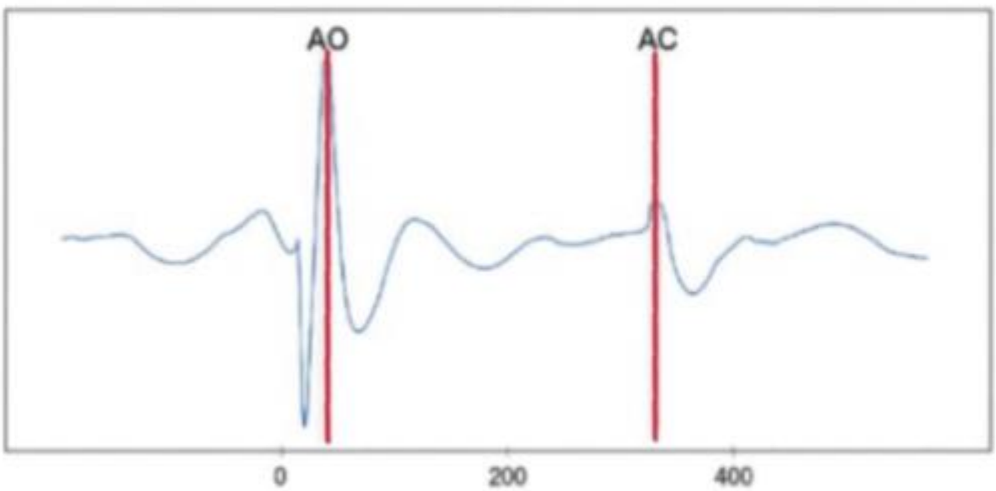
Long-Term Continuous Monitoring of Signal Quality and LVET: Analysis of 24-Hour Period Variations

Master's Thesis in Clinical Science and Technology



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Reading guide:

This article is organized as follows: The introduction outlines the background and rationale for the study, followed by a methods section describing the data collection and analysis procedures. The results section presents key findings, while the discussion interprets these in relation to existing literature. The article ends with a conclusion of the key findings.

The article is accompanied by a supplementary worksheet to support transparency and enhance understanding. The worksheet provides additional details and clarifications regarding the introduction and methods. Readers are encouraged to use the worksheet if any parts of the main text within the background or methodological sections require further explanation.

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Abstract:

Background: Heart failure (HF) is a major public health challenge and a leading cause of hospitalization, particularly among the elderly. Telemedicine is a promising solution to alleviate the burden of HF. Additionally, limited research exists on the feasibility and signal quality of long-term recordings conducted in real-world, non-controlled environments, especially when using wearable technologies. This study aims to evaluate SCG signal quality and LVET variations recorded by the eMech sensor in real-world settings.

Methods: Five healthy adults wore the eMech sensor to collect Seismocardiography (SCG) signals during real-world settings. A total of 150 signals per participant were targeted to represent full 24-hour period. Signal quality was manually assessed, and LVET was annotated. Time of day differences in signal quality were tested with Friedman and Wilcoxon signed-rank tests. LVET variability across day, evening, and night was analyzed using repeated measures ANOVA.

Results: SCG signal quality varies by time of day. The highest proportion of good-quality signals appears to be recorded during the night, while a greater proportion of medium and poor quality signals are more commonly recorded during the day and evening. LVET was significantly longer at night (306.8ms) compared to the evening (269.5ms), while no significant differences were found between day and evening or between day and night.

Conclusion: The study demonstrates that SCG signals can be reliably extracted in real-world settings. The quality assessment found that the recordings during the night appear to have the highest proportion of high quality signals. Additionally, the identified circadian variation in LVET across a 24-hour period highlights the importance of considering time of day variation when analyzing cardiac parameters.

Introduction: Heart failure (HF) is a major public health challenge. Worldwide, the number of HF patients is estimated to be around 26 million people (1). It's a leading cause of hospitalization, particularly among the elderly. Heart failure patients admitted to the hospital experience high event rates, with 10–15% dying and 30–40% rehospitalized within six months after discharge (1,3). Heart failure patients are often advised to monitor their condition at home using clinical parameters such as weight, blood pressure, and heart rate (3). While these measurements are widely accessible, research suggests that they may not reliably detect early hemodynamic changes. Advanced technologies, including implantable sensors, have been shown to identify fluctuations in cardiac pressures significantly earlier than conventional monitoring methods (3–6). In addition to basic monitoring, invasive technologies like CardioMEMS can detect worsening in HF weeks before symptoms appear (7). However, Studies by Chaudhry et al. demonstrate a lack of significant benefits of short-term telemonitoring, indicating that both the duration and modality of monitoring may play a crucial role in achieving clinically meaningful outcomes. (6). This is supported through a meta-analysis by Umeh et al., where the researchers found that prolonged monitoring (≥12 months) was associated with a significant reduction in both mortality and hospitalizations (8). In contrast, short-term interventions demonstrated a limited benefit. Notably, the monitoring of the patients in the study was not continuous during the whole day (8). Furthermore, limitations of short-term recordings are highlighted by Liberman et al. and Bieganowski et al., who emphasize that 24-hour Holter monitoring may fail to capture clinically relevant events (9).

In this context, Telemedicine is a promising solution to alleviate the burden of HF (2,10). Beyond basic remote monitoring, newer wearable technologies, such as seismocardiography (SCG) provide a noninvasive approach to estimating cardiac function. Seismocardiography has demonstrated the ability to extract clinically relevant parameters, such as Left Ventricular Ejection Time (LVET). A study by Di Rienzo et al. demonstrated that wearable SCG could estimate LVET intervals on a beat-to-beat basis in an ambulant setting, which revealed physiological changes influenced by autonomic modulation. However, this study was limited to a single subject and did not explore how these cardiac time intervals might vary throughout a 24-hour period, limiting its generalisability (11).

Additionally, there is limited research on the feasibility and signal quality of long-term SCG recordings conducted in real-world, non-controlled environments (8,9,12).

A major challenge in signals conducted in the real-world is noise contamination, many factors can impact the reliability of the recorded signals (9,13,14).

Study aim: The aim of the study is to evaluate the quality of SCG signals captured by the eMech sensor over a full 24-hour period and to determine the feasibility of reliably extracting LVET from these recordings. The study also examines time of day patterns in signal quality and LVET variability. This study represents an initial exploration into the potential of long-term noninvasive cardiac monitoring.

Methods:

Seismic Heart: The Seismic Heart project is a collaborative research between Aalborg University, Aalborg University Hospital, and Herlev-Gentofte Hospital, focusing on patients with HF. The primary objective is to develop algorithms capable of predicting clinical decline in HF patients based on the SCG and ECG data, and thereby enabling timely interventions and potentially reducing hospital admissions. This study is a pilot study within the Seismic Heart project, and contributes to the project by testing continuous SCG monitoring with the eMech sensor in real-world settings, exploring the potential of wearable SCG technology for long-term cardiac monitoring.

Population and Ethical Considerations: The participant group consisted of five subjects, either working or studying at Aalborg University. Inclusion criteria were ≥18 years, no relevant medical conditions, and the ability to wear the sensor for five days. Exclusion criteria included known arrhythmias, pacemaker, diagnosed movement disorder, or incomplete data collection. The aim was to collect a dataset and gain insights into signal patterns acquired in real-world settings using the eMech sensor. Participants were recruited among staff and students at the university department. Furthermore, the study was conducted following the principles of the Declaration of Helsinki and applicable national regulations. Written informed consent was obtained from all participants before inclusion (15). The study involved minimal risk to participants. Some could experience skin irritation or allergic reactions from the adhesive patch used to mount the sensor, although the patch was medically approved. Any unforeseen risks were documented accordingly.

Data Collection: Data was collected using the eMech sensor, consisting of a sensor with an accelerometer, microprocessor, ECG amplifier (MAX30003), and a battery, all in a small 3D-printed enclosure (50x20x5 mm). The device was attached using a medical-grade adhesive patch at the xiphoid process to optimize both SCG and ECG recordings, but only SCG recordings were included in this study. The eMech sensor served as the primary recording device, while a smartphone initiated recordings every 30 minutes and transferred data via Bluetooth to cloud storage. The transfer takes anywhere from a few seconds up to a minute. Each sensor and smartphone were uniquely identifiable for traceability. The recordings were not visible to participants and were not used for diagnostic purposes. Image 1 below visualizes the eMech sensor.

Image 1: Visualization of the eMech sensor and placement.

Included data:

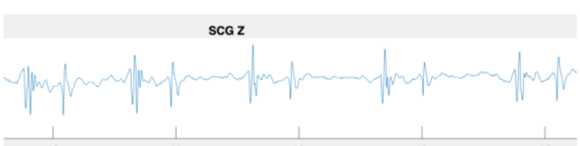
In the study, the aim was to collect data representing a full 24-hour period, which was the reason for collecting 150 signals from each participant. The estimated period of wearing the sensor to collect 150 signals was approximately five days. It was not expected that all scheduled recordings would be successfully captured. The reason for this is that the recording process relies on the smartphone, connected to the sensor, to be within Bluetooth range and active during scheduled measurements. In practice, the smartphone may enter sleep mode or be located out of range, which can interrupt data collection.

Quality Assessment: Signal quality was evaluated with a color-coded scale: blue (1) indicated high quality signals with ≥ 90% of the fiducial points clearly identifiable with minimal noise. Red (2) indicated medium quality signals. Between 50–89% of the fiducial points could be identified, with moderate noise. Orange (3) indicated signals of poor quality, where fewer than 50% of fiducial points could be identified. These signals typically contained high levels of noise and lacked clearly identifiable fiducial points, or were otherwise unsuitable for analysis. The specific criteria are presented in Table 1.

Classification	Description
Blue (1)	≥ 90% of fiducial points are clearly identified. Signal quality is evaluated as high, with no to minimal noise.
Red (2)	Between 50–89% of fiducial points can be identified, but there is moderate noise.
Orange (3)	< 50% of the fiducial points can be identified. The signal either contains a lot of noise or may occasionally show a flat line, indicating the signal is not being collected corretly.

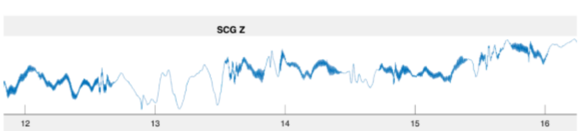
Table 1: Classification of signal quality

The quality of the signals was manually evaluated using a tailored MATLAB GUI. This allowed for simultaneous visual inspection of the ECG signal along with the SCG signals (X, Y, and Z axes). Since the Z-axis in the SCG signal is commonly used in SCG analysis, it became the primary focus for further analysis (12).



Signal rated with best possible quality - 1.

Signal rated with medium quality - 2.



