An Alternative Method for Correct Placement of Electrocardiogram Electrodes V1 and V2

University of Stavanger

Faculty of Health Sciences

Master in Pre-Hospital Critical Care

Master Thesis (30 ECTS)

Student: Dag Uno Furuknap

Main supervisor: Oddvar Uleberg

Co-supervisor: Lars Petter Bjørnsen

Co-supervisor: Vegard Malmo

07.11.2022

UNIVERSITY OF STAVANGER

MASTER IN PRE-HOSPITAL CRITICAL CARE

Master thesis

Semester: **Autumn 2022**

Author/Thesis candidate: Dag Uno Furuknap

Main supervisor: Oddvar Uleberg, MD, PhD, consultant anesthesiologist, St. Olav

Co supervisor: Vegard Malmo, MD, PhD, consultant cardiology, St. Olav

Co supervisor: Lars P Bjørnsen, MD, PhD, consultant emergency medicine, St. Olav

Thesis Title:

Norsk tittel (Norwegian title): En alternativ metode for korrekt plassering av elektrokardiogramelektrodene V1 og V2

English title:

An alternative method for correct placement of electrocardiogram electrodes V1 and V2

KEYWORDS/SEARCH WORDS:

ECG Precordial V1 V2 misplacement CT

NUMBER OF PAGES: 62

STAVANGER November7th / 2022

PREFACE

I would like to thank the following professionals for willingness and good help:

Main supervisor Oddvar Uleberg, MD, PhD, consultant anesthesiologist, St. Olav

Co-supervisor Vegard Malmo, MD, PhD, Clinic of Cardiology St. Olav's Hospital
Co-supervisor Lars Petter Bjørnsen, MD, PhD, Emergency Department St. Olavs Hospital

Ingrid H Strand, MD, radiologist, Department of Radiology and Diagnostic Imaging, St. Olav's Hospital

Thank you also to my family for their patience and to my employer for giving me financial support for travel and accommodation in Stavanger.

CONTENT

SUMMARY

Misplacement of the precordial electrodes V1 and V2 is a common technical error when performing an electrocardiogram. Misplacement may affect interpretation and analysis of an electrocardiogram and is a both a patient safety issue and a cost issue because some conditions may be missed, and false findings may lead to delay in other diagnostics pending a cardiac work-up. The traditional methods to identify the fourth intercostal space has a success rate found in literature between 6% to 90%, with an average success rate less than 50%. An alternative method, the 1/2 – 1/4 method was investigated in this thesis. It was done by attaching the electrodes V1 and V2, by the new method measuring one quarter up on the sternum, in non-urgent patients at St. Olav's University Hospital, receiving a diagnostic computed tomography of the chest as part of their standard care. The placement of V1 and V2 was confirmed by computer tomography imaging. Fifty consecutive patients were included in the trial. The CT images were also investigated to see if the anatomical proportions of the 1/2–1/4 method were valid. In the electrode trial, 44% had both V1 and V2 placed in the fourth intercostal space. Ninety-two percent of the electrodes were either in the fourth intercostal space or within one intercostal space away from the fourth. The anatomical review of the method found correct location in 95,7% of the patients. Computer tomography imaging appears to be an accurate method to verify electrode placement.

INTRODUCTION

Prehospital electrocardiogram (ECG) has an important role in the diagnostics and treatment decisions mainly in ST-elevation myocardial infarction (STEMI) [1]. As part of standard care, diagnostic ECG is commonly performed by prehospital personnel, mostly emergency medical services (EMS) and then uploaded from the ambulance monitor before transmission to an in-hospital cardiologist or other doctors for evaluation. It is also often included in the patient record for future evaluation. While some EMS paramedics do have skills in interpreting the ECG [2], their main responsibility in the Norwegian EMS system is still to acquire a technically acceptable ECG for the doctor to evaluate,

ECG equipment has improved over the years. It has become lighter, cheaper and has advanced software. The standards for lead directions and electrode placement have however mainly remained the same since 1938 [3]. Literature indicate that misplacement of electrodes is a common and underrated human error, especially placement of the precordial electrodes V1 and V2 [4 -34].

Literature describes many causes of poor quality in acquiring ECG, including misplacement of any of the 10 electrodes, interchange of electrodes, electromagnetic interference, and wrong use of filters [4,5,6,7]. This thesis focuses on misplacement of the electrodes V1 and V2, as this is probably the most common mistake [4-34]. If these electrodes are placed correctly, the success rate increases for V3-V6 as well, since the placement of these electrodes depends on the placement of V1 and V2. The traditional method of finding the fourth intercostal space is by counting the ribs downwards. This is not always easy to do, both due to mission context-sensitive environment and patient specific conditions like urgency and body stature. An alternative method to place V1 and V2 is proposed in this thesis. The aim of this thesis is to provide EMS paramedics with an alternative method to find the placement of V1 and V2 that is simpler, and by that reducing error due to misplacement of the electrodes V1 and V2. An optimal method should both be fast, not dependent of special equipment and function well independently of different body statures. The method that is investigated in this study utilizes the use of hands and symmetry. The thesis investigates the accuracy of the alternative method. The proposed alternative method is also solely for location of the correct landmark for these electrodes.

An alternative method, which proves to be more accurate than the traditional method, may have a potential for implementation in education and training of prehospital health care professionals who perform diagnostic ECGs. This could possibly result in better and safer treatment of patients.

THEORETICAL BASIS

Misplacement of the ECG electrodes V1 and V2 is a common technical mistake both prehospitally and in other settings. An alternative method of placing these electrodes is proposed and the research question of the thesis is: *"What is the accuracy of a new and alternative method for the correct placement of the ECG electrodes V1 and V2?*"

The electrocardiograph has been used since it was invented by Willem Einthoven at the beginning of the twentieth century [35]. It measures small differences in voltage on the human skin, reflecting the electric activity in the heart. This is typically displayed as a voltage – time curve on a screen or on paper. The display produced by an electrocardiograph is called an electrocardiogram or ECG. ECGs are used in diagnostics of heart arrhythmias and heart disease, like myocardial infarction (MI), but can also reveal information about electrolyte disorders and use of medication. The typical ECG displays the electrical activity from 12 different angles measuring voltage differences between 10 electrodes. The electrical vectors on display and the electrode placement have been the same for a long time, with the American Heart Association and the Cardiac Society of Great Britain and Ireland being as early as 1938 to standardize placement of the precordial leads [3]. The standardization of lead placement was soon described as necessary and advantageous in using ECGs as a diagnostic tool [36]. As technology has evolved, the equipment has become lighter, more advanced and costs less, while electrode placement has been done manually about the same way as it always has been done. Personnel categories performing the procedure however have become more diverse, now including paramedics, nurses, doctors, secretaries, and cardiac technicians. Differences are likely to exist in how much focus they have on the technical aspects on acquiring ECGs during their education and on their workplaces.

