A Comparison of Infrasonic and Audio Components in the Seismocardiogram

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Abstract

In an earlier study, based on ECHO, we showed that the opening of the aorta valve happens before the peak in the SCG that many authors have associated with this event. Within the audible band of the acceleration signal a transient event is often seen during the S1 sound, possibly coinciding with aorta opening.

Data were available from 44 normal subjects. We manually analyzed the S1 complex in the SCG in two frequency bands: 1-25 Hz (LF) and 40-400 Hz (HF) and annotated mitral valve closure in both frequency bands, the main peak in the LF SCG as fiducial point for aorta opening, and the start of the transient in the HF sound as a hypothesized indicator for aorta opening.

The estimated timing of the mitral valve closure in the HF band was 1.6 ms earlier than in the LF band (sd = 5.8 ms). The estimated timing of aorta opening was 12.6 ms (sd = 9.4 ms) earlier in the HF. Thus, the estimated isovolumetric contraction time was 39 versus 50 ms.

The estimated mitral valve closures in the LF and HF bands of the SCG were almost identical, whereas there was a clinically significant difference between the estimations of the aorta openings. The latter agrees with our earlier work where SCG and ECHO were compared. The true origin of the high frequency transient in the audible frequency band is still open for discussion.

1. Introduction

Despite a high level of inter-subject variability, the normal seismocardiogram (SCG) has several characteristic peaks and valleys that clearly can be distinguished in almost all subjects. Sørensen *et al*. [1] have given the most extensive labelling, with 11 different fiducial points in the systolic complex and 9 fiducial points in the diastolic complex in the SCG. However, the relation between timing of events in the cardiac cycle and times of occurrence of the fiducial points are still a matter of debate. Sørensen *et al*. especially challenged the synchrony of the main positive peak in the systolic complex and the opening of the aortic valve (AO): comparing SCG with echocardiograms, they positioned AO on the positive slope before the main peak. In a second paper concerning SCG of cases of left bundle branch block, there was no longer a clear relationship between the fiducial points and AO [2].

The SCG is traditionally a low-frequency signal (up to 30 Hz [3]). However, modern MEMS accelerometers have a much higher bandwidth that includes the bandwidth of the phonocardiogram (PCG). The PCG allows for an accurate timing of the mitral valve closure (MC) and aorta valve closure. The opening of the aorta valve has so far not been demonstrated in the PCG. Because AO is happening during the S1 sound it might be expected that AO should be visible in the PCG. Indeed, in most cases in the high frequency part of the accelerometer signal (40-400 Hz) a sudden change is visible in the S1 complex (figure 1). Since this change seems to be too late to account for the closure of the tricuspid valve (see Discussion) we hypothesize that it indicates AO, the opening of the aorta valve.

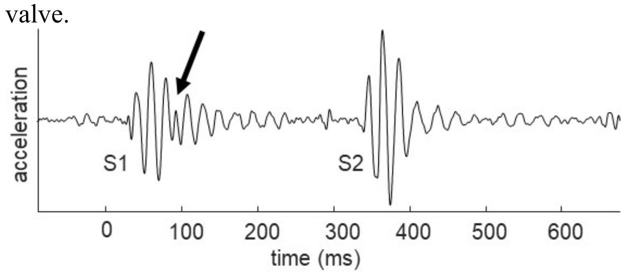

Figure 1. High-frequency part of the SCG (40-400 Hz). The arrow indicates a transient disturbance of S1.

In the current work we thus compare the timings of the MC and AO in the low frequency SCG and the high frequency acceleration signal.

2. Methods

Data from an earlier study [1] were used, where 44 normal subjects were enrolled. For the current work, signals (accelerations) were used that were measured perpendicular to the body surface, from a position just superior to the xiphoid process. Up to 50 s of data was available from each recording. Of the 44 recordings, 9 were discarded because of noise (2 recordings), right bundle branch block on the ECG (1 recording), no sign of transients in S1 (2 recordings), ambiguous SCG annotation (4 recordings).

We manually analyzed the S1 complex in the SCG in two frequency bands: 1-25 Hz (LF) and 40-400 Hz (HF) and annotated the following events: MC in both frequency bands, the main peak in the LF SCG as fiducial point for AO, and the start of the high frequency transient in the HF sound as a hypothesized indicator for AO. Elliptic filters were used with 1 dB ripple in the passband and 40 dB attenuation in the stopband. Forward-backward filters were used to avoid delays, but because of the non-causality of those filters the timings of the HF MC and AO were obtained using a forward filter, corrected for the filter delay, and then compared with the forward-backward filtered signal. The filter delays were 11-13 ms.

Means and standard deviations were calculated for the differences between LF and HF estimates of the times of occurrence of MC (t_{AO}) and AO (t_{MC}), and for the derived isovolumetric contraction times ($IVCT = t_{AO} - t_{MC}$). Statistical significance was calculated using paired Student-t tests.

3. Results

In all accepted 35 recordings episodes of more than 5 s of low noise signal were present. More or less (figure 2) pronounced transients were present in those recordings. To avoid detecting spurious transients, the same pattern had to be present in multiple beats.

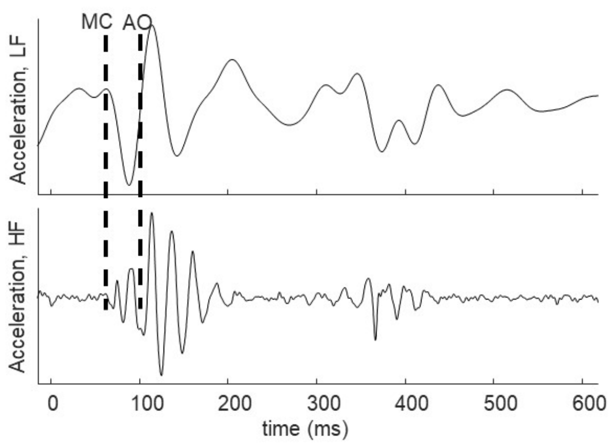

Figure 2. Comparison of LF and HF SCG. A small but clear change in the HF S1 pattern, which was visible in multiple beats, is labeled as AO. MC coincides in both frequency bands.

The estimated timing of MC in the HF band was 1.6 ms earlier than in the LF band (sd = 5.8 ms), which was not statistically significant. The estimated timing of aorta opening was significantly earlier (12.6 ms, sd = 9.4 ms, $p<0.001$) in the HF band as compared with the LF band. The estimated isovolumetric contraction time was shorter in the HF band: 39.4 ms versus 50.4 ms ($p<0.001$).

4. Discussion

We found that the estimated mitral valve closures in the LF and HF bands of the SCG were almost identical, whereas there was a statistically and clinically significant difference between the estimations of AO. The latter agrees with our earlier work [1] where SCG and ECHO were compared. Moreover, the obtained IVCT of 39.4 ms agrees very well with the 38 ms as given by Katz [5].

The true origin of the high frequency transient in the audible frequency band is still open for discussion. It is though highly unlikely that closing of the tricuspid valve was mistaken for AO. Indeed, the tricuspid valve usually closes later than the mitral valve, but the difference is known to be less than 10 ms, although Rahko *et al*. [4] found an average of 25 ms. Even this more extreme finding is significantly less than the 39 ms we found for IVCT.

A further analysis of the audio band of the SCG in comparison with the infrasonic SCG may reveal other interesting features, such as the closing of the pulmonic valve in S2. This will be subject for further research, but the authors have already experienced that a parallel analysis of the HF and LF SCG greatly simplifies the annotation of MC and aorta closure in the seismocardiogram.

References

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