Signal rated with lowest quality - 3.

Figure 1: Example of SCG signal quality classification.

Quality Ratings and Annotated Signals:

After quality evaluation, all available signals were manually annotated using a MATLAB GUI. The GUI was developed specifically for identifying fiducial points. The signals were segmented using a Markov Model as part of the annotation tool, as described in a study by Ahmad et al. (16). The annotation tool operated independently of the quality assessment. The fiducial points: aorta opening (AO) and aorta closure (AC), were identified and annotated manually along the Z-axis.

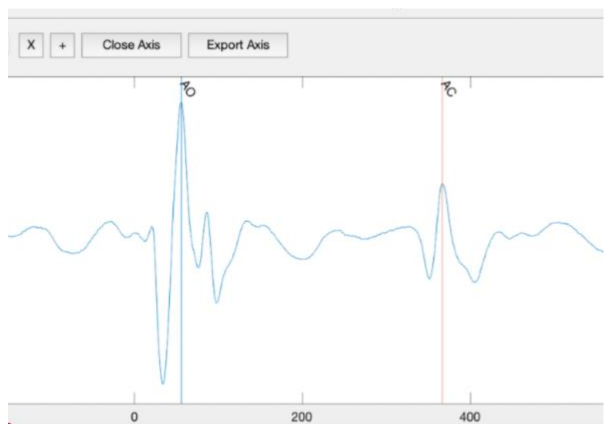


Figure 2: Example SCG signal with annotation

The quality evaluation and annotation were performed by the research team. Prior to annotation, the team agreed on general guidelines for identifying fiducial points to promote consistency. Afterwards, the subjects were divided among the research team for annotation. This approach was applied due to the group size of the research team and time constraints. Any uncertainties were discussed in the research team to maintain reliability. Importantly, the annotator did not have access to the previously assigned quality classifications during the annotation, ensuring that the annotation process remained unbiased. Although the main purpose of this setup was to identify LVET, it also provided an opportunity for an indirect evaluation of the initial signal quality ratings.

Statistical analysis:

Descriptive analysis: A descriptive statistical analysis was conducted to provide an overview of the dataset and illustrate the distribution of annotated signals and the quality rated signal. For each category (1 = good, 2 = medium, 3 = poor), the number of signals and proportion of annotated data were calculated. In addition, a summary table was created presenting the total number of evaluations for quality and annotated data for each of the three quality categories, along with the corresponding annotation percentages. This type of analysis was selected to provide a clear and structured description of the data.

Friedman: To assess whether signal quality varied across the day, a repeated measures Friedman test was selected as the most appropriate method. This test was suitable when the assumption of normality was not met, which was assumed in this case, as the data was categorical and consisted of only three quality levels (1 = good, 2 = medium, 3 = poor) (17). The Friedman test evaluated whether there were any systematic differences in signal quality across three time blocks while accounting for within-subject variability (17).

To examine pairwise differences in signal quality between the three time blocks, a post-hoc comparison using the Wilcoxon signed-rank was considered an appropriate method, since the test was suitable for repeated measure designs with ordinal data (18).

A Bonferroni correction was applied to adjust the probability (p) values due to the risk of a Type 1 error. The risk of type 1 error was increased when making multiple statistical tests (19). These statistical analyses were performed in MATLAB.

ANOVA: To explore potential differences in LVET across different time periods, a One Way Repeated Measures ANOVA was considered the most valid approach. This test was appropriate for analyzing repeated measurements from the same subjects (20). To test if the data were normally distributed, a Shapiro-Wilk test was identified as the most fitting method. If the assumption of normality was not met, it was still possible to proceed by testing the assumption of homogeneity of variances (21). Given the homogeneity of variance, repeated measures ANOVA was used for the analysis (17).

Results:

Demographic data: Five participants, three men, two women, ended up being included in this study. Participants were aged between 26 and 49 years. Weight between 66 and 91 kg, and Height between 176 and 187 cm. All participants reported being physically active in their daily lives. Among the participants, two reported getting to bed early and getting up early, one reported going to bed late and getting up early. The last two participants reported irregular sleep patterns. Furthermore, all participants reported that their daily occupation was primarily sedentary. Four participants rated their overall health as really good, one rated it as average.

As a result of the missing transmission, one participant ended up wearing the sensor for eight days. The participant wearing the sensor for the shortest period was wearing the sensor for 3.4 days. The average period for the sensor to collect 150 signals was 4.8 days. The study ended up including a total of 750 signals.

Distribution of Quality Ratings and Annotated Signals: Table 2 presents the number of signals that were quality assessed in each of the three categories (1=good, 2=medium, 3=poor), as well as how many of these were annotated for the analysis of LVET. A total of 238 signals were assessed in category 1, of which 218 (91.6%) were annotated. In category 2, 283 signals were assessed, with 190 (67.1%) annotated. Finally, in category 3, 228 signals were assessed, and 75 (32.9%) of these were annotated.

Quality score	Evaluated for quality	Annotated	Percentage annotated
1 = good	238	218	91.6%
2 = Medium	283	190	67.1%
3 = Poor	228	75	32.9%

Table 2: Number of SCG segments evaluated for signal quality and the proportion annotated, grouped by quality score.

Results of quality: During the night (23-07), 219 (29.2%) recordings were obtained, day (07-15), 264 (35.3%) recordings, and evening (15-23), 266 (35.5%) recordings. Of the total recordings, 218 (31.7%) were classified as category 1 with the best score, 283 (37.7%) as category 2 with medium quality, and last 228 (30.4%) as category 3 with the lowest quality. In Table 3 below, the number of signals with good, medium, and poor quality in each of the time periods is shown.

Time period/ Quality rating	1=Good	2=Medium	3=Poor	Total
Day (07-15)	72	101	91	264
Evening (15-23)	56	99	111	266
Night (23-07)	110	83	26	219

Table 3: Distribution of SCG signal quality ratings across the three time periods.

The median quality score for the signal quality on the Z-axis varied across the time periods; the median score during the day was 2.17, evening 2.27, and night 1.55.

The Friedman test indicated a significant difference between the three time periods (*p = 0.04076*). The Wilcoxon signed-rank test of pairwise comparison did not reveal any significant differences between any of the groups after the Bonferroni correction (α=0.0167). The test found the following: Night vs Day *(p=0.125)*, Night vs Evening *(p=0.0625),* and last Day vs Evening *(p=0.125).*

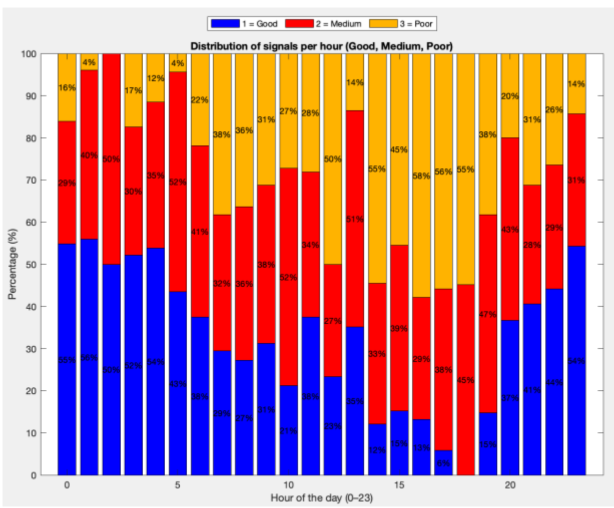


Figure 3: Hourly distribution of SCG signal quality over a full 24-hour period.

Figure 3 illustrates the hourly distribution of signal quality over a period of 24 hours in percentage. The results found a circadian pattern with the highest proportion of signals of good quality during the night, specifically between 11 pm and 5 am. During the daytime, there was an increase in medium and poor quality signals. The worst signal quality was at 5 and 6 pm. Signal quality improved slightly during the late evening hours, though it remained lower than during the night.

Results LVET: Table 4 presents the number of signals that were used to evaluate differences in LVET during the three time periods. A total of 509 signals were included. 164 signals recorded during the day 07-15, 148 signals recorded during the evening 15-23, and 197 signals recorded during the night 23-07.

Time period	Total amount of included Signals
Day 07-15	164
Evening 15-23	148
Night 23-07	197
Total	509

Table 4: Total number of SCG signals included in the evaluation of LVET.

Descriptive analysis found that mean LVET was 272.7ms *(SD=58.9)* during the day, 269.5ms *(SD=57.6)* in the evening, and 306.8ms *(SD=63.1)* at night. Figure 4 below presents a boxplot of LVET distribution during day, evening, and night. Each box represents the middle 50% of the data (interquartile range), with the red line indicating the median LVET value. The "whiskers" extend to show the range of values within 1.5 times the interquartile range from the lower and upper quartiles.

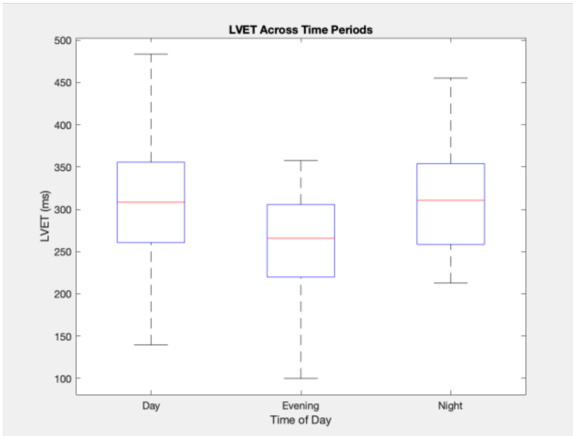


Figure 4: Boxplots showing LVET

To evaluate differences in LVET during the three time periods, the assumption of normality was first evaluated using the Shapiro-Wilk test. The results found that all three groups significantly deviated from a normal distribution *(p<0.001),* which indicated that the assumption of normality was not met. The homogeneity of variance was confirmed using Levene's test, as the results found no significant difference in variance between groups *(p=0.111)*, therefore, the assumption of variance was met.

Repeated measures ANOVA found a significant difference in LVET across the three time periods *(p=0.024)*, as 60.7% of the variation was explained by the measurement time. Results from Post-hoc pairwise comparisons using Bonferroni correction found a significant difference between evening and night *(p=0.009)*. The test found no significant differences between day and evening *(p=1.000)* or day and night *(p=0.133).*

Discussion:

This study reveals two key findings concerning the quality of SCG signals and the circadian variation in LVET across a 24-hour period.