Literature search

Literature search strategy should answer the following questions: How common is misplacement of the precordial ECG electrodes V1 and V2? What are the consequences of misplacement of the precordial electrodes V1 and V2? What are the methods of finding the correct positions for V1 and V2, including alternative methods not described in traditional medical education?

A traditional PICO set up could look like this:

Population	Adult patients or volunteers
Intervention	12 lead diagnostic ECG
Comparison	Correct vs incorrect placement of the precordial electrodes V1 and V2
Outcome	Extent and consequences of incorrect placement Alternative/New/Better methods to find correct placement

Table 1A PICO setup - traditional

The first column would be superfluous, as the words “patients” and “volunteers” do not contribute to the search in a meaningful way.

The search could also be divided in two searches, as the Outcome parameters “Incidence” and “Consequences” are likely to be found in the same studies, while “New method” is somewhat different. A modified PICO could look like table 1.

Intervention	**Comparison**	**Outcome**
ECG	Placement	Incidence
Electrodes	Precordial	Consequences
	V1	Alternative
		New Method

Table 1B PICO setup - modified

After a librarian consult, the outcome column was also left out. A search was performed in PubMed with the search phrase “Misplacement AND ECG AND (Precordial OR V1)”. This returned 40 studies where 14 were relevant for this thesis. A search was also done in Embase, where same search phrase returned 1202 studies. The phrase “intercostal space” was added to the search string. The search then returned 300 studies. 16 of them were relevant for this thesis. 10 of them were duplicates of the search in PubMed, so searching these two databases retrieved 20 relevant studies. These reference list of these studies were explored and an additional 14 relevant studies were found. Among them were two systematic reviews of the topic: “Accurate interpretation of the 12-lead ECG electrode placement: A systematic review” by Khunti et al [8], and “Is the correct anatomical placement of the electrocardiogram (ECG) electrodes essential to diagnosis in the clinical setting: a systematic review" by Hadijantoni et al [9]. It was useful to see their search strategies and reviews of the topic.

A total of 34 relevant studies were then explored for incidence and consequences of misplacement of the precordial ECG electrodes V1 and V2. They were also reviewed to find methods of finding the correct positions for V1 and V2, including alternative methods not described in the traditional medical education.

The literature search was done without time limit, as electrocardiography is an old technique and efforts have been made to address the problem with precordial ECG electrode misplacement for decades. In addition to the 34 studies retrieved in the literature search, some sources were explicitly searched to support claims in the text, not known for non-medical professionals.

The following studies retrieved describe the extent and incidence of V1 and V2 misplacement (Table 2):

Incidence in literature

Table 2 Sources describing incidence of V1 and V2 misplacement

Author and year	Study and population size	Method	Results	Reccomendation
Gregory et al (2021) [10]	N=52 paramedics, 1 male model. Observational study.	Placing precordial electrodes on a male model	3/52 (5,8%) placed the electrodes correctly	Correct placement of V1 improved placement of the other electrodes. Improved initial and refresher training necessary
Rajaganeshan et al (2007) [11]	N=119. Observational comparative study, multi-center.	Placing precordial electrods on a diagram.	V1 correctly placed in 31% (physicians), 49% (nurses), 90% (cardiac technicians) and 16% (cardiologists) of the cases.	Further education and training.
Wenger & Kligfield (1996) [12]	N=30 experienced technicians. Observational multi-centre study.	Placing precordial electrodes on 3 male and 4 female patients. Correct locations marked with UV ink.	64% of the precordial electrodes were placed within 3 cm of the correct locations. More than 50% of V1 and V2 were placed more than 1,6 cm too high.	Careful attention should be given to the location of the fourth intercostal space prior to application of the precordial leads.

Kligfield et al (2007) [13]	Summary of guidelines	Description of current recommendations	Superior displacement of V1 and V2 in the second or third intercostal space is a common (> 50%) error.	Technicians should have periodic retraining in electrode positioning.
Rehman & Rehman (2020) [14]	N=9424. Analytic observational study	Finding ECGs which could falsely be labelled as MI because of precordial electrode misplacement.	1018 of 9424 (10,8%) ECGs could possibly falsely be labelled as MI	Further studies are needed to assess the financial burden of precordial electrode misplacement.
McCann et al (2007) [15]	N=77 patients. Observational study	Two and two of three experienced clinicians assessed the precordial electrode placement done by nurses in the ED, producing 924 paired measurements.	Experienced clinicians did not agree on the correct placement and demonstrated high degree of variability in their assessment.	Individual assessments of “correct” location is not reliable, even if it is done by trained and experienced clinicians. Other methods for determination of correct location should be used.
Medani et al (2018) [16]	N=100 medical personnel. Pre- and post-intervention observational study.	Physicians, nurses and cardiac technicians placed precordial electrodes on a mannequin.	Allowing for 2,7 cm deviation, the initial result was that 26% (physicians), 36% (nurses) and 55% (technicians) placed the precordial electrodes correctly. Over all 34%.	More education. 7 minutes of education improved the results from 34% to 83% in this group.
Ferrie et al (2005) [17]	N=25 physicians. Observational study	Emergency physicians were asked to locate the correct location for needle thoracocentesis on a male volunteer. Correct location verified by the two authors, using ultrasound and palpation.	15 of 25 (60%) correctly located the second intercostal space.	Greater emphasis on competency-based training.

Twelve of the studies underline that misplacement of V1 and V2 is a common mistake. One study described a similar problem in finding the 2. intercostal space for needle thoracocentesis [17].

