$  and  $47 \pm 15\text{ms}$ , respectively. When compared with the mechanical timings, the timing of the U wave had better correlation with the QQ interval, with the R square increasing from 0.76 to 0.95. Our finding suggests that the characteristics of the U wave may be more related to electrical activity than the mechanical events.*

## 1. Introduction

The Q point of the QRS complex on an electrocardiogram (ECG) indicates the start of ventricular depolarisation, which induces mechanical contraction of the ventricles. During the contraction, the mitral valve (MV) closes, while the aortic valve (AV) opens to allow the blood in the left ventricle to be pumped into the aorta. The T wave represents the repolarisation of the ventricles, which causes ventricular relaxation. Within this period, the AV closes and the MV opens so that the blood in the atrium can flow into the ventricle.

The U wave, which was first designated by Einthoven in 1903 [1], follows the T wave in a normal ECG. However, the generation of the U wave is still in debate. Currently, the three main hypotheses for the U wave

generation include: 1) repolarisation of the Purkinje fibres, 2) repolarisation of some portions of ventricular myocardium, 3) stretch-induced delayed after-potentials caused by mechano-electric coupling [2]. However, none of them has been universally accepted.

The aim of this study was to investigate the relationship between the occurrence of the U wave and both the electrical and the mechanical timing sequence using simultaneously recorded ECG and M-mode echocardiography.

## 2. Methods

### 2.1. Data acquisition

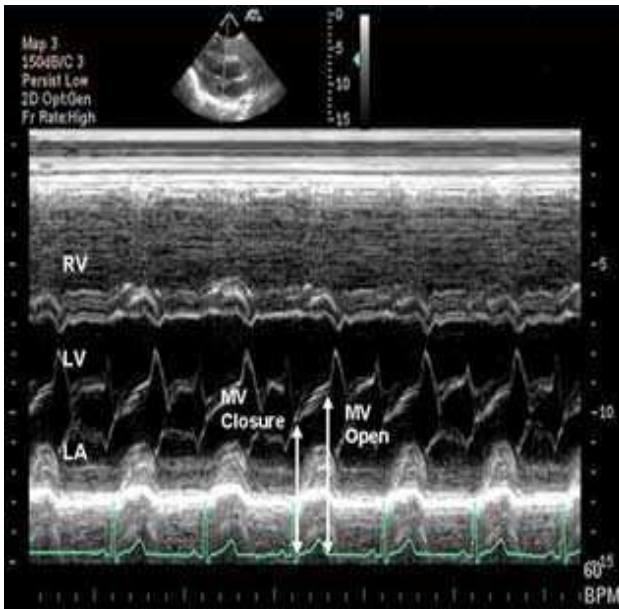
The echocardiogram and 12-lead ECG were simultaneously recorded from 4 healthy subjects, whose ages ranged from 22 to 45 years. For each subject, there were four repeat recordings, with a length of 15 s for each.

The ECG and echocardiography for both AV and MV were recorded from all four subjects. The order of echocardiograms for AV and MV alternated between subjects.

Echocardiograms were recorded with a Phillips/ATL HDI5000 ultrasound machine. All recordings were obtained with subjects having normal gentle breathing and lying on their left side. To get better quality of echo images, subjects were asked to recline at around 45 degrees and put the left arm behind the head. A P4-2 ultrasound probe was positioned on the echo window for the parasternal long axis (PSLAX) view. M-mode echocardiography was used, because it has an advantage of high time resolution when monitoring the movement of the valves [3]. Figure 1 shows a typical example of the recorded echo images from a subject presenting the movements of the two valves.

During the echo image acquisition, a synchronised 12-lead digital ECG was recorded simultaneously to a computer for off-line timing sequences analysis. The lead II ECG was used to trigger the echocardiogram capturing to achieve synchronization.

(A)



(B)