Firstly, SCG signal quality varies by time of day. The highest proportion of good-quality signals appears to be recorded during the night, while a greater proportion of medium and poor quality signals are more commonly recorded during the day and evening. Evening hours, in particular, appear more likely to be affected by motion artifacts and noise, which may be due to increased physical activity, food intake, and pre-sleep routines (22). Although the Friedman test shows a statistically significant overall difference in signal quality across time periods, post hoc comparisons do not identify specific time intervals with significant differences. These findings may be influenced by inter-individual differences or the relatively small sample size. The results indicate the importance of accounting for time of day in both data collection and analysis. This aligns with a study by Sjöros et al., which examines how the timing and duration of data collection affect accelerometer-based activity and measurements. The study by Sjöros et al. highlights the importance of considering time of day, as behavioral patterns vary and different time periods may not be directly comparable (23).

Secondly, LVET shows a significant time of day dependency. Repeated measures ANOVA reveals that LVET is significantly longer during the night (306.8 ms) compared to the evening (269.5 ms), suggesting that ejection time is modulated by circadian physiological mechanisms. This aligns with known patterns of autonomic regulation, where parasympathetic activity increases during sleep, leading to a lower heart rate and a prolonged ejection time (22,24,25). The average nighttime LVET in this study exceeds reported normative values, 296 ± 22 ms for women and 286 ± 23 ms for men. This may further support the involvement of circadian mechanisms that influence cardiac function. These findings emphasize the importance of considering circadian variations when interpreting cardiac timing parameters such as LVET. Comparisons across different times of day without accounting for physiological context may lead to misleading conclusions (26). Similar observations have been reported by Bernardi et al., who emphasize the influence of circadian rhythms on cardiac function (26). Yamasaki et al. further support this by showing that LVET is a dynamic marker of physiological state, sensitive to changes such as sleep (22).

The results demonstrate that LVET can be reliably measured in non-controlled, real-world environments. This opens new possibilities for long-term, continuous cardiac monitoring. Such findings are particularly relevant in the context of HF, where early detection and ongoing assessment are critical for improving patient outcomes. By showing that SCG-based measurements are feasible under real-world conditions, this study provides valuable insight that supports the continued development of technologies like the eMech sensor. As described in the methodology, the SeismicHeart project aims to create a system for continuous, non-invasive monitoring of cardiac function in HF patients using SCG and ECG signals. The results presented in this study support the goal by demonstrating the feasibility of SCG signal collection and LVET estimation in non-clinical settings.

Study limitations: In this study, all participants are healthy individuals without medical conditions that interfere with data collection. This ensures that the signals do not compromise any underlying disease. However, healthy individuals may be more physically active than HF patients, which could increase the risk of motion artefacts. Therefore, the findings should be interpreted with caution, as they may not be directly transferable to HF patients, who are often less active.

Even though all signals are filtered and rated for quality, some signals can be affected by motion artifacts. The raw signals are processed using a high-pass filter with a cutoff frequency of 1 Hz and a low-pass filter with a cutoff frequency of 100 Hz. Additionally, the Markov Algorithm uses the S1 peak to calculate an average across all beats, which allows noise components to be identified and effectively removed from the signal.

The study only includes five subjects, which can reduce the generalizability of the findings and limit the statistical power, which increases the risk of bias and reduces the robustness of the conclusion (27,28).

Further investigations: Further studies can explore how activity level, body position, and sleep stage may influence signal quality and LVET.

Conclusion:

This study demonstrates that SCG signals can be reliably extracted in real-world settings, supporting the feasibility and the potential for continuous, non-invasive cardiac monitoring outside controlled environments. Quality assessment found that the recordings during the night appear to have the highest proportion of high quality signals. Additionally, the observed circadian variation in LVET across a 24-hour period highlights the importance of considering time of day variation when analyzing cardiac parameters. This emphasizes the importance of considering circadian variations in cardiac monitoring.

Literature:

1. Mesquita ET, Jorge AJL, Rabelo LM, Souza Jr. CV. Understanding Hospitalization in Patients with Heart Failure. International Journal of Cardiovascular Sciences [Internet]. 2016 [cited 2025 May 10]; Available from: http://www.onlineijcs.org/sumario/30/pdf/en_v30n1a10.pdf

2. Telemedicin til mennesker med hjertesvigt: anbefalinger til målgruppe, sundhedsfagligt indhold, ansvar og samarbejde. Version: 1. Sundhedsstyrelsen; 2020.

3. Adamson PB. Pathophysiology of the transition from chronic compensated and acute decompensated heart failure: New insights from continuous monitoring devices. Curr Heart Fail Rep. 2009 Dec;6(4):287–92.

4. McDonagh TA, Metra M, Adamo M, Gardner RS, Baumbach A, Böhm M, et al. 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: Developed by the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC) With the special contribution of the Heart Failure Association (HFA) of the ESC. European Heart Journal. 2021 Sep 21;42(36):3599–726.

5. Remote monitoring reduces heart failure hospitalisations and improves quality of life [Internet]. [cited 2024 Oct 7]. Available from: https://www.escardio.org/The-ESC/Press-Office/Press-releases/Remote-monitoring-reduces-heart-failure-hospitalisations-and-improves-quality-of-life

6. Chaudhry SI, Mattera JA, Curtis JP, Spertus JA, Herrin J, Lin Z, et al. Telemonitoring in Patients with Heart Failure. New England Journal of Medicine. 2010 Dec 9;363(24):2301–9.

7. Azari S, Mousavi SH, Markazi Moghaddam N, Rezapour A, Zargar Balaye Jame S, Kolivand P, et al. Cost-Effectiveness of Remote Cardiac Monitoring With the CardioMEMS Heart Failure System: A Systematic Review. Med J Islam Republ Iran [Internet]. 2023 Mar 30 [cited 2025 Mar 3]; Available from: https://mjiri.iums.ac.ir/article-1-8409-en.html

8. Umeh CA, Torbela A, Saigal S, Kaur H, Kazourra S, Gupta R, et al. Telemonitoring in heart failure patients: Systematic review and meta-analysis of randomized controlled trials. World J Cardiol. 2022 Dec 26;14(12):640–56.

9. Liberman L, Liberman N, Silver ES. Cardiac monitoring: is longer better? Kardiol Pol. 2021 Feb 25;79(2):110–1.

10. Urbich M, Globe G, Pantiri K, Heisen M, Bennison C, Wirtz HS, et al. A Systematic Review of Medical Costs Associated with Heart Failure in the USA (2014–2020). PharmacoEconomics. 2020 Nov;38(11):1219–36.

11. Di Rienzo M, Vaini E, Castiglioni P, Meriggi P, Rizzo F. Beat-to-beat estimation of LVET and QS2 indices of cardiac mechanics from wearable seismocardiography in ambulant subjects. In: 2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) [Internet]. Osaka: IEEE; 2013 [cited 2025 Mar 3]. p. 7017–20. Available from: http://ieeexplore.ieee.org/document/6611173/

12. Das M, Choudhary T, Sharma LN, Bhuyan MK. Analyzing SCG methodology for identification of ventricular depolarization events. Biomedical Signal Processing and Control. 2025 Feb 1;100:106940.

13. Zakeri V, Tavakolian K, Blaber AP, Dehkordi P, Khosrow-khavar F. Estimation of systolic time intervals among healthy subjects using cardiac electromechanical signals: a repeatability study.

14. Schmidt SE, Toft E, Holst-Hansen C, Struijk JJ. Noise and the detection of coronary artery disease with an electronic stethoscope. In: 2010 5th Cairo International Biomedical Engineering Conference [Internet]. Cairo: IEEE; 2010 [cited 2025 Mar 11]. p. 53–6. Available from: http://ieeexplore.ieee.org/document/5716077/

15. Hostrup MCF, Sofie Nielsen A, Sørensen FE, Kragballe JO, Østergaard MU, Korsgaard E, et al. Accelerometer-based estimation of respiratory rate using principal component analysis and autocorrelation. Physiol Meas. 2025 Mar;46(3):035005.

16. Agam A, Søgaard P, Kragholm K, Jensen AS, Sørensen K, Hansen J, et al. Correlation between diastolic seismocardiography variables and echocardiography variables. European Heart Journal - Digital Health. 2022 Oct 3;3(3):465–72.

17. Kim HY. Statistical notes for clinical researchers: Nonparametric statistical methods: 2. Nonparametric methods for comparing three or more groups and repeated measures. Restor Dent Endod. 2014 Nov;39(4):329–32.

18. Kim HY. Statistical notes for clinical researchers: Nonparametric statistical methods: 1. Nonparametric methods for comparing two groups. Restor Dent Endod. 2014 Aug;39(3):235–9.

19. Armstrong RA. When to use the Bonferroni correction. Ophthalmic and Physiological Optics. 2014;34(5):502–8.

20. Muhammad LN. Guidelines for repeated measures statistical analysis approaches with basic science research considerations. J Clin Invest. 133(11):e171058.

21. Kim TK. Understanding one-way ANOVA using conceptual figures. Korean J Anesthesiol. 2017 Feb;70(1):22–6.

22. Yamazaki EM, Rosendahl-Garcia KM, Casale CE, MacMullen LE, Ecker AJ, Kirkpatrick JN, et al. Left Ventricular Ejection Time Measured by Echocardiography Differentiates Neurobehavioral Resilience and Vulnerability to Sleep Loss and Stress. Front Physiol. 2022 Jan 11;12:795321.

23. Sjöros T, Vähä-Ypyä H, Laine S, Garthwaite T, Löyttyniemi E, Sievänen H, et al. Influence of the Duration and Timing of Data Collection on Accelerometer-Measured Physical Activity, Sedentary Time and Associated Insulin Resistance. IJERPH. 2021 May 6;18(9):4950.

24. Di Rienzo M, Vaini E, Castiglioni P, Merati G, Meriggi P, Parati G, et al. Wearable seismocardiography: towards a beat-by-beat assessment of cardiac mechanics in ambulant subjects. Auton Neurosci. 2013 Nov;178(1–2):50–9.

25. Di Rienzo M, Vaini E, Castiglioni P, Lombardi P, Parati G, Lombardi C, et al. Wearable seismocardiography for the beat-to-beat assessment of cardiac intervals during sleep. Annu Int Conf IEEE Eng Med Biol Soc. 2014;2014:6089–91.

26. Bernardi J, Aromolaran KA, Zhu H, Aromolaran AS. Circadian Mechanisms: Cardiac Ion Channel Remodeling and Arrhythmias. Front Physiol. 2021 Jan 14;11:611860.

27. Alhakak AS, Teerlink JR, Lindenfeld J, Böhm M, Rosano GMC, Biering-Sørensen T. The significance of left ventricular ejection time in heart failure with reduced ejection fraction. Eur J Heart Fail. 2021 Apr;23(4):541–51.

28. Alhakak AS, Olsen FJ, Skaarup KG, Lassen MCH, Johansen ND, Jørgensen PG, et al. Age- and sex-based normal reference ranges of the cardiac time intervals: the Copenhagen City Heart Study. Clin Res Cardiol. 2025 Apr;114(4):430–42.