This is not a recent matter of concern. Already in 1960, Kerwin et al stated: “*One of the skeletons in the family closet of electrocardiography…is the fact that the selection of* *exactly the same sites for placement of the chest electrodes is rarely achieved even where reasonable care is employed*" [4]. They describe large variations in placement of chest electrodes by several technicians and on repeated attempts by the same technician.

While some of the studies just describe displacement of V1 and V2 as "*a common problem*" [13,14,18-30], some of them quantify the success rates of the traditional method of placing V1 and V2. There is some variation in the numbers, dependent on profession, situation and how it is measured. One British study [10], involving paramedics found a success rate of only 5,8%, but where not only V1 and V2 were assessed, but the success rate of all precordial electrodes was evaluated. Conversely a study done by Rajaganeshan et. al., ECG-technicians showed a 90% success rate. Nurses scored 49%, physicians 31% and cardiologists 16% [11]. The two other studies investigating success rates state that it is "*less than 50%*" [14, 18]. The study looking at location of the second intercostal space for needle thoracocentesis found that 60% of the emergency physicians did this correctly [17]. Comparison of success rates between professions can be found in Table 3.

Ilg et al reports the same observations; *"Gross violations taking place almost universally"*, describing a case where the consequence was loss of a job opportunity of an individual due to precordial ECG electrode misplacement, and which was not discovered by three different medical facilities [5]. The authors outline that *"for too long, improper precordial lead placement has been dismissed as low priority technical issue"* [5]. They recommend increased educational efforts, involving traditional and non-traditional approaches to promote accuracy.

Table 3 Incidence of **correctly** placed V1 V2 or precordial leads among professions

Study	Paramedic	Nurse	Technician	Doctor	Other
Gregory et al (2021) [10]	5,8%				
Rajaganeshan et al (2008) [11]		49%	90%	31%	16%*
Wenger & Kligfield (1996) [12]			64% **		
McCann et al (2007) [15]		75%			
Medani et al (2018) [16]		36%	55%	26%	
García-Niebla et al (2009) [19]			64%		

Ferrie et al (2005) [17]				60%***	

* Cardiologists ** Allowing for 3 cm displacement. 27% within 1,6 cm. *** Finding second intercostal space for thoracocentesis

The lack of studies investigating paramedic performance makes it difficult to know the accuracy for paramedics in specific regions or for paramedics overall. An estimate could be to use the average success rate for all the studies combined, except cardiac technicians. Cardiac technicians perform many ECGs every day in facilitated environments, while paramedics do not. The amounts of ECGs performed by paramedics are more comparable with doctors and nurses. This would present an average of 34% by just summing the percentages.

Some studies refer to the method Body Surface Potential Mapping (BSPM), which uses up to 192 electrodes. Kania et al did comparisons of precordial lead shifts using 64 precordial electrodes [20] and Bond et al, who found that there is a 17% - 24% chance that the diagnosis given by a clinician will be different because of electrode displacement [21]. Their findings of consequences of electrode misplacement are relevant for this thesis, but BSPM as a method is not relevant in the prehospital setting because it is to advanced and extensive. Most of these studies support the statement that 2.0 – 2.5 centimetres or more deviation from the correct electrode position increase misdiagnoses. Body surface potential mapping as a method is not relevant for the prehospital environment because of its complexity.

Consequences in literature

Table 4 Sources describing consequences of V1 and V2 misplacement

Author and year	Study and population size	Method	Results /Consequences	Recommendation
Kania et al (2013) [20]	N=60 patients. Observational cohort study, single centre.	Using 64 precordial electrodes in 60 cardiac male patients, analysing effects of electrode misplacement on the ECG.	A misplacement of more than 2 cm resulted in altered R-wave progression, QRS complex and T-wave, leading to false statements about myocardial ischemia or infarction, ventricular hypertrophy, Brugada syndrome and right bundle branch block.	None.

Rehman & Rehman (2020) [14]	Retrospective review of 9424 ECGs	Analysing 9424 ECGs, they identified ECGs with poor or reversed r-wave progression and septal infarction interpretations which were likely caused by precordial lead misplacement.	1018 (10,8%) could be falsely labelled as MI. Most common error relates to misplacement of V1 and V2. In USA: estimated 3,2 billion dollars in unnecessary testing annually.	Address the causes: carelessness, haste, difficulties finding landmarks.
Rajagenshan et al (2007) [11]	N=119. Observational cohort study, multi-centre.	Placing precordial electrodes on a diagram.	Potential harmful treatment, delay in other treatment, overlooking diagnoses, wrongfully assuming misplacement. Cost.	Further education and training. Need for a clinical method that involves no required memory of anatomy.
Kligfield et al (2007) [13]	Summary of guidelines	Description of current recommendations	Poor R-wave progression, rSr-pattern and T-wave inversion, wrongfully suspecting MI because of superior misplacement of V1 and V2.	Technicians should have periodic retraining in electrode positioning.
Bond et al (2012) [21]	N=464 ECGs. Retrospective, analytical and observational study.	Using 192-lead BSMP ECGs, half of the ECGs had the V1 and V2 placed in the second ICS. Two clinicians assessed the ECGs.	Clinical diagnosis is affected in 17% - 24% of the patients when the electrodes are misplaced.	Further education of medical and paramedical personnel and novel tools are needed.
Walsh B (2018) [22]	N=4 Case presentations	Description of case, general discussion.	Common findings caused by superior V1 and V2 misplacement are incomplete RBBB, anterior T-wave inversion, septal Q waves and ST-segment elevation. Unneeded testing, expense and anxiety.	Raised awareness of common mimics generated by lead misplacement.
Garcia-Níebla J (2009) [19]	N=101 healthy individuals. Cross-sectional study	ECG electrodes V1 and V2 placed in second, third and fourth intercostal spaces to see the difference in ECG.	Incorrect placed V1 and V2 produced significant errors in 3 of 5 ECGs.	None
Ilg et al (2012) [5]	Case description, general discussion	Illustration of a case. Summary of findings in literature.	False diagnosis of septal MI caused by ECG lead misplacement. Personal consequence	Redoubled educational efforts involving both traditional and possibly non-

			loss of job opportunity for one patient.	traditional approaches.
Abobaker & Rana (2021) [18]	Case studies	Description of 3 false ECG findings because of V1 and V2 lead misplacement	False old septal MI, false incomplete RBBB and false anterior STEMI. Delay of surgical procedures and increased cost.	Raised awareness necessary
Ajmal M & Marcus F (2021) [23]	Review of literature	Discussion of standards and coherence to them.	Cost of ECGs in the USA today is approximately 2 billion dollars. Incorrect placement of precordial leads may lead to a false diagnosis of MI	Other techniques to locate the fourth interspace to place V1 and V2 are needed.
Harrigan et al (2012) [7]	Clinical review	Unclear, not mentioned.	Improper position of the electrodes on the chest is common and may mimic a pseudoinfarction pattern or ST-segment/T-wave changes.	Patterns of electrode misplacement can be recognized and should be in the differential diagnosis of ECG changes.