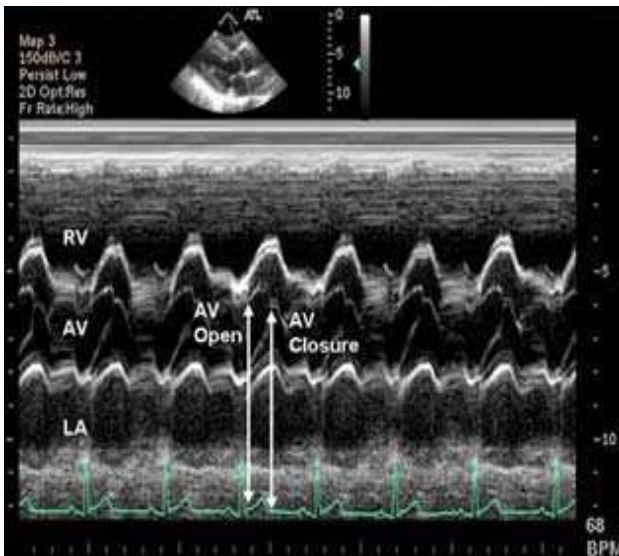


Figure 1. M-mode echocardiography with Lead II ECG at the bottom. (A): M-mode cursor is put through the mitral valve (MV) on a parasternal long axis (PSLAX) view. The biphasic movement of mitral leaflets can be seen. (B): M-mode cursor is aligned through the aortic valve (AV) on a PSLAX view. The leaflets open during left ventricular systole and close during diastole. On both A and B, valve closing and opening points are indicated by arrows.

## 2.2. Time sequence measurements

The timings of the MV and AV opening and closing (MVo MVc, AVo, AVc) were determined manually with the assistance of the offline measurement tool on the ultrasound machine. The electrical time sequences, including the peak and end of T wave (Tp, Te), the peak and end of U wave (Up, Ue), and the QQ interval were determined from Lead V3 of the ECG by an interactive MATLAB program. All the electrical and mechanical timing measurements were referred to the Q point of the QRS complex in each cardiac cycle. The average value from all the available beats in each 15s recording was used as the reference for that recording.

## 2.3. Data and statistical analysis

The means and standard deviations (SD) of all the electrical and mechanical timings were firstly calculated across all the subjects studied. They were then normalised to the QQ interval in each individual. The overall mean and SD of the normalised timing sequences were also calculated. Finally, the linear regression analysis was used to investigate the relationship between the QQ interval and the other calculated electrical and mechanical timing sequences, with the R square value given.

## 3. Results

Figure 2 shows the overall means and SDs of the measured electrical and mechanical timing sequences. Q point was immediately followed by the MV closing at  $46 \pm 11$ ms and then the AV opening at  $113 \pm 5$ ms. During left ventricular repolarisation, specifically, after the peak of T wave at  $327 \pm 35$ ms, the AV closed, at  $395 \pm 27$ ms. The end of T wave localised at  $441 \pm 36$ ms, which was preceded by the opening of MV ( $431 \pm 39$ ms). The peak and end of U wave occurred at  $523 \pm 44$ ms and  $657 \pm 60$ ms respectively.

After comparing the occurrence of the U wave (also considered as the end of the T wave for healthy subjects) with the mechanical timings, it showed that the MV opening and AV closing preceded the start of U wave by  $9 \pm 11$ ms and  $47 \pm 15$ ms respectively. The timing difference can be seen more easily in a normalised scale in Figure 3, where the U wave occurs right after the MV opening induced by the left ventricular relaxation.

The relationship between the QQ interval and the other timing sequences is shown in Figure 4. In general, the electrical timings had better linear correlation with the QQ interval than the mechanical timing sequences. The end of the U wave had the best linear relationship with QQ interval (R square = 0.95). However, the interval from the Q point to the AV closing was modestly correlated with the QQ interval (R square = 0.76).