Worksheet:

Indholdsfortegnelse

1.0 Introduktion:

Patienter med hjertesvigt fylder meget i sundhedsvæsenet, både i Danmark og USA. Ifølge en rapport fra 2020 fra Sundhedsstyrelsen, levede der på daværende tidspunkt 62.000 mennesker med hjertesvigt i Danmark, endvidere viste rapporten at man estimerede med ca. 12.000 nye tilfælde af hjertesvigt årligt. Grundet den demografiske udvikling, hvor befolkningen bliver ældre, forventes det at antallet af hjertesvigtspatienter vil stige i fremtiden (1). I Usa er byrden af hjertesvigt også stor, i et studie af Urbich M. et. al. blev det anslået at omkring 6,9 millioner amerikaner levede med hjertesvigt i 2020, de samlede omkostninger blev estimeret til at ligge på $42.6 milliarder. Endvidere forventes det, at omkostninger vil stige til $69,7 milliarder, såfremt der ikke sker forbedringer i behandlingen af hjertesvigtspatienterne (2). Hospitalsindlæggelse er den største omkostning, som alene udgjorde $15.879 per Patient (2).

Anvendelsen af telemedicin kan hjælpe med at reducere byrden på sundhedsvæsenet. Monitorering af patienter i eget hjem, hvor der opsamles data der kan anvendes til at følge udviklingen i patientens sygdom, kan potentielt reducere antallet af akutte indlæggelser af hjertesvigtspatienter (1,2). Hjemmemonitorering af hjertesvigtpatienter har et stort potentiale for implementering og kan skabe skalerbare løsninger, både på et nationalt og globalt plan. Endvidere forventes det at kunne gavne både på det individuelle plan, men også på det samfundsmæssige plan (1,2).

Der er foretaget meget forskning inden for det telemedicinske område, specifikt med henblik på hjertesvigtspatienter. I et studie af Umeh A. et al., blev 38 randomiserede kontrollerede forsøg analyseret, forsøgene omhandlede hvorvidt hjemmemonitorering kunne forbedre hjertesvigts patienternes prognose, der var ialt 14.993 hjertesvigtpatienter inkluderet i forsøgene (3). Studiet viste at langvarig monitorering, mindst 12 måneder, viste markant forbedring i både dødelighed og antallet af indlæggelser, men at monitorering over korte perioder ikke viste den samme effekt. Resultaterne fra dette studie er med til at understøtte hvordan hjemmemonitorering kan forbedre behandlingen og samtidig aflaste sundhedsvæsenet (3). I Nordjylland i Danmark, findes en telemedicinsk ordning som hedder TeleCare Nord, her får hjertesvigtspatienter udleveret en tablet, en vægt og et blodtryksapparat. Patienterne sender data til sundhedsfagligt personale via. tabletten, hvilket er med til at understøtte den medicinske behandling af patienten og kan medføre tidlig opsporing af forværringer i patientens sygdomstilstand (1).

1.1 Videnshuller:

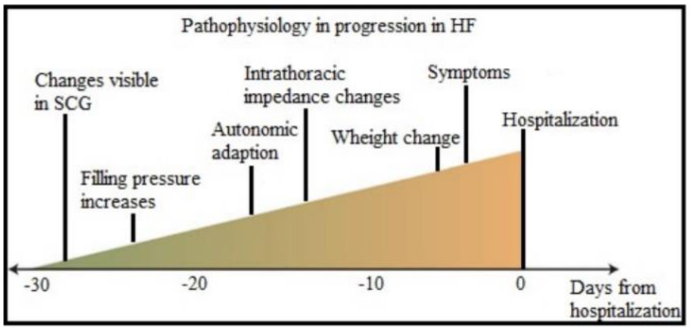
Et studie af Liberman L et. al viser potentialet for monitorering af hjertepatienter over længere perioder, studiet viser, at længere optagelser forbedrer detektionsraten og øger sandsynligheden for at opfange f.eks. Arytmier, som kan blive overset ved kortere monitoreringsperioder (4). Resultaterne i artiklen understøttes af et multicenterstudie af Bieganowski et al., i studiet blev det undersøgt hvorvidt længere monitorings perioder identificerede flere udslag fra hjertet, studiet kom frem til, at den ene gruppe der blev monitoreret over længere tid havde 44% af forsøgspersonerne i gruppen udslag, hvor kun 12% af forsøgspersonerne i den anden gruppe havde udslag når de blev monitoreret i 24 timer. Endvidere viste studiet, at 24-timers monitoring kan give misvisende resultater. Studiet af Liberman L et at., understøtter at længerevarende monitorering er mere pålidelig end kortvarig, men der er fortsat et behov for yderligere forskning inden for området (4).

I et studiet af Zakeri V et., påpeges et videnshul i præcisionen og påligeligheden af SCG optagelser foretaget uden for kontrollerede forhold. Studiet understreger, at optagelser fra normale dagligdags aktiviteter er utilstrækkeligt undersøgt. Dette understøtter relevansen i, at undersøge seismokardiografi (SCG) og elektrokardiogram (EKG) signalernes kvalitet, for at kunne foretage hjemmemonitorering af hjertesvigtspatienter, som afspejler en normal hverdag.

Overordnet støtter begge artikler op omkring behovet for yderligere forskning, af SCG og EKG optagelser uden for laboratorie setting, samt optagelser der er foretaget uden for kontrollerede forhold. Artiklerne i fællesskab understreger vigtigheden i at undersøge SCG optagelser i dagligdagen, under mindre kontrollerede forhold. Endvidere indikerer artiklerne at målinger over længere perioder kan hjælpe med at give en mere pålidelig indsigt i hjertets funktion.

1.2 Seismic heart:

Seismic Heart er et nyt projekt som foregår i et samarbejde mellem Aalborg Universitet, Aalborg Universitetshospital og Herlev-Gentofte Universitetshospital. Formålet med projektet er at undersøge ændringer i hjertets tilstand hos hjertesvigtspatienter ud fra SCG og EKG signaler. Signalerne bliver optaget hver halve time i 30 sekunder hen over 30 dage. Håbet med projektet er, at man ud fra signalerne kan skabe algoritmer der kan forudsige forværringer i hjertesvigtets patienternes tilstand, hvilket potentielt på sigt kan medføre færre indlægger og bedre livskvalitet for patienterne.



Figur 1 - Fra protokollen til seismic heart projektet.

Ovenstående figur er taget fra protokollen til Seismic Heart. Figuren illustrerer den patofysiologiske progression af hjertesvigt over tid, fra de tidligere ændringer og frem til hvornår hospitalsindlæggelse er nødvendigt. X-aksen viser dage før hospitalsindlæggelser og Y-aksen repræsenterer udviklingen af fysiologiske forandringer i kroppen. 30 dage inden hospitalsindlæggelse vil de første fysiologiske ændringer kunne ses på SCG signaler, ændringerne i SCG signalerne kan være et tegn på begyndende hæmodynamiske ændringer, men patienterne vil oftest ikke selv have mærkbare symptomer her.

Såfremt SCG optagelserne fra Seismic Heart projektet har tilstrækkelig kvalitet, kan SCG potentialet være med til at opspore tidlige ændringer i hjertesvigts patienternes tilstand, hvilket kan medføre at klinikere har mulighed for at foretage ændringer i patientens behandling, hvilket kan hjælpe på symptomer, nedsætte antallet af hospitalsindlæggelser og potentielt øge overlevelsesraten.

1.3 Prævalens og incidens:

På verdensplan er prævalensen af hjertesvigt estimeret til at være omkring 64 million mennesker. Der ses en stigning i prævalensen af hjertesvigt, selvom der er forbedrede kliniske muligheder for at behandle akutte hjerteproblemer, der kan føre til hjertesvigt. En af årsagerne til den stigende prævalens er, at befolkningen bliver ældre (5).

Incidensen af hjertesvigt i Danmark ligger på 1-1,5 pr. 1000 pr. År. Prævalensen af hjertesvigt er på omkring 1,5-2%, hvor ca. 1% af tilfældene skyldes reduceret funktion af venstre ventrikel. Ca. 5% over 75 år har hjertesvigt og det er estimeret til at omkring 10% over 85 år har hjertesvigt (7).

Dette indikerer, at der kan forventes en stigning i antallet af hjertesvigtspatienter i fremtiden, da befolkningen bliver ældre (6).
Iskæmiske hjertesygdomme er førende dødsårsag på globalt plan, en tilstand som hjertesvigt er tæt forbundet med. Hjertesvigt udvikler sig ofte som en konsekvens af længerevarende iskæmisk hjertesygdom, hvor hjertemusklen svækkes efter gentagne episoder med reduceret blodforsyning. I 2019 døde omkring 17.9 millioner mennesker af en hjerte-kar-sygdom, det svarer til 32% af alle globale dødsfald i 2019 (7).

1.4 Ana/fys overordnet om hjertesvigt:

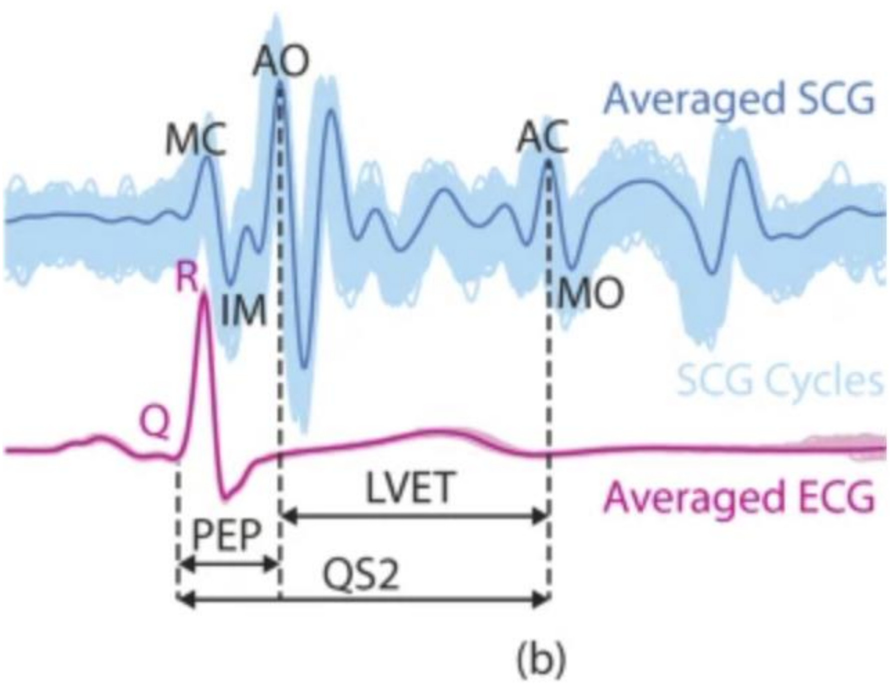
Hjertesvigt repræsenterer det kroniske stadie af flere sygdomme, som kan medføre nedsat hjertefunktion (8). Hjertesvigt opstår oftest som et resultat af flere samtidig faktorer. Komorbiditeter kan forekomme uafhængigt af hjertesvigt, men deler ofte samme risikofaktorer og kan bidrage til sygdomsprogressionen. Komorbiditeten kan være vedvarende bidragende faktor til forværring af hjertesvigt (8). Årsagen til hjertesvigt skyldes en kombination af kardiovaskulære risikofaktorer som hypertension, iskæmisk hjertesygdom, livsstilssygdomme samt socioøkonomiske faktorer (8).