There are direct medical consequences of misplaced V1 and V2 mentioned in the studies (Table 4). Falsely diagnosing a myocardial infarction is described by several studies, leading to potentially harmful treatment, and delaying other treatment [5,7,13,14,18,22,23]. Myocardial infarctions may even be overlooked and missed because of misplaced precordial electrodes [11,21]. In a study by Bond et al, 11% of ST-elevation myocardial infarctions were missed [21]. Other false findings in the ECG because of misplaced electrodes include poor R-wave progression [13,20], rSr-patterns and T-wave inversion [7,13,19,20,22], right bundle branch block, RBBB [18,22], ventricular hypertrophy and Brugada syndrome [20] and inter-ventricular conduction disorder [21]. Three of the studies highlight that there is a considerable cost involved in unnecessary cardiac testing and treatment, both for individuals and for the society [14,22,23]. Each patient may also experience unnecessary anxiety and personal consequences [5,22]. Some cardiac conditions may even be overlooked because the cardiologist assume that the ECG change is caused by misplacement of electrodes [11]. In total there are considerable consequences because of false diagnoses and missed diagnoses. These cause diagnostic delays, personal consequences, and a considerable financial burden.

New methods in literature:

Table 5 Sources describing new methods of placing V1 and V2

Author and year	**Study and population size**	**Method**	**Results**	**Recommendation**
Soliman, EZ (2008) [24]	Quality control. N=0	Describing an idea	Measuring and documenting distance from sternal notch to V1 position, called "NV" (Notch to V).	Measured NV distance should be attached to the ECG and be a part of it.
Herman et al (1991) [25]	Quality control. N=100.	Using a plastic ruler to determine V3 – V6. V1 and V2 still require manual location.	Increased precision in serial ECGs	Possibly useful to ensure low variability in serial ECGs
Roy et al (2020) [26]	N=100. Observational/Experimental quality control.	Traditional ECG acquirement vs belt with prepositioned precordial electrodes, assessed by 3 cardiologists	No difference between individually placed electrodes and prepositioned electrode belt. Possibly faster.	Further studies needed to reduce the problem of misplacement.
Baas et al (2003) [27]	Observational. Quality control. N=100	Testing a new "V-Quick" patc, a plastic ruler ensuring correct vertical positioning of V1 – V6.	No difference compared to a manually adapted ECG.	"V-Quick" patch possibly useful in serial ECGs.
Bell et al (2001) [28]	Observational. Quality control. N= unknown number of experienced ECG technicians	Testing of "ECG BELT", a rubber band with prepositioned electrodes. Aims to reduce time consumption and misplacement.	Did not fit all. Poor recording quality in 11%. Significant baseline wander and artifact.	Not adequate for clinical use. The need for a new method that saves time and improve electrode placement accuracy is obvious.
Bond et al (2016) [29]	Observational. Quality control. N= 20 technicians, 60 ECGs, one male model.	Testing of "Cardio Quick Patch", a sliding ruler with electrodes vertically prepositioned but horizontally movable.	Reduction of variability in serial ECGs. Possibly faster than traditional method.	Claims that the CQP is a promising device. In 2022 their home/sales page cardiosys.com is not working and the domain is for sale.
Luc et al (2013) [30]	N=428. Randomized controlled trial	Testing PhysioGlove, a glove with prepositioned electrodes.	The glove fitted92% of the patients. By expert opinion, diagnostic accuracy was 91% compared to ordinary ECG acquisition.	Possibly useful in some circumstances and for serial ECGs. Not adequate for prehospital use.
Day et al (2015) [31]	Observational. N= 55 CT images	Examining length from sternal notch to the xiphoid process in CT images	Distance from sternal notch to fourth ICS on average 67% of total length of sternum. Considerable variation.	Possibly useful information to locate fourth ICS in a clinical setting.

Rautaharju et al 1998 [32]	Analytical study	Manual method to find V1 and V2. Examining the use of the “Heart Square” to find V4. and if electrodes should be placed on or under female breasts	Advice on how to find V1 and V2. Heart Square useful to find V4	Sternal angle should be found three fingers width below sternal notch, then counting to fourth ICS. Heart Square can be used to find V4 location, breast tissue has negligible effects on ECG.
Marcus et al (2017) [33]	Observation al. N= 55 CT images	Examining length from sternal notch to the xiphoid process in CT images	Distance from sternal notch to fourth ICS range from 57% if total sternum length is 26 cm to 77% if total sternum length is 15 cm. A slidable ruler was developed to find length from sternal notch to fourth ICS.	Helpful device to locate fourth ICS in obese patients. Possibly challenge to locate the tip of processus xiphoideus.
Lehmann et al (2012) [34]	Observation al. N=112	Using patient hand with to locate the sternal angle, and from there locate the second ICS.	In 89,3% of the patients, the method landed on the second rib or second ICS.	Useful in patients where the sternal angle is not palpable. Still have to count downwards to find the fourth ICS.

Several devices and new methods have been proposed, though they do not seem to have been adopted into a clinical setting (Table 5). Prehospital use favor techniques that are not dependent on equipment. Another reason for this is the need to have a method working under hostile environment (e.g. cold weather, darkness), among several individuals and the need to reduce the amount of inappropriate utensils, which already challenge the maximum weight capacity of ground- and air ambulances.

