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Detecting Preload Changes Using Seismocardiography

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Abstract

Seismocardiography (SCG) is a non-invasive tool that utilizes the chest wall vibrations from the beating heart to measure cardiac movements through a highly sensitive accelerometer. SCG offers continuous measurement of cardiac function that could be utilized for monitoring, diagnostic assessments, and prognostic health checks. The aim of this study was to investigate if the SCG could detect an increase in preload by intravenous saline infusion. Twenty-six subjects were included in this study, sixteen with cardiac disease and ten healthy subjects without known cardiac disease. Post infusion the diastolic SCG amplitudes D_d increased 27% (p=.016), E_d increased 48% (p = <.000) and the systolic L_s increased 19% (p = <.015). Diastolic time intervals B_d to F_d decreased with 10% (p = .010)% (p = .040). The same was observed for early systolic time intervals E_s to G_s that decreased 4% and E_s to L_s that decreased 14% (p = <.000) However, the mid systolic interval G_s to B_d increased 5%, L_s to B_d increased 16% and B_d to E_d increased with 1%. The results found in this study demonstrates a significant difference in the SCG measures after preload augmentation, thus indicating that the SCG could potentially be utilized to detect preload changes, for example signs of decompensated heart failure.

1. Introduction

Cardiovascular disease is the leading cause of death globally, therefore assessment of the function of the cardiovascular system is important. Non-invasive cardiac imaging such as trans-thoracic echocardiography (TTE), cardiac magnetic resonance (CMR) and cardiac computed tomography (CCT) provides assessment of the cardiac function. However, all these modalities require a clinical setting and highly trained staff. For CCT and CMR the equipment is expensive, and the availability is usually not as high as for TTE, which causes delays in access to these examinations.

Seismocardiography (SCG) is a non-invasive tool for recording and analyzing the vibrations generated by the heart during its movement [12]. The accelerations produced when the heart contracts and relaxes are recorded with an accelerometer usually located at the xiphoid process a technique that was introduced by Patrick Mounsey in 1957 [7]. Even though the SCG could be utilized for cardiac measures, it has not been used in a clinical setting, but the progression of microelectromechanical system could change that. The accelerometers utilized in the SCG has become smaller and lighter, thus transforming the SCG from a tool utilized mainly in supine position, to a potential wearable technology, with highly feasible measurements that could even be conducted at home [2,5,10]. The normal SCG waveform in healthy subjects displays a sequence of peaks and valleys. Based on simultaneous SCG and echocardiography recordings, it has been demonstrated that these patters can be presented as fiducial points associated with the aortic valve opening (AO), aortic valve closing (AC), mitral valve opening (MO) and mitral valve closing (MC) [1,5,10]. A study be *Agam et al*. utilized the fiducial points and showed a correlation between the diastolic variables in the SCG and echocardiography, thus indicating that the SCG could be used to evaluate the diastolic function [1]. Non-invasive SCG could potentially be utilized for early detection of cardiovascular disease and to determine cardiac function or early signs of cardiac decompensation by monitoring cardiac function routinely.

The aim of this study was to investigate if the SCG could detect an increase in preload by intravenous infusion of isotonic saline.

2. Methods

2.1 Study population

The subjects in this report were part of project with eighty-five subjects included from the Echo lab at Rigshospitalet [6]. They were examined to investigate the

differences between various imaging modalities and the impact of preload [6]. The data were collected from twenty-six subjects, fifteen subjects with cardiac disease such as hypertrophic cardiomyopathy, dilated cardiomyopathy, aortic valve disease or ischemic heart disease (age 45.8±17.4 years and 86.7% male) and eleven subjects without known cardiac disease (age 43.5 ±14.4 years and 63.7% male). The inclusions criteria were age ≥18 years old. Exclusion criteria were:

- Atrial Fibrillation
- NYHA-Class III-IV
- Contraindication for MR
- Estimated glomerular filtration rate >45 ml/min
- Dementia or mental retardation
- Pregnancy or breastfeeding.

2.2 Ethical considerations

The study was conducted in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards and approved by the local ethical committee of the Capital Region of Denmark. Protocol number H-16029778.

2.3 Experimental design

The subjects were told to abstain from any oral intake five hours prior to the examination. SCG was recorded from the xiphoid process using a custom-made sensor, while subjects were in a supine position. The accelerometers used were 0 placed in a 3D-printed plastic housing (19 mm wide, 21 mm long, and 11 mm high, it weighed 5 g). The subjects were then administered an intravenous infusion of isotonic saline (median 2.0 L) over approximately 45 min. Directly after fluid administration, the same procedure with SCG recordings were done.