Hjertesvigt er en kronisk tilstand, hvor hjertekamrene ikke er i stand til at pumpe tilstrækkelige mængder blod, for at opfylde kroppens behov (9). Som følge af den nedsatte pumpeevne påvirkes cirkulationen i kroppen, da denne bliver forringet og ikke kan opretholde tilstrækkelig ydeevne til kroppens behov for ilt og næringsstoffer. En utilstrækkelig ydeevne kan medføre kardielle symptomer i form af åndenød, træthed og væskeophobning. Hjertets evne til at pumpe tilstrækkelige mængder blod rundt afhænger af den systoliske og diastoliske funktion (9). Hjertesvigt kan opstå i flere former, symptomerne afhænger af hvilken form for hjertesvigt der er diagnosticeret (10). Dette inkluderer højre-, venstre- eller dobbeltsidigt, kronisk eller akut og systolisk eller diastolisk (10). Ved højresidigt hjertesvigt opstår symptomerne i form af væskeophobning, vægtøgning eller udspilet mave (11). Ved venstresidig hjertesvigt bliver venstre ventrikel svækket over tid, som medfører at væsken presses tilbage gennem lungerne og på sigt kan medføre skade på højre ventrikel. Her opstår symptomer i form af åndenød, som kan opleves ved anstrengelse eller liggende stilling (11). Kronisk hjertesvigt er en kombination af både venstre- og højresidigt hjertesvigt, hvor der ses nedsat systolisk og diastolisk funktion. Akut hjertesvigt opstår med ovenstående symptomer i løbet af kort tid, og derudover ses der generel kardiel dysfunktion, da hjertet har nedsat evne til at pumpe blodet rundt i kroppen. Akut hjertesvigt kan opstå grundet forværring af eksisterende hjerte-kar-problematikker eller grundet nye ikke kendte problematikker (11).

Hjertesvigt inddeles i tre forskellige grupper ud fra ejection fraction (EF), heart failure with reduced ejection fraction (HFrEF) <40%, heart failure with midrange ejectionfraction (HFmrEF) 40-49% og heart failure with preserved ejection fraction (HFpEF) >50% (11). Derudover benyttes klassifikationssystemet New York Heart Association (NYHA) til at klassificere graden af hjertesvigt, for at kunne strukturere og planlægge behandlingen (11).

1.5 SCG-komplekset:

SCG-komplekset refererer til specifikke mønstre i SCG-signaler og forbindes med hjertets mekaniske bevægelser under både systolen og diastolen (12).



Figur 2, SCG og EKG signal, inklusiv LVET, PEP og QS2 (13)

I ovenstående figur ses en illustration er SCG komplekset, endvidere illustrerer figuren EKG komplekset.

Mitralklappens lukning (MC) er tæt forbundet med den isovolumetriske kontrakion (IM), som opstår når hjertet genererer tryk, men blodet endnu ikke er begyndt at forlade ventriklen gennem aorta. Aortaklappens åbning (AO) markerer starten på den venstre ventrikulære ejektionsfase (LVET), mens aortaklappens lukning (AC) angiver afslutningen af samme fase. Det sidste fiducial point er mitralklappens åbning (MO), som markerer starten på den ventrikulære fyldningsfase (14).

Forkortelse	Betegnelse/beskrivelse
MC	Lukning af mitralklappen
IM	Isovolumetriske sammtrækning
AO	Åbning af aortaklappen
AC	Lukning af aortaklappen
MO	Åbning af mitralklappen

Tabel 1: Forkortelser og beskrivelser af fiducial points.

1.6 Left Ventricular Ejection Time:

Left Ventricular Ejection Time er en væsentlig faktor i vurderingen af hjertets pumpefunktion (15). Det refererer til den tid, som venstre ventrikel bruger for at tømme sig under systolen, fra begyndelsen af den ventrikulære kontraktion til slutningen af ejektion-fasen. Dette kan anvendes til at vurdere hjertets systoliske funktion, og venstre ventrikels kontraktionsevne, samt hjertets generelle pumpefunktion (15). Både forlænget og forkortet LVET kan skyldes problemer med venstre ventrikels funktion, som opstår i form af nedsat kontraktion eller ændring i den vaskulære modstand. Left Ventricular Ejection Time er et interessant interval hos patienter med hjertesvigt, da det kan anvendes til at overvåge graden af hjertesvigt, samt evaluere effekten af behandlingen (15).

I klinisk praksis kan LVET anvendes til at få indsigt i hjertets mekaniske aktivitet, og bruges i sammenhænge til at analysere systoliske tidsintervaller (15). Det kan være relevant at inddrage LVET intervallet, da det bliver påvirket af preload og kan medføre ændringer i salgvolumen og den venøse fyldning, hvilket afspejler sig i målingerne. Et studie af S. Schmidt et al. bidrager til viden om preload ændringer ved hjælp af SCG, da det undersøger om SCG kan detektere en stigning i preload gennem intravenøs Nacl-infusion (16). Resultaterne viste, at efter infusionen blev der observeret signifikante stigninger i de diastoliske SCG-amplituder (27%) og i den systoliske amplitude (19%) (16). Dette indikerer, at SCG kan benyttes til at opdage ændringer i preload, hvilket gør LVET relevant at undersøge, da det kan give indsigt i hjertets pumpe- og fyldningsfunktion. I det følgende afsnit vil mekanismen bag preload i relation til LVET intervallet blive uddybet.

1.7 Frank-Starling mekanismen:

Hjertet er i stand til kontinuerligt at pumpe optimal blodmængde ud til kroppen og hurtigt justerer ud fra dynamiske ændringer i den hæmodynamiske load (17). Stræk i venstre ventrikels muskel fører til øget kontraktilitionskraft for at øge stroke volume, med dette menes at des mere hjertet bliver strukket, des stærkere vil kontraktionen af hjertemusklen under systolen være. Denne respons kaldes for Frank-Starling-mekanismen. Frank-Starling-mekanismen er forholdet mellem volumen af blod, som hjertet fyldes med og kraften som hjertet kontraherer med (17). Hjertets evne til at strække sig før en sammentrækning kaldes preload. Sker der ændringer i preload, kan det påvirke den ventrikulære slagvolumen. Øget preload medfører øget slagvolumen, hvor reduceret preload medfører reduktion i slagvolumen, dette skyldes at sammentrækningskraften ændrer sig (17). Preload kan påvirkes af flere faktorer, blandt andet tyngdekraften. Ved ændringer i kropspositionen f.eks. var liggende til stående, vil der ske en ændring i preload, dette skyldes ændringer i venetrykket og volumen i venstre ventrikel (17). Ved nedsat funktion af venstre ventrikel, vil der opstå en reducering i preload og hjertets kontraktilitetsevne. Dette kan medføre at hjertet ikke kan opretholde et tryk under hele LVET-perioden, et forkortet LVET kan indikere nedsat Left ventricular ejection fraction (LVEF) (17).

1.8 Accelerometerets anvendelse i SCG:

Et centralt element i seismokardiografi (SCG) er de tre akser i accelerometeret, som registrerer hjertets mekaniske bevægelser samt kroppens orientering i forhold til tyngdekraften. Accelerometeret måler acceleration i tre retninger: X-akse (longitudinal/hoved-fod), Y-akse (lateralt/side til side) og Z-akse (dorso-ventral/bryst til ryg) (12). Når kroppen er i hvile, vil tyngdekraften forårsage en konstant statisk acceleration på cirka 1g i den akse, der vender mod jordens centrum. Dette princip gør det muligt at estimere kroppens position (stående, siddende, liggende) ud fra, hvilken akse der registrerer den højeste statiske acceleration. For eksempel: Når en person står op, vil tyngdekraften typisk virke ned gennem X-aksen. Når en person ligger på ryggen, vil Z-aksen blive domineret af tyngdekraften. I sideliggende position vil Y-aksen vise størst påvirkning. Denne metode til vurdering af kropsposition anvendes blandt andet i studiet af Di Rienzo et al., hvor MagIC-SCG systemet benyttes til at analysere variationer i SCG signalerne i relation til testpersonernes kropsposition (12).

1.9 Støj:

Ved SCG optagelse over længere perioder på forsøgspersoner, der færdes i deres normale hverdag, er det vigtigt at være opmærksom på støj, der kan forekomme på signalerne. Støj kan påvirke nøjagtigheden og kvaliteten af de målte signaler (18). Støjen, som kan forekomme på SCG-signaler, kan stamme fra flere kilder. Dette kan gøre det vanskeligt at identificere hjertets mekaniske bevægelser præcist (19). I et studie af Schmidt S. et al. blev fire typer støj defineret herunder; omgivende støj fra patienter, sundhedspersonale og udstyr, optagelse støj fra friktion mellem hud og teknologien, respirations støj fra ind og udånding samt abdominal støj fra maven (19). For at afhjælpe problemet med støj på signalerne, kan filtre anvendes. Det er dog væsentligt at være opmærksom på, hvordan filtre kan ende med at påvirke signalet. For at sikre valide signaler, er det af denne grund vigtigt at være opmærksom på, at væsentlige dele af signalerne ikke bliver fjernet ved filtrering (20). Under længerevarende målinger, kan det være udfordrende at håndtere mulige støjpåvirkninger, hvilket skyldes kropsposition, aktivitet og omgivelser som ændrer sig over tid. Som beskrevet tidligere, så vil tyngdekraftens påvirkning af accelerometerets akser variere ift. om det er stående, siddende eller liggende position (21).