Belts with prepositioned electrodes and slidable plastic rulers have so far not produced convincing and credible results, except possibly the HeartSquare, as invented by Rautaharju and described by Rautaharju et al, and commonly used as a tool to find the location for the electrode V4 [32]. They still will have to find the location for V1 and V2 by traditional methods. Luc et al tested a glove with 10 prepositioned electrodes [30]. The glove is to be fitted on the patient’s left arm and held into the chest. They demonstrated 93% diagnostic accuracy compared to ordinary acquired ECGs, but the glove does not fit every patient. The patient’s upper body must be undressed, and the glove prevents intravenous access to left arm while the ECG is taken. It is also dependent on a specific software algorithm to compensate for the unconventional placement of the limb leads. Because of this, the glove is not considered to be useful in the prehospital environment.

The studies of Day et al and Marcus et al explored the proportions of human anatomy and ratios on the sternum [31,33]. They used CT images to see if the fourth intercostal space was to be found in a fixed proportion in relation to the length of the sternum. Day et al concluded that the fourth intercostal space, on average, was located at 67% of the distance from the sternal notch to the xiphoid process [31]. Their data displayed however a trend that this percentage may be dependent on sternum length, with the percentage decreasing as the sternum length increased. Marcus et al did a follow-up on this study, using both CT images and clinical measurements in patients and test persons. They found that the ratio varied between 57% to 77% dependent of the total length of the sternum, including the xiphoid process [33]. One possible weakness with the work of Day and Marcus is that they looked at the proportion of length between sternal notch to the fourth ICS compared to the total length of sternum, including the xiphoid process. The processus xiphoideus' length and shape has great variations in the human being and may have contributed to the variation in their results. In patients in the study described in this thesis, the xiphoid process varied from 20 millimeters to 79 millimeters. Finding the tip of the xiphoid process may not be an easy task in a prehospital setting. This was also commented by Marcus et al, suggesting that this task could be helped with the use of a pillow behind their back [33]. The use of a pillow is not a very elaborate task, but in the prehospital environment it takes some of the simplicity away from the method. Marcus et al developed a sliding ruler which can be used to find the fourth intercostal space, as it accounts for the percentages to decrease when the length of the sternum increases.

Lehman et al [34] proposed a manual method for finding the second intercostal space in obese patients, as the sternal angle can be hard to detect in some patients. They place the patient's hand to the front of the neck and visualized a horizontal line from the transition of the first finger (thumb) and wrist and to the base of the fifth finger. This level was directly over the second rib or the second intercostal space in 100 of their 112 (89,3%) patients. Having located the second intercostal space, counting spaces downwards should locate the fourth intercostal space. They used expert opinion to decide the correct location. This method is not very different from the method described by Rataharju et al, stating that the sternal angle is found three fingers with from the top of the sternal notch [32].

This review of alternative methods found in previous studies does not reveal any single method that stands out as a fast, simple, equipment-independent, and accurate method to find the correct placement of the precordial electrodes V1 and V2.

METHOD

Description of the traditional method

The precordial electrodes V1 and V2 should be placed directly to the left and right of the sternum in the fourth intercostal space [3]. Traditionally, this is done by finding the joint between the manubrium and the sternum, the sternal angle (angle of Louis) since the second rib is connected to this joint, then counting intercostal spaces from cranial to caudal to the fourth intercostal space. Many also try to locate the first rib under the clavicle and then counts downwards from there. This method is not considered very successful. This is because the clavicles partly cover the first rib, and the space between the clavicles and the first rib can easily be mistaken for the first intercostal space. Occasionally the precordial electrodes would just be put where the operator think they belong, without using any specific method [5,25,34].

Description of the 1/2–1/4 method

The alternative method investigated in this thesis does not count ribs but uses assumptions of the proportions of human anatomy. The method has been used and taught by the author for a decade as an alternative, in patients where the traditional method is difficult to accomplish. The method has never been validated.

Two anatomical landmarks are identified. The upper landmark is the suprasternal notch (top edge of the manubrium). This point is easy to detect in all people including obese. The lower point is where the costal margins meet. This is found by following the costal margins upwards with the fingers. This point is not the lower edge of the sternum or the edge of the xiphoid process, even if this may coincide in some patients.

The distance between these two points is divided in four equal lengths. Human ability to divide a line in two equal parts is described in literature as very good. This is described several places, for example in "A Review on Human Symmetry Perception, which states this in their conclusion: "*symmetry detection is quick, sensitive to deviations from perfect symmetry, and robust to noise*" [37]. By dividing the described distance two times, it will be the point 1/4 of the line from the caudal end of sternum. The fingers should then palpate for the closest intercostal space found directly to the side of the sternum. The assumption tested in this thesis is that this intercostal space equals the fourth intercostal space. Proper anatomy charts suggest this relationship (Figure 1).

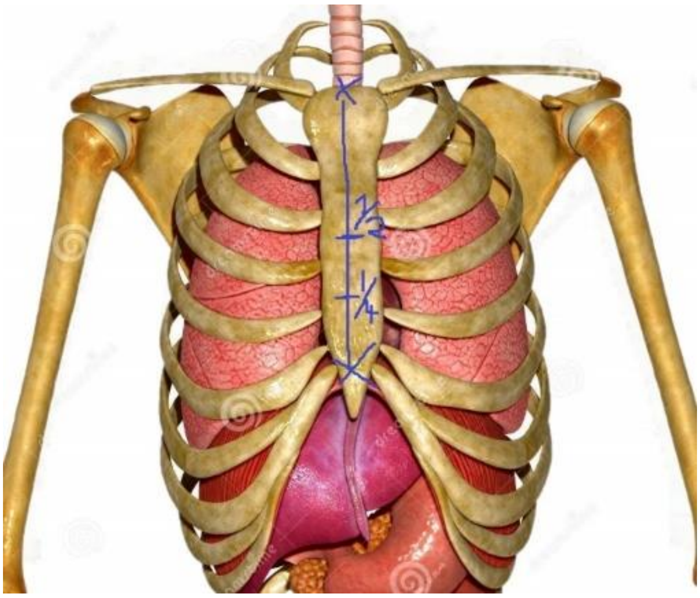


Figure 1. *(www.dreamstime.com Scientific picture 44797637 royalty-free)*

A visualization of the alternative method is shown in figure 2.