2.4 Signal processing

The recorded data from the iWorx system was processed in MATLAB (Mathworks, USA). The duration-dependent hidden Markov model (DHMM) was utilized to divide the SCG signals into individual heart beats, this model is also used by *Sørensen et al.* [11] and *Agam et al* [1]. The systolic and diastolic segments were aligned and averaged to produce a low noise ensemble average SCG beat as described by *Sørensen et al.* [11]. A custom developed fiducial point detection algorithm was utilized to identify the fiducial points.

2.5 SCG variables

The study by *Sørensen et al.* [11] identified fiducial points from the SCG, these fiducial points were utilized in this study to investigate if the SCG could detect an increase in preload. The time intervals between the SCG fiducial points were measured, the diastolic time intervals were: B_d to F_d and B_d to E_d, the systolic time intervals were E_s to G_s, E_s to L_s, G_s to B_d and L_s to B_d. In addition, the diastolic amplitudes were C_d, D_d, E_d, B_d, F_d, and C_d to D_d. The systolic amplitudes were L_s, E_s and G_s.

2.6 Statistical analysis

All the data from the SCG were tested for normality by plotting them in a Q-Q plot and visualizing the histogram. The variables presented a non-normal distribution. To test if the SCG could detect a preload increase we used Wilcoxon signed rank test as a paired t-test to test if there was a significant difference between the SCG data before and after fluid infusion. P-values <0.05 were considered statistically significant. All statistical analyses were conducted using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, NY, USA). Data is represented by median and interquartile range (IQR).

3. Results

Table 1 presents the SCG variables before and after fluid infusion. A total of 28 subjects participated in this study. The data of two subjects were lost when collecting the SCG data. Therefore 26 subjects were included in the final study population: 15 subjects with cardiac disease such as hypertrophic cardiomyopathy, dilated cardiomyopathy, aortic valve disease or ischemic heart disease and eleven subjects without known cardiac conditions (age 45 ± 16, male gender 77%) and 11 subjects without known cardiovascular disease (42%; age 42.1±14.4 years and 70% male). Because of technical problems, recordings for two subjects were not obtained post-infusion, for the final SCG data, 26 subjects were analyzed pre-infusion, and 24 subjects were analyzed for the post-infusion. Figure 1 visualizes the SCG waves pre and post fluid infusion for one subject with the fiducial points E_s (mitral valve closing), G_s (aortic valve opening), B_d (aortic valve closing) and F_d (mitral valve opening).

Table 1:
Seismocardiogram measures before and after fluid infusion (n=26 pre fluid, n=24 post fluid)

	Amplitudes (g)						**Time intervals (ms)**					
	D_d	**C_d**	**E_d**	**G_s**	**L_s**	**C_d to D_d**	**B_d to F_d**	**B_d to E_d**	**E_s to G_s**	**E_s to L_s**	**G_s to B_d**	**L_s to B_d**
Pre fluid	3.10 (2.28-7.61)	-2.80 (-4.335--1.24)	-2.89 (-4.43--2.36)	5.83 (2.30-9.07)	2.61 (1.84-3.65)	6.02 (3.52-11.25)	89.80 (79.50-100.55)	42.80 (38.65-53.00)	35 (29.6-42.05)	140.50 (120.05-154.50)	315.90 (297.15-340)	210.40 (191.55 - 235.75)
Post fluid	3.95 (2.20-8.32)	-2.63 (-4.33--1.44)	-4.26 (-6.00--3.42)	6.13 (2.66-11.57)	3.10 (2.46-3.72)	6.79 (4.17-12.79)	80.80 (71.90-88.10)	43.20 (36.85-48.95)	33.60 (30.10-41.10)	121 (111.20-144.80)	330.50 (317.70-343.10)	243.40 (216.35 - 256.75)
Difference (pre-post) (%)	0.85 **(+27)**	0.17 **(-6)**	-1.37 **(+48)**	0.30 **(+5)**	0.49 **(+19)**	0.78 **(+13)**	-9 **(-10)**	0.40 **(+1)**	-1.40 **(-4)**	-19.50 **(-14)**	14.60 **(+5)**	33 **(+16)**
p	.016**	.391	.000**	.253	.015**	.287	.010**	.040**	.954	.001**	.000**	.000**