1.10 Monitorering af hjertesvigt:

Patienter der er diagnosticeret med hjertesvigt opfordres til at monitorere deres sygdom når de er hjemme, herunder deres vægt, samt andre symptomer der kan være relateret dertil, dette kan f.eks. være ændringer i vejrtrækningen (22). Hurtigt vægtøgning kan indikere akut ændring i hjertesvigt, hvilket er essentielt at reagere hurtigt på. Endvidere kan ændringer i blodtrykket også være et tegn på, at der er ændringer i deres sygdom (22). Ved hjemmebaseret monitorering af hjertesvigt anvendes ovenstående symptomer aktuelt som primære parametre til vurdering af sygdomspregression. (23). Mere avancerede teknologier såsom CardioMEMS, kan anvendes til hjemmemonitorering, med CardioMEMS monitoreres det intrakardielle og pulmonal arteriernes tryk. CardioMEMS kan assistere med væsentlig viden omkring hjertet fyldningstryk, ofte længe før patienterne selv opdager symptomerne (24).

Derudover anvendes regelmæssige blodprøver, herunder ProBNP til at overvåge hjertets arbejdsbyrde. ProBNP kan indikere, hvor meget pres hjertet arbejder under. Ved at overvåge disse parametre kan klinikere justere behandlingen af hjertesvigtpatienter, hvilket kan hjælpe med at undgå forværringer af sygdommen (25).

2.0 Metode:

2.1 Usystematisk litteratursøgning:

Den usystematiske søgning blev udarbejdet, for at indsamle relevant information om SCG og brugen heraf til vurdering af hjertets mekaniske funktion, specifikt ift. LVET. Ydermere blev der foretaget en usystematisk søgning i Google Scholar med følgende søgeord: ”SCG”, ”heart failure” og ”LVET”, dette blev gjort for at afdække information om lignende studier samt videnshuller. Desuden blev der udarbejdet en usystematisk søgning i Pubmed med samme søgeord som ovenstående. Til sidst blev AAU’s projektbibliotek anvendt for at identificere tidligere projekter, som var relateret til samme forskningsemne. Resultaterne af den ovenstående usystematiske litteratursøgning peger på, at der er begrænset forskning inden for langtidsmonitorering med SCG, herunder signalkvalitet under ukontrollerede forhold. Der blev identificeret et videnshul i hvordan hjertets cyklus ændrer sig over døgnet samt hvordan signal kvalitet påvirkes uden for kontrollerede forhold.

2.1.1 Oversigt over studier inkluderet fra den usystematiske søgning:

Artikler anvendt fra usystematisk litteratursøgning					
Artikler	**Anvendt tjekli**	**Formål**	**Metode**	**Deltagere**	**Resultater**

	ste				
Beat-to-beat estimation of LVET and QS2 indices of cardiac mechanics from wearable seismocardiography in ambulant subjects	Casp	Studiets formål er at validere og vurdere nøjagtigheden af beat-to-beat-estimering af venstre ventrikels ejektionstid (LVET) og QS2-intervallet ved hjælp af seismokardiografi (SCG) hos ambulante personer.	Validering Metode	En forsøgsperson	Studiet viste, at seismokardiografi (SCG) kan måle LVET og QS2 på et beat-to-beat-niveau, hvor resultaterne viste variationer og forskelle afhængigt af omgivelserne.
Wearable seismocardiography for the beat-to-beat assessment of cardiac intervals during sleep	Casp	Formålet er at vurdere, om man præcist kan estimere hjertets tidsmæssige parametre på et slag til slag niveau, under søvn.	Pilotstudie	En forsøgsperson.	Studiet kom frem til, at vejrtrækning påvirker hjertets tidsmæssige faser, såsom tiden mellem hjerteslag, tiden før hjertet begynder at pumpe blod, og varigheden af sammentrækninger, men ikke afslapnings tiden. Desuden blev variationen i tiden før hjertet begynder at pumpe blod reduceret med cirka 50 %, efter at tiden mellem hjerteslagene pludseligt steg.
Wearable seismocardiography: towards a beat-by-beat assessment of cardiac mechanics in	Casp	Formålet med studiet var at evaluere, om systemet kaldet MagIC-SCG, kunne måle hjertets mekaniske funktioner på et slag-for-slag-niveau hos personer i	Pilotstudie - Metoden omfattede to eksperimenter: I det første eksperiment bar seks raske forsøgspersoner systemet,	Studiet inkluderede syv forsøgspersoner ialt.	Resultaterne viste, at ændringer i kropsstilling påvirkede PEP og LVET som forventet, og at systemet kunne registrere beat-for-beat variationer i LVET under daglige aktiviteter, hvilket tyder på, at

ambulant subjects		bevægelse.	mens de skiftede mellem liggende og stående stilling, for at vurdere ændringer i PEP og LVET. I det andet eksperiment blev én person overvåget kontinuerligt i 12 timer under daglige aktiviteter for at vurdere LVET's variationer.		MagIC-SCG er en lovende metode til kontinuerlig overvågning af hjertets mekaniske funktioner.
Estimation of systolic time intervals among healthy subjects using cardiac electromechanical signals: a repeatability study	Casp	Formålet med dette studie er at undersøge gentagelsesnøjagtigheden af estimering af systoliske tidsintervaller (STI) hos raske personer ved hjælp af elektromekaniske hjertesignaler.	Valideringsstudie	21 raske forsøgspersoner	Resultaterne indikerede variation i de systoliske tidsintervaller (STI) målt ved hjælp af CV-værdier. Det kan konkluderes, at estimering af STI gennem elektromekaniske hjertesignaler kan gentages flere gange med mindre variation.

Tabel 2: Oversigt over inkluderet studier, herunder tjekliste anvendt til vurdering.

2.2 Systematisk litteratursøgning:

Pubmed blev udvalgt til at udføre den systematiske søgning, da den indeholder sundhedsvidenskabelige publikationer vedrørende sundhedsvidenskab og biomedicin (26).

Der blev udarbejdet en PICO, for at præcisere og strukturere søgningen til udvælgelsen af de inkluderede studier (27). Picoen bestod af fire blokke, som hver indeholdt synonymer til henholdsvis hjertesvigt, SCG og langtidsmonitorering. De relevante søgeord blev fundet gennem databasen Pubmed i forbindelse med den usystematiske søgning, hvor keywords fra de relevante artikler blev anvendt. Nedenstående tabel 3 viser PICO-modellen.

P(Population)	I(Intervenetion)	C(Context)	O(Outcome)
Cardiac Patients, Heart disease, Heart failure (HF), Healthy subjects, Adults, Elderly	Seismocardiopgrahy (SCG), electrocardiography (ECG), Cardiac time intervals (CTI), Pre-ejection period (PEP), Left ventricular ejection time (LVET), Electromechanical systole (QS2), Wearable sensors.	Long-term monitoring in daily life, home-based use, non-clinical environment	Early diagnosis, Non-invasive measurements, signal processing, fiducial points, Cardiac function assessment, Cardiac monitoring

Tabel 3: PICO-model

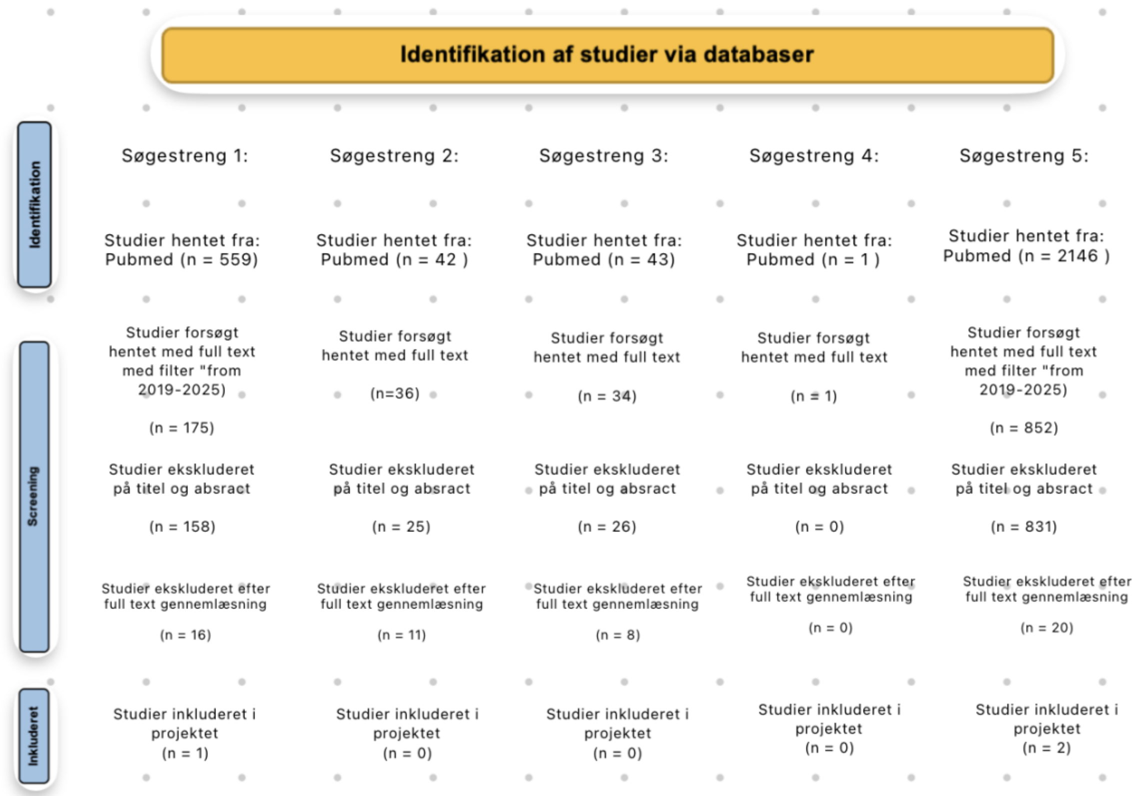
2.2.1 Oversigt over studier inkluderet fra den systematiske søgning:

Artikler anvendt fra systematisk litteratursøgning					
Artikler	**Anvendt tjekliste**	**Formål**	**Metode**	**Deltagere**	**Resultater**
Noise and the detection of coronary artery disease with an electronic stethoscope	Casp	Studiet undersøger, hvordan baggrundsstøj påvirker evnen til at detektere koronar hjertesygdom (CAD) ved hjælp af en elektronisk stetoskop. Forskningen fokuserer på udviklingen af en metode til automatisk segmentering af hjertelyde og ekstraktion af relevante akustiske træk, der kan indikere tilstedeværelsen af	Valideringsstudie	633 stethoscope recordings	Resultaterne viser, at selvom støj er en betydelig faktor, kan avancerede signalbehandlingsmetoder forbedre pålideligheden af CAD-detektion ved brug af elektroniske stetoskoper.