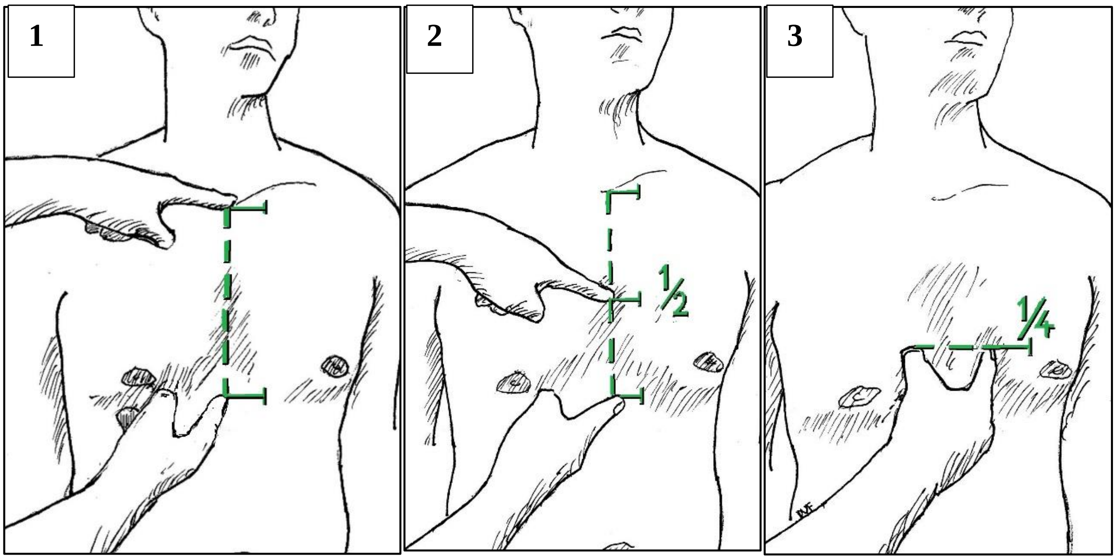


Figure 2. Visual explanation of the 1/2-1/4 method (drawing by the author).

Design

The study design of this thesis consists of a 1) literature review and 2) an experimental observational study design. In the experimental observational study, electrodes V1 and V2 were placed on 50 consecutive patients who then would undertake CT imaging of their chest. Electrode placements were confirmed by investigating the CT images to see how well the placements of the 1/2–1/4 method were. The CT-images were then reviewed to how well the proportions of anatomy in the chest related to the 1/2–1/4 method, regardless of electrodes.

In testing of methods, both traditional and new ones, the actual placement of the electrodes need to be confirmed by a method that is both reliable and obtainable with the resources at hand. Other studies have used invisible ink marked by expert opinion [12,29], ultrasound [17], diagrams [11], transparent overlay [10], CT imaging [31,33] or just expert opinion without specifying [4,7,16,21,28,38]. In the two studies where they used expert opinion and invisible ink, many participants placed the electrodes on a few numbers of test persons [12,29]. This was originally the method of choice in this thesis, but this test method has the weakness of representing just a few different body statures.

St. Olav's University Hospital offered access to non-urgent patients arriving in the emergency room. Many of these would receive a chest x-ray as a part of their standard care. Chest x-ray was ruled out as a method for placement confirmation after consulting the department of radiology, as the single images would not display both the electrodes and the corresponding intercostal space evidently enough. Ultrasound was also discussed but was abandoned for the same reason. CT imaging has the advantage of visualizing exactly where the electrodes ended up in relation to anatomical structures, invisible from the outside. Many studies have used expert opinion to define the "correct" answer in their testing [4,7,10-12,16,17,21,28,29,38]. This method may not be as accurate as previously assumed. McCann et al [15] did plan to use "*expert opinion*", but from the initial testing, they realized that even experienced professionals do display considerable inter-individual variation. They rather went for exploring that variation, with a cut-off at 2,5 cm as this is the suggested threshold for ECG misinterpretations. They found that 25% of the comparisons were off by more than 2,5 centimeters and concluded that individual expert assessment of correct ECG electrode location is not a reliable reference standard.

In this thesis, the accuracy of an alternative method was investigated by placing the V1 and V2 electrodes exactly 1/4 cranially directed from where the costal margins meet in 50 consecutive patients eligible for inclusion.

Data collection – electrode placements

The data was collected in three of the laboratories performing computer tomography (CT) scans at the Department of Radiology and Diagnostic Imaging, St. Olav's Hospital

In four days medio March 2022, 50 consecutive patients were included in the trial. These patients were not selected in any other way than that they would have an elective CT scan of the thorax. All 50 patients gave consent to participate in the study. These patients would then have a random age, sex, body weight and body shape. The word "sex" is used in tables rather than "gender" to distinguish between male and female patients, as it is more precise in anatomical terms.

Inclusion criteria:

- Adult patients 18 years or above admitted to St. Olav`s University hospital
- Non-urgent patients – no need of immediate diagnostic or interventional therapeutic interventions
- A CT-scan of the chest is performed as part of standard care
- Consent to participate

Exclusion criteria:

- Patients who were not receiving a chest CT. This is because chest CT is necessary to confirm the actual placement of the electrodes and patients should not be exposed to unnecessary diagnostic imaging or radiation
- Patients with a time-critical condition. These patients should not have their diagnostics or treatment delayed because of the trial, even if the delay is minor.
- Patients not consenting to participating in the trial. Participating in the study is voluntarily.
- Patients under 18 years old or not able to give an informed consent. The trial requires adult consent and children do not commonly receive an ECG in prehospital emergency care.

The patients participating in the study randomly arrived at the CT laboratories at St. Olav's Hospital. Each patient was approached in the radiology department by the project-coordinator (DUF) just prior to their CT-scan. After information about the study was given and consent obtained, their age and self-reported height and body weight were recorded. All patients were sitting, either on a chair or in their bed when the electrodes were attached. This was done to separate the study intervention from the CT examination. After a test patient, not included in the trial, it became clear to the project coordinator that the actual CT scan was performed with the patient lying supine with both their arms stretched out above their heads, in the cranial direction. All, except one patient were then asked to raise their arm while the measurement and electrode placement was conducted. After signing the written consent, while sitting on a chair or their hospital bed, the top of the manubrium (sternal notch) and the point where the costal margins meet at the low end of the sternum were identified. These are two anatomical landmarks that are easy to find, even with deviating anatomy. The distance between these points was recorded. Three quarter of this distance was found by multiplying by 0,75 on a hand calculator. Using the measuring tape, the V1 and V2 electrodes were placed with their metal notch 75% of the total top-down distance from the sternal notch, on each side of the sternum. This equals 1/4 (25%) of the height from the point where the costal margins meet, to the suprasternal notch / top edge of the manubrium (Figure 1).