Table 1: Data from seismocardiography before (pre) and after (post) fluid infusion. **P < 0.01 and *P < 0.05. Data represents median and IQR. Differences are pre-post. **g** gravity **and ms** millisecond

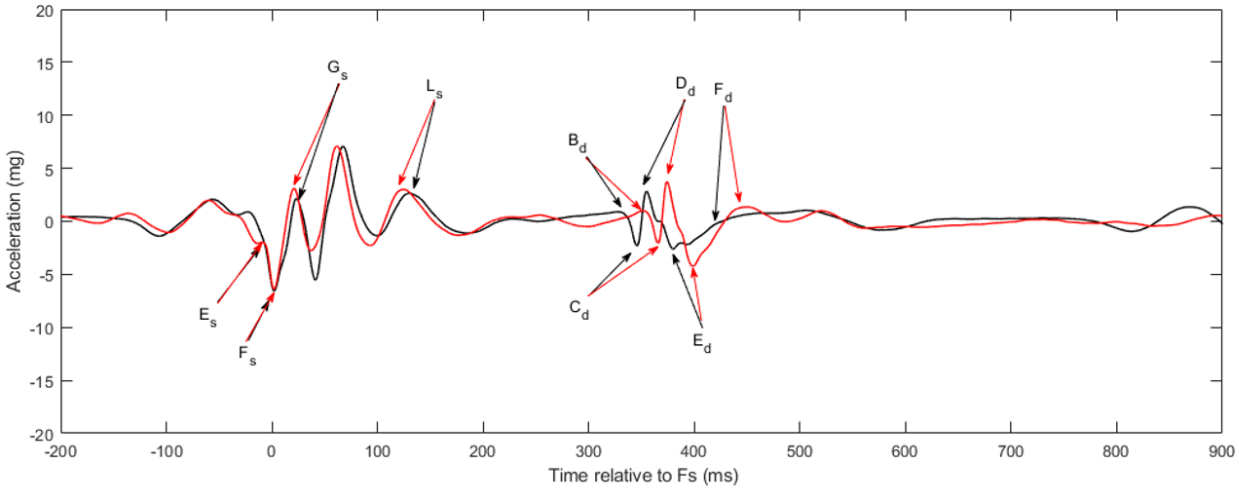

Figure 1: Demonstration of the SCG waves before (black) and after (red) fluid infusion for one subject with the fiducial points E_s (mitral valve closing), G_s (aortic valve opening), B_d (aortic valve closing) and F_d (mitral valve opening). **mg** milligravity, **ms** millisecond

4. Discussion

The SCG showed a significant difference in the diastolic SCG amplitudes D_d, E_d and the systolic SCG amplitude L_s, the diastolic time intervals B_d to F_d and B_d to E_d and the systolic time intervals E_s to L_s and L_s to B_d when comparing pre fluid and post fluid (Table 1). The diastolic and systolic SCG amplitudes increased after fluid infusion, in contrast to the diastolic and systolic time intervals who decreased. These results indicates that SCG has the potential to detect a difference when the preload increased. This may indicate that the SCG has the potential to be used in a clinical setting, to detect preload alterations, for example early signs of decompensated heart failure. The subjects had differences in BMI; thus, the amount of infused fluid has different impact depending on the body size. In the study by *Agam et al. [1]* the SCG was also used to detect significant differences in preload alterations using the mechanism of tilting the subjects instead of fluid infusion [1]. The results from that study indicated that only the amplitude E_d changed significantly during preload alterations, thus indicating that the SCG to a lesser extent were able to detect preload differences. The findings in this study differs from the previous study and demonstrates a significant effect of preload augmentation in both amplitudes and time intervals, when compared to the findings in the study from *Agam et al* [1]. The differences in the mechanism of inducing preload augmentation may also explain the differences between the previous study (REF Agam et al) and this study. The findings in this study are however in accordance with the results from the study by *Hasan Shandi et al. [4]* that demonstrated that SCG timing correlated well with preload alterations. Thus, furtherly confirming that SCG measures are sensitive to preload alterations [11]. The results found in this study indicates that the SCG is sensitive to increase in preload which could be utilized in clinical practice, since an increase in preload is seen in serval conditions such as decompensated heart failure and kidney failure with impaired urine production. Therefore, the SCG could potentially be used to monitor patients with pathological conditions in clinical practice [8].

5. Conclusion

The measurements obtained using SCG detects significant differences in heart movements during augmentation of preload by infusion of isotonic saline. Thus, SCG has the potential to be used in a clinical setting to detect signs of increased preload, such as decompensated heart failure.

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