		CAD. En central udfordring i studiet er håndteringen af støj, såsom friktionslyde og omgivende baggrundsstøj, som kan forstyrre nøjagtigheden af diagnosen.			
Cost-Effectiveness of Remote Cardiac Monitoring With the CardioMEMS Heart Failure System	Casp	Vurdering af omkostningseffektiviteten af fjernovervågning af hjertepatienter ved hjælp af CardioMEMS, som bruges til at monitorere pulmonalarterietryk hos patienter med hjertesvigt.	Systematic review	5 artikler blev inkluderet i dette review	Resultaterne viste, at CardioMEMS system nedsatte antallet af dødligehed og hospitalsindlæggelser, samt at patienterne opleve mere quality of life. Endvidere kom studiet frem til, at CardioMEMS er omkostningseffektiv til at monitorere pulmunal arterie trykket hos hjertesvigtspatienter.
Cardiac monitoring: Is longer better?	Casp	Studiet undersøger anvendeligheden af langvarig EKG-monitorering i forhold til standard 24-timers Holter-monitorering til diagnosticering af rytmeforstyrrelser hos børn med hjertebanken.	Multicenter studie	Børn fra 13 forskellige pædiatriske kardiologiske afdelinger i Polen	studiet viser, at længere optagelser forbedre detektionsraten og øger sandsynligheden for at opfange f.eks. Arytmier, som kan blive overset ved kortere monitoreringsperioder

Tabel 4: Inkluderede studier fra systematisk søgning. herunder tjekliste anvendt til vurdering.

2.3 Flowchart:



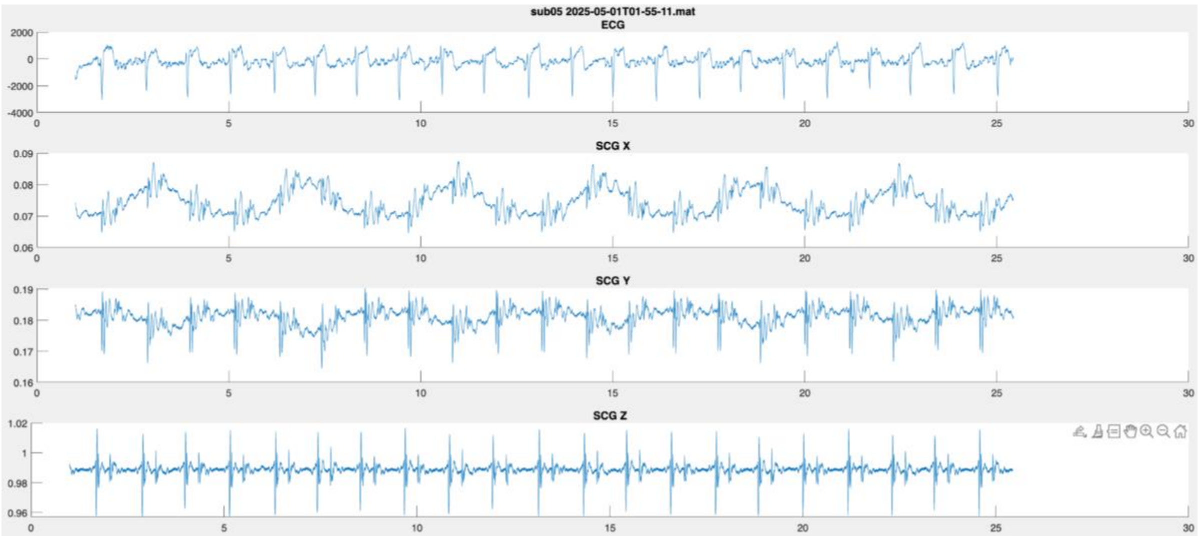
Tabel 5: Flowchart - identifikation af studier via databaser.

2.4 Signalbehandling:

Til den manuelle behandling af signalerne blev der anvendt to separate MATLAB GUI'er, der hver især var udviklet med specifikke funktioner: én til visuel vurdering af signalkvalitet og én til manuel annotering af fiducial points (28). GUI'erne fungerede uafhængigt af hinanden og blev anvendt i forskellige faser af analysen.

2.4.1 Kvalitetsbehandling:

Signalkvalitet blev vurderet manuelt ved hjælp af en GUI, der gjorde det muligt at visualisere EKG-signalet samt SCG-signalerne (X-, Y- og Z-akserne) samtidigt. Hvert signal blev vurderet og tildelt en kvalitetsvurdering hhv. 1 = god, 2 = medium, 3 = dårlig. Formålet med denne vurdering var at dokumentere signalernes kvalitet som grundlag for senere analyser, vurderingen havde ingen direkte betydning for, hvilke signaler der blev taget videre til annotering. De nedenstående figurer 3, 4 og 5 viser eksempler fra kvalitetsvurderingen af SCG signalerne. Samtidig illustrerer figurerne, hvordan de tre akser X, Y og Z, variere alt efter forsøgspersonens kropsposition.



Figur 3: Z-aksen viser en stabil baseline omkring 1g, hvilket indikerer, at tyngdekraften primært er i denne retning. X og Y har lavere gennemsnitsniveauer. Dette stemmer overens med, at testpersonen ligger på ryggen, hvor accelerometerets Z-akse vender opad – vinkelret på underlaget og parallelt med tyngdekraftens retning. Signalet blev kvalitetsvurderet som kategori 1 (høj kvalitet).

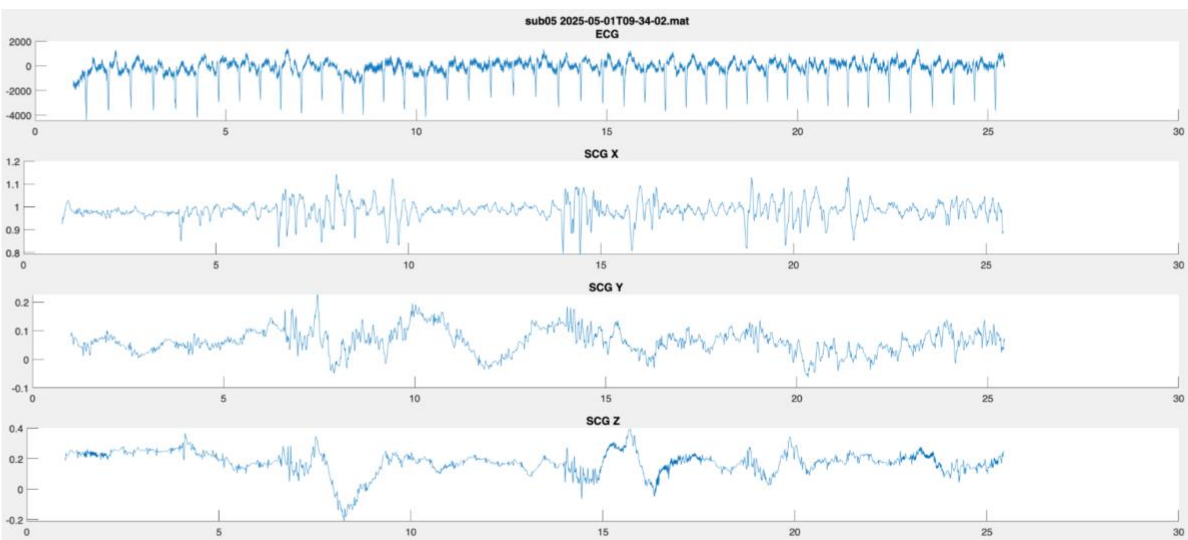
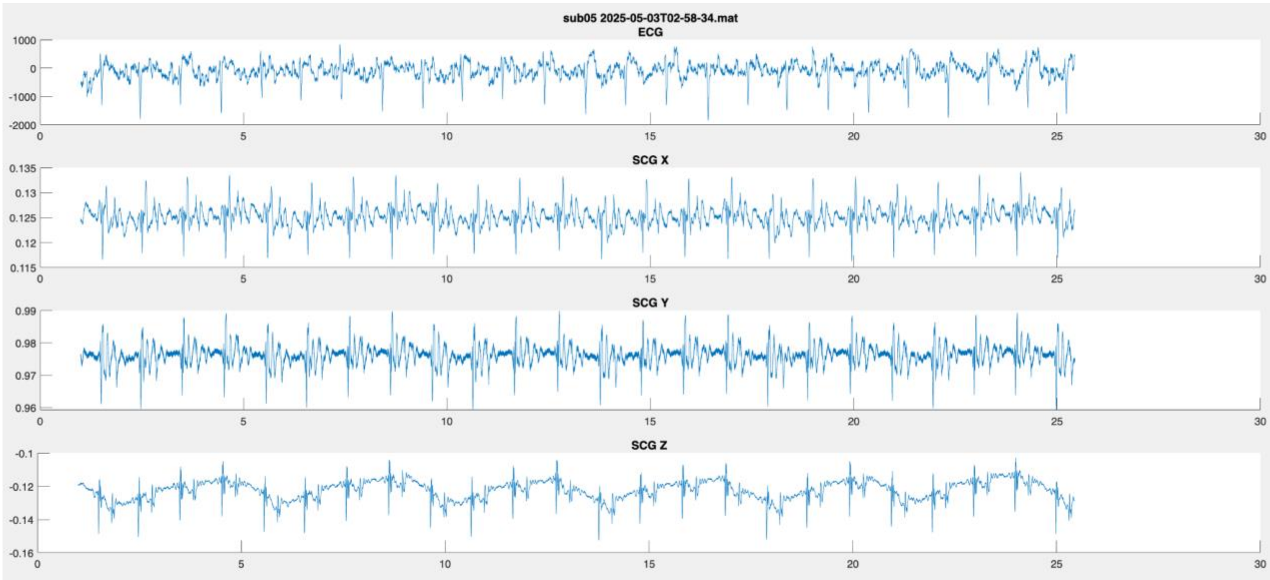