Figure 3. Equipment for locating and placing electrodes V1 and V2 (photographed by the author).

The ECG electrodes that were used, were the same (Cleartrace RTL1700C, Conmed©) as used in standard diagnostics in the emergency department and they are visible in the CT images. The CT images would then be available for radiologists to examine according to their ordinary routine, with a small note saying that the two ECG electrodes were put there as a part of a study and should be disregarded.

Before the study was conducted, it was assessed whether ECG electrodes placed on the skin at the level of the sternum could cause artefacts on the images which could interfere with the interpretation of the tissue immediately under the electrodes. This was not the case, and the study proceeded as planned. The CT machine made section images of the patient in the transverse, coronal and sagittal plane. Images were sent from the CT machine to a digital imaging tool, Picture Archive Communication System (PACS), provided by Sectra (Sectra AB, SE-583 30 Linköping Sweden). Patients were examined on one of three different Siemens CT machines: Somatom Definition Flash, Somatom Definition Flash and Somatom Definition AS+. 3D and multi planar reconstructions (MPR) were performed for registration of the placement of the electrodes by radiologist Dr. Ingrid H. Strand. The assessment of the electrode placements was based on reconstructions of the 1 mm thin sections and reconstructed with "soft images".

Dr. Ingrid H. Strand then examined the 50 CT scans separately to assess the placement of the electrodes relative to the costae and intercostal spaces. The project coordinator was not informed of the success rates of placement during the patient inclusion period. Two images from each of the 50 patients were adopted, showing the placement of V1 and V2 electrodes and each of the two images detailing the placement of V1 and V2 respectively. The project coordinator later reviewed the same images together with the radiologist to see if there were any disagreements. The electrode location was determined only by use of a measuring tape and not by palpating for intercostal spaces Because of this, some of the electrodes were placed directly over ribs. When this was the case, the placement was looked at in detail to see if the direction from the electrode perpendicularly to the rib wall ended over or under the centre of the rib. If the perpendicular line hit just below the centre of the fourth rib, it was judged as “in fourth intercostal space”. If it hit above the centre, it was judged as “in third intercostal space. The rationale for this is that in the actual method, fingers would have found the space closest to where the fingers ended up using the 1/2-1/4 method.

Data collection – proportions in the CT images

Besides having the results of the electrode trial, the 50 CT-images were also investigated to explore the proportions of anatomy and the theoretical basis of the 1/2-1/4 method. The images were printed on paper and measurements were made by a millimetre rated ruler. The measurement uncertainty was about 0,5 millimetres. Four measurements were recorded from each image. 1) The total distance from the top of the sternal notch (manubrium) to the point where the costal margins meet. 2) The distance from the point where the costal margins meet to the centre of the fifth rib. 3) The distance from the point where the costal margins meet to the centre of the fourth rib. 4) 25% of the distance from where the costal margins meet to the top of the sternal notch. As in the trial with the electrodes attached on the patients, the fourth intercostal space was defined as an interval, from centre of the fourth rib to the centre of the fifth rib. Then the number of patients with the ¼ distance within the fourth intercostal space was counted. The numbers were converted into ratios of the total distance because the scale of the CT images was not consistent between the 50 images. Several studies imply that more than 2 – 2,5 cm misplacement increase the risk of misdiagnoses [4,12,13,15,20,24,25,29]. The number of patients with the ¼ in the fourth intercostal space or anywhere on the ribs four and five were then also recorded. Even if it is not within the fourth intercostal space, it is still within 2 cm form the centre of the fourth intercostal space. Three of the images could not be used. Two of them did not display the rib to sternum attachment points and one did not display the top edge of the manubrium.

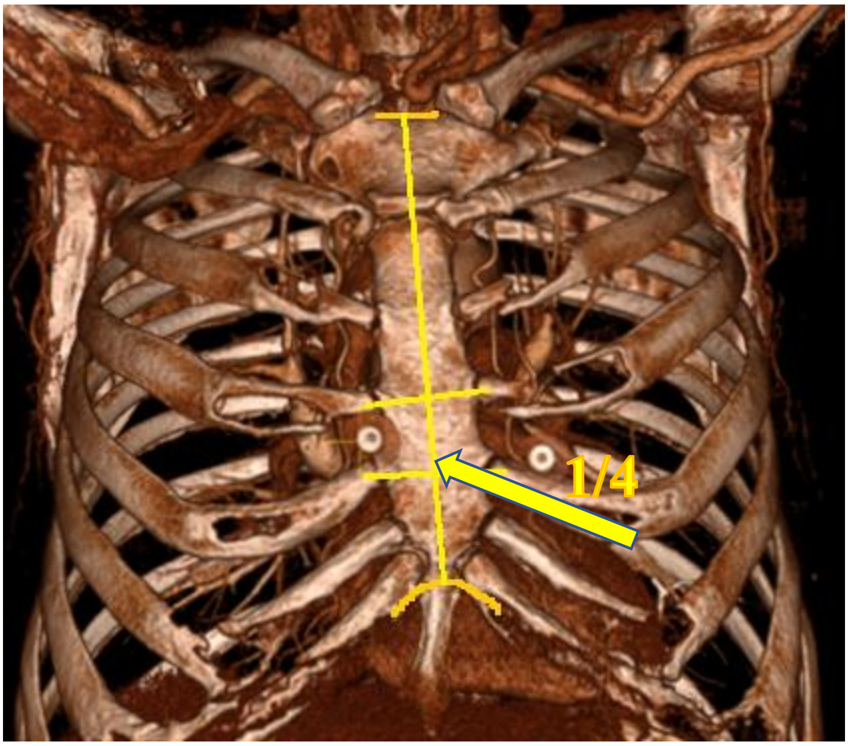


Figure 4. Measurement on the CT images. Markings on top edge of the manubrium, where the costal margins meet, the boundaries for fourth ICS and the 1/4 distance (written patient consent and permission for publication obtained).