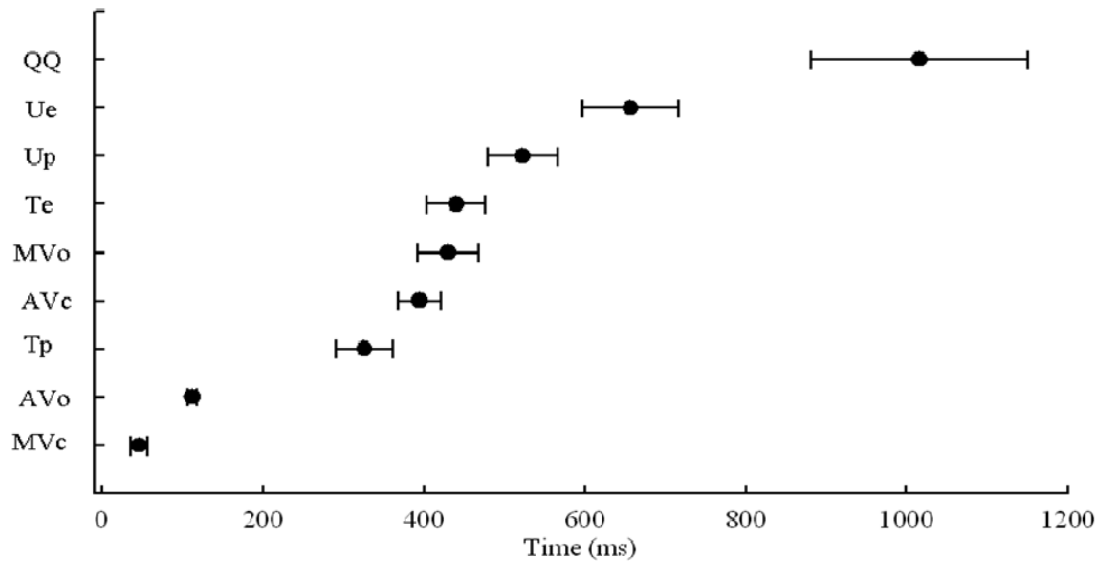


Figure 2. Overall mean and SD of mechanical timing (from echocardiograms) and electrical timing (from ECG), referred to the Q point of the QRS complex.

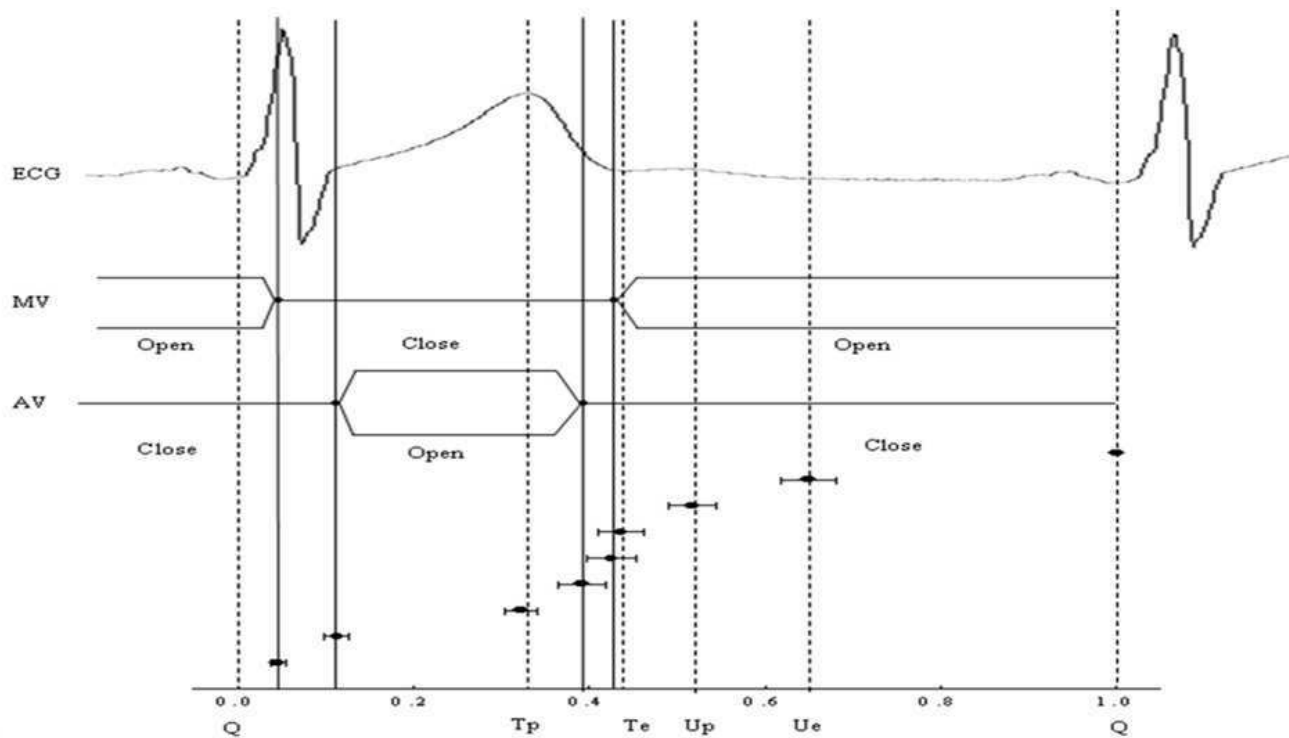


Figure 3. Timing sequence of the electrical activity, as well as the MV and AV opening and closing in a cardiac beat. The timings of Tp, Te, Up, Ue, MVo, MVc, AVo, AVc are normalized to the QQ interval. Dashed vertical lines demonstrate the ECG related parameters, while four solid vertical lines are for the opening and closing times of valves (corresponding to MVc, AVo, AVc and MVo from left to right).