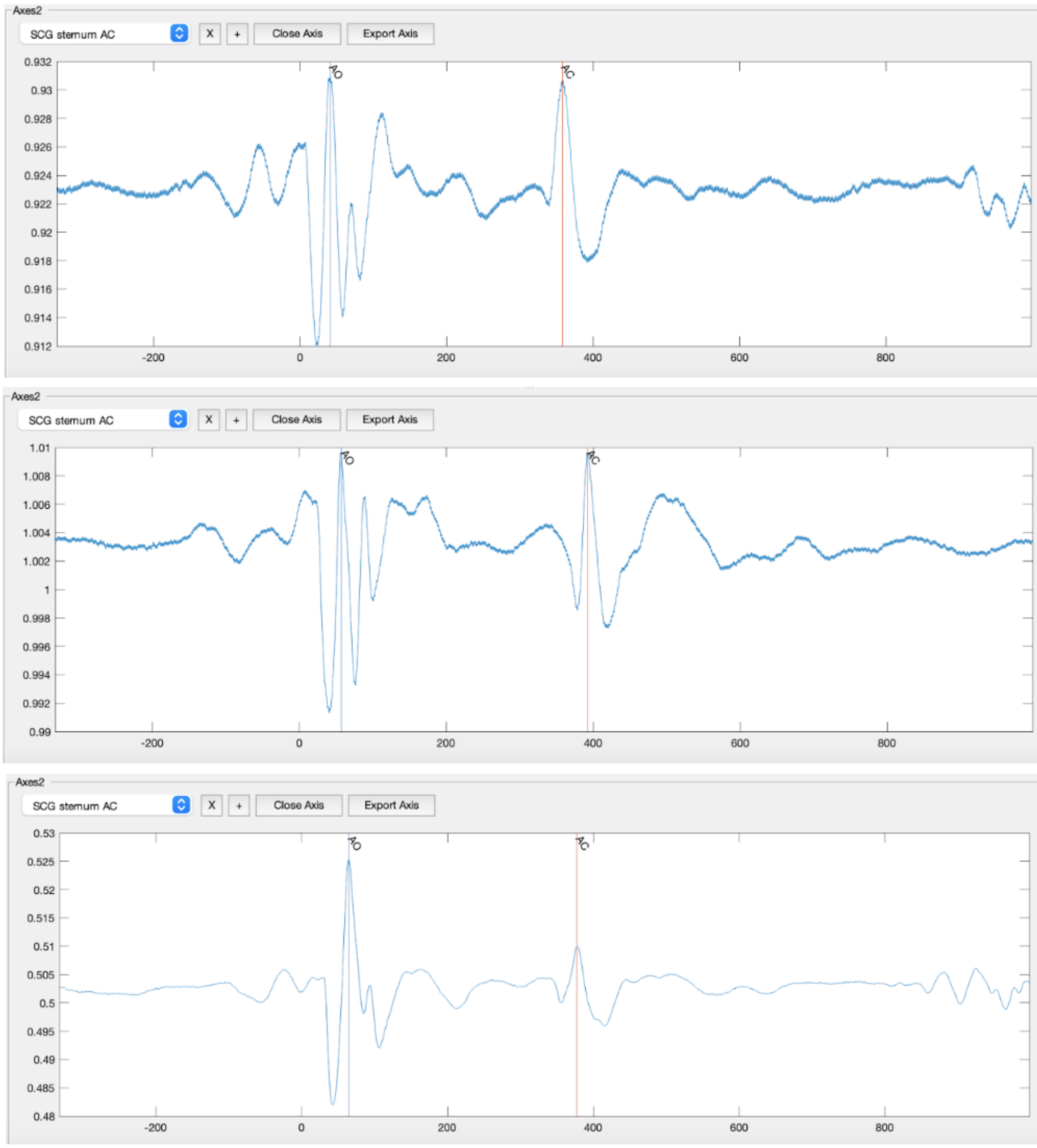
Figure 4: Y-aksen ligger tættest på 1g, hvilket indikerer, at tyngdekraften primært er i denne retning. Z og X har lavere gennemsnitsniveauer. Hvilket svarer til en siddende position, hvor kroppen er opret, og sensoren vender bagud mod rygraden. Signalet blev kvalitetsvurderet som kategori 3 (lav kvalitet).



Figur 5 : X-aksen er tæt på 1g, mens Z- og Y-akserne viser æavere værdier. Dette svarer til en opretstående position, hvor accelerometerets X-akse vender nedad i tyngdekraftens retning – altså parallelt med kroppens lodrette akse. Signalet blev kvalitetsvurderet som kategori 2 (middel kvalitet).

2.4.2 Annoteringsprocess:

Annoteringen af fiducial points blev foretaget i en anden MATLAB-GUI (SCG Viewer), hvor hvert hjerteslag blev vist med både EKG og SCG-signalet, her var der primært fokus på SCG Z-aksen. I denne GUI blev aortaåbning (AO) og aortalukning (AC) identificeret og manuelt annoteret ved hjælp af visuelle markører, dette er illustreret i de nedstående figure. GUI'en understøttede segmentering baseret på Markov-model (28). Nedenstående figur 6 illustrerer eksempler på de manuelle SCG annoteringer.



Figur 6: Tre eksempler på manuel annotering af SCG-signaler, hvor fiducial points AO og AC er annoteret.

Annoteringsprocessen blev udført uafhængigt af den oprindelige kvalitetsvurdering. I praksis betød det, at operatøren under annotering kunne revurdere signalets anvendelighed, hvilket samtidig fungerede som en intern kontrol på kvaliteten fra første vurderingsrunde. Dette medførte en mere nuanceret vurdering af signalets egnethed til videre analyse.

Referenceliste:

1. Telemedicin til mennesker med hjertesvigt: anbefalinger til målgruppe, sundhedsfagligt indhold, ansvar og samarbejde. Version: 1. Sundhedsstyrelsen; 2020.

2. Urbich M, Globe G, Pantiri K, Heisen M, Bennison C, Wirtz HS, et al. A Systematic Review of Medical Costs Associated with Heart Failure in the USA (2014–2020). PharmacoEconomics. 2020 Nov;38(11):1219–36.

3. Umeh CA, Torbela A, Saigal S, Kaur H, Kazourra S, Gupta R, et al. Telemonitoring in heart failure patients: Systematic review and meta-analysis of randomized controlled trials. World J Cardiol. 2022 Dec 26;14(12):640–56.

4. Liberman L, Liberman N, Silver ES. Cardiac monitoring: is longer better? Kardiol Pol. 2021 Feb 25;79(2):110–1.

5. Shahim B, Kapelios CJ, Savarese G, Lund LH. Global Public Health Burden of Heart Failure: An Updated Review. Card Fail Rev. 2023;9:e11.

6. Inge Schjødt. Dansk hjertesvigts database - om databasen [Internet]. Dansk hjertesvigts database; [cited 2025 Mar 6]. Available from: https://www.sundk.dk/kliniske-kvalitetsdatabaser/dansk-hjertesvigtdatabase-dhd/om-databasen/

7. Cardiovascular diseases (CVDs) [Internet]. [cited 2024 Oct 2]. Available from: https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds)

8. Roger VL. Epidemiology of Heart Failure: A Contemporary Perspective. Circ Res. 2021 May 14;128(10):1421–34.

9. Falkenberg Nielsen O, Bojsen-Møller MJ. Anatomi og fysiologi. København: Munksgaard; 2012. S. 49-119.

10. Kemp CD, Conte JV. The pathophysiology of heart failure. Cardiovasc Pathol. 2012;21(5):365–71.

11. Glud H, Kjærgaard J, editors. Håndbog i sygepleje: kardiologi. 1. udgave. Kbh.: FADL; 2019.

12. Di Rienzo M, Vaini E, Castiglioni P, Merati G, Meriggi P, Parati G, et al. Wearable seismocardiography: towards a beat-by-beat assessment of cardiac mechanics in ambulant subjects. Auton Neurosci. 2013 Nov;178(1–2):50–9.

13. Shafiq G, Tatinati S, Ang WT, Veluvolu KC. Automatic Identification of Systolic Time Intervals in Seismocardiogram. Sci Rep. 2016 Nov 22;6(1):37524.

14. Mora N, Cocconcelli F, Matrella G, Ciampolini P. Detection and Analysis of Heartbeats in Seismocardiogram Signals. Sensors. 2020 Mar 17;20(6):1670.

15. Alhakak AS, Teerlink JR, Lindenfeld J, Böhm M, Rosano GMC, Biering-Sørensen T. The significance of left ventricular ejection time in heart failure with reduced ejection fraction. Eur J Heart Fail. 2021 Apr;23(4):541–51.

16. Agam A, Søgaard P, Burup Kristensen C, Møgelvang R, Schmidt S. Detecting Preload Changes Using Seismocardiography. In 2023 [cited 2025 Mar 12]. Available from: https://www.cinc.org/archives/2023/pdf/CinC2023-201.pdf

17. Kaihara K, Kai H, Chiba Y, Naruse K, Iribe G. Stretch-induced reactive oxygen species contribute to the Frank–Starling mechanism. The Journal of Physiology. 2024 Sep;602(18):4347–62.

18. Jain PK, Tiwari AK, Chourasia VS. Performance analysis of seismocardiography for heart sound signal recording in noisy scenarios. Journal of Medical Engineering & Technology. 2016 Apr 2;40(3):106–18.

19. Schmidt SE, Toft E, Holst-Hansen C, Struijk JJ. Noise and the detection of coronary artery disease with an electronic stethoscope. In: 2010 5th Cairo International Biomedical Engineering Conference [Internet]. Cairo: IEEE; 2010 [cited 2025 Mar 11]. p. 53–6. Available from: http://ieeexplore.ieee.org/document/5716077/

20. Skoric J, D'Mello Y, Plant DV. A Wavelet-Based Approach for Motion Artifact Reduction in Ambulatory Seismocardiography. IEEE J Transl Eng Health Med. 2024;12:348–58.

21. SENS Innovation ApS. Beskrivelse af accelerometer. Beskrivelse af accelerometer. 2024.

22. McDonagh TA, Metra M, Adamo M, Gardner RS, Baumbach A, Böhm M, et al. 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: Developed by the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC) With the special contribution of the Heart Failure Association (HFA) of the ESC. European Heart Journal. 2021 Sep 21;42(36):3599–726.

23. Remote monitoring reduces heart failure hospitalisations and improves quality of life [Internet]. [cited 2024 Oct 7]. Available from: https://www.escardio.org/The-ESC/Press-Office/Press-releases/Remote-monitoring-reduces-heart-failure-hospitalisations-and-improves-quality-of-life

24. American College of Cardiology [Internet]. [cited 2024 Oct 7]. Focus on Heart Failure | Remote Monitoring in CHF: Staying #Healthy@Home. Available from: https://www.acc.org/latest-in-cardiology/articles/2021/10/01/01/42/http%3a%2f%2fwww.acc.org%2flatest-in-cardiology%2farticles%2f2021%2f10%2f01%2f01%2f42%2ffocus-on-heart-failure-remote-monitoring-in-chf-staying-healthy-at-home

25. Joseph P, Dokainish H, McCready T, Budaj A, Roy A, Ertl G, et al. A multinational registry to study the characteristics and outcomes of heart failure patients: The global congestive heart failure (G-CHF) registry. American Heart Journal. 2020 Sep 1;227:56–63.

26. Research Skills Guide: PubMed. Feb 10, 2025 10:22AM.

27. Methley AM, Campbell S, Chew-Graham C, McNally R, Cheraghi-Sohi S. PICO, PICOS and SPIDER: a comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. BMC Health Serv Res. 2014 Dec;14(1):579.

28. Agam A, Søgaard P, Kragholm K, Jensen AS, Sørensen K, Hansen J, et al. Correlation between diastolic seismocardiography variables and echocardiography variables. European Heart Journal - Digital Health. 2022 Oct 3;3(3):465–72.