Statistical analysis – electrode placements

Analysis of the actual placement was done by listing them in a spreadsheet and counting the frequencies of placement for each intercostal space. The spreadsheet also contained the measured length, sex, age, height, and weight for each patient. The results are shown in the result section in this thesis and Appendix B. The results were also analyzed, applying the Statistical Package for the Social Sciences (IBM Corp. Released 2021. IBM SPSS Statistics for Windows, Version 28.0. Armonk, NY: IBM Corp).

The results were compared to the patient sex, body weight, body height and sternum length to see if there were any correlation. Scatter plots were produced to get an impression of how it looks. These can be found in Appendix C. Sex was converted to the digit 0 for females and digit 1 for males. The intercostal space placement was described by the digits 2 to 6, corresponding to the intercostal spaces respectively. If one electrode was in the third intercostal space and one in the fourth space, it was assigned the value 3,5. The data were also checked for correlation with help of the same programme package.

In search for correlation, careful consideration was put into interpretation of what the numbers really reflect. No correlation would be expected between the intercostal space placement versus age and weight. It could be expected some correlation between the intercostal space placement versus body height and length of the sternum. Correlation between intercostal space placement and sex is unknown. Correlation between intercostal space placement and the variables height, sternum length and possibly weight and age could be assumed to be linear.

A common method for proving bivariate linear correlation is the use of Pearson's correlation coefficient. It will return a value between minus one and plus one. Minus one or plus one means perfect correlation, a straight line with all the measurements on it. A zero means absolutely no correlation at all. The null hypothesis will be that there is no correlation. To get an answer saying something about the statistical significance, some assumptions must be met. The variables should be roughly normally distributed, which they almost are. Height, weight, and sternum lengths are expected to be normally distributed in random populations. Intercostal space placement is centred around the fourth intercostal space and could be said to have an approximately normally distribution. Each observation in the data set have a pair of values, which is also a requirement that is met. The data set should have no significant outliers, as the Pearson correlation coefficient is very sensitive to outliers. This requirement is not met in this data set. Two of the outliers could be explained by conditions not related to the method. One is patient #6, who had extensive thoracic deformities. She had both electrodes placed in the sixth intercostal space. The other was patient #16, whom I forgot to ask to raise her arms. The electrodes were in second and third intercostal space on the CT images. Even if these two outliers were removed, there are still one patient with electrode placements in sixth intercostal space and one with the electrodes in the second and third intercostal space. At least one of them could be regarded as a significant outlier and the assumptions for using Pearson's correlation coefficient is still not met.

A better method for investigating correlation in this data set is to use the Spearman's rank-order correlation. It does not require that the variables are normally distributed, and it is not sensitive to outliers. A valid result can be obtained even if there are outliers in the data set. This means that all 50 patients could be included in the analysis of correlation. Spearman's correlation returns the same format of results as Pearson's correlation coefficient, a number from minus one to plus one. The number is also called "Spearman's rho". Assumptions that must be met using the Spearman's correlation are that the variables should be measured on an ordinal, interval, or ratio scale. This assumption is met. The two variables compared should be paired observations, which they are. The last assumption is that there should be a monotonic relationship between the two variables. This means the variable correlation should be either increasing or decreasing, not both, in the same comparison. Visual inspection of the scatter plots reveals no signs of non-monotonic behaviour from any of the variables, so this assumption is also met. Using the Spearman's rank-order correlation in SPSS gave the values of Spearman's correlation (Spearman's Rho), 95% confidence intervals (CI) and p-values (P). These can be found in the Result-section.

Statistical analysis – proportions in the CT images

The distances measured on the CT images were all converted to ratios and percentages. This is because the CT images had slightly different scales. The target measure for the 1/2-1/4 method is then 25% in all the images, while the lower and upper limit for the fourth intercostal space have various ratios. This is presented visually in Figure 6 in the Result chapter. To see how the 25%-mark placed itself relatively to the borders of the fourth intercostal space, it was useful to convert the lower and upper borders to fixed values. This was done by min-max normalization. For all images, the lower border the becomes 0 and the upper border becomes 1. The new 25%-mark value can then be calculated as:

Z = (0,25 – lower limit) / (upper limit – lower limit) = the new relative 25% value.

The distribution is presented in Figure 7 in the Result chapter.

The probability that the 1/4 distance falls within the fourth intercostal space was calculated using the measurements from the images.

Research-ethical considerations

Using real life patients requires carefully regard to the ethics involved. The decision to include patients instead of healthy volunteers was based on two considerations 1) to be able to include persons with variation in demographics (sex, age, body height and body height) to evaluate possible inter-individual differences 2) as eligible patients were to undergo diagnostic imaging as part of standard care, exposure to x-ray radiation was reduced to an absolute minimum. Thereby avoiding the exposure of radiation to healthy volunteers. The use of ultrasound imaging, which eliminate radiation, was evaluated as not sensitive enough to identify the specific intercostal spaces. The study did not involve any medical treatment but included placing two electrodes on their chest as part of the study. These had no role in diagnostics or treatment, and they were removed immediately after they completed their chest CT. The patients included in the study were non-urgent patients to make sure the short time consumption required to inform, obtain consent and to attach the electrodes did not significantly delay diagnostics or treatment. The consent form can be seen in Appendix D.

In an emergency medicine setting where medical personnel initiate research projects, they patients may feel obliged to participate to be obliged to receive adequate medical care. The study group was aware of the potential situation. For this reason, the project coordinator involved in the study data collection was not a part of the medical treatment team. In addition, the intervention performed was non-invasive and is seen as a non-obtrusive interventional measure not affecting the health of the patient or any potential other diagnostic and/or therapeutic measures.

Contact was made to the regional ethics committee. They answered 20.12.2021 that their approval is not necessary for this project. See Appendix E.

An application was also sent to the Norwegian Center for Research Data (NSD). After adjusting the consent form according to their advice, an approval was given. See Appendix F.

RESULTS

Most of the patients were elderly, age ranging from 30 to 85 years, with mean and median age 65 years and 70 years respectively. There were 31 female and 19 male participants in the study. Body weight was ranging from 30 to 104 kg, with mean and median body weight 70 kg. Body height was ranging from 150 to 187 cm, with mean and median body height 168 cm.

Results – electrode placements