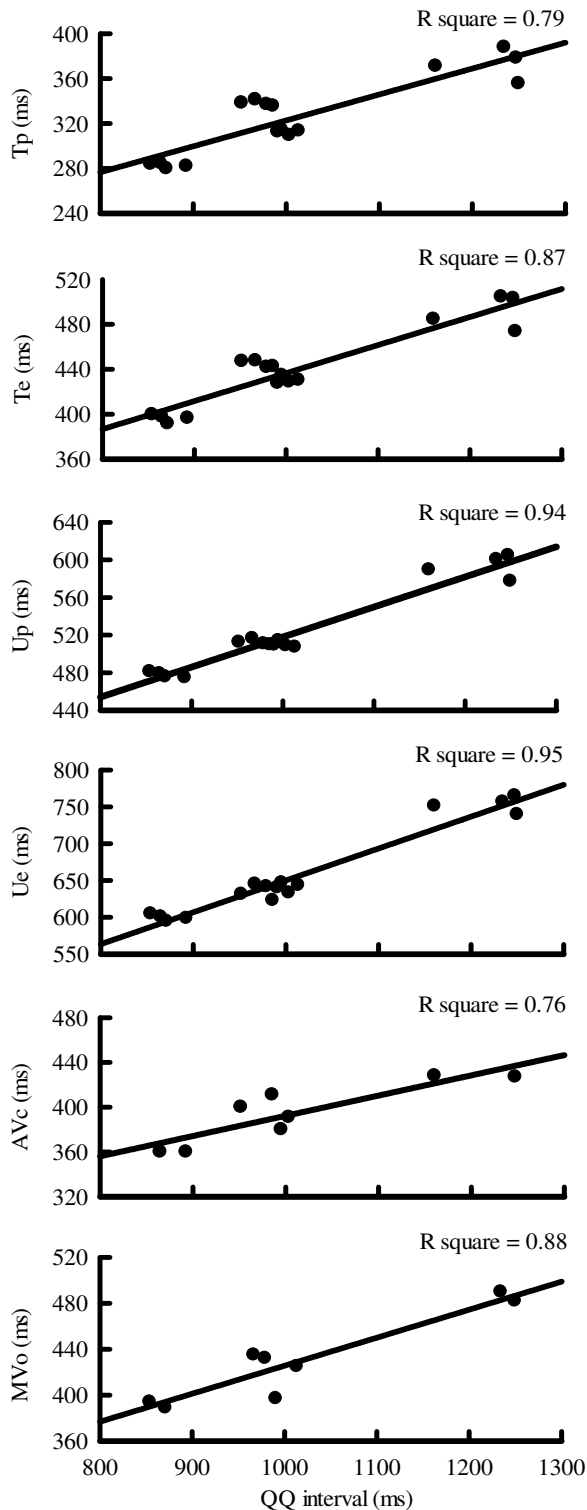


Figure 4. The relationship between the QQ interval and the timings of Tp, Te, Up, Ue, AVc and MVo.

#### 4. Discussion and conclusion

Firstly, the measured timings of the T wave, AV and MV movements follow the theoretical sequence of the electrical and mechanical events in each normal heart beat.

For the occurrence of the U wave, it appears soon after the MV opening during ventricular diastole, i.e. the beginning of passive filling. Furthermore, the occurrence of the U wave was tens of ms later than AV closure, which is in accordance with Surawicz et al's finding, where they reported that the U wave begins usually with the second heart sound produced by AV closure [2]. We also found that the U wave timing was better correlated with the QQ interval than mechanical valve timing. This suggests that the characteristics of the U wave may be more related to electrical activity than to mechanical events.

This finding is contrary to Schimpf et al's work [4], where they reported that in short QT syndrome (SQTS) patients the occurrence of U waves coincided with the AV closure and isovolumic relaxation, and concluded that the U wave is related to mechanical stretch. The different conclusions suggest that further investigation needs to be done in the future with more normal healthy subjects as well as patients.

#### References

- [1] Einhoven W. Die galvanometrische Registrierung des menschlichen Elektrokardiogram. Pfluger's Arch 1903; 99:472-480.
- [2] Surawicz B. U Wave: facts, hypotheses, misconceptions, and misnomers. J Cardiovasc Electrophysiol 1998; 9:1117-1128.
- [3] Feigenbaum H. Role of M-mode technique in today's echocardiography. J Am Soc Echocardiogr 2010; 23:240-257.
- [4] Schimpf R, Antzelevitch C, Haqhi D, et al. Electromechanical coupling in patients with the short QT syndrome: further insights into the mechano-electrical hypothesis of the U wave. Heart Rhythm 2008; 5:241-245.

Address for correspondence.

Wenfeng Duan  
 Medical Physics Dept  
 Freeman Hospital  
 Newcastle University  
 Newcastle upon Tyne  
 NE7 7DN  
 UK  
[w.duan@ncl.ac.uk](mailto:w.duan@ncl.ac.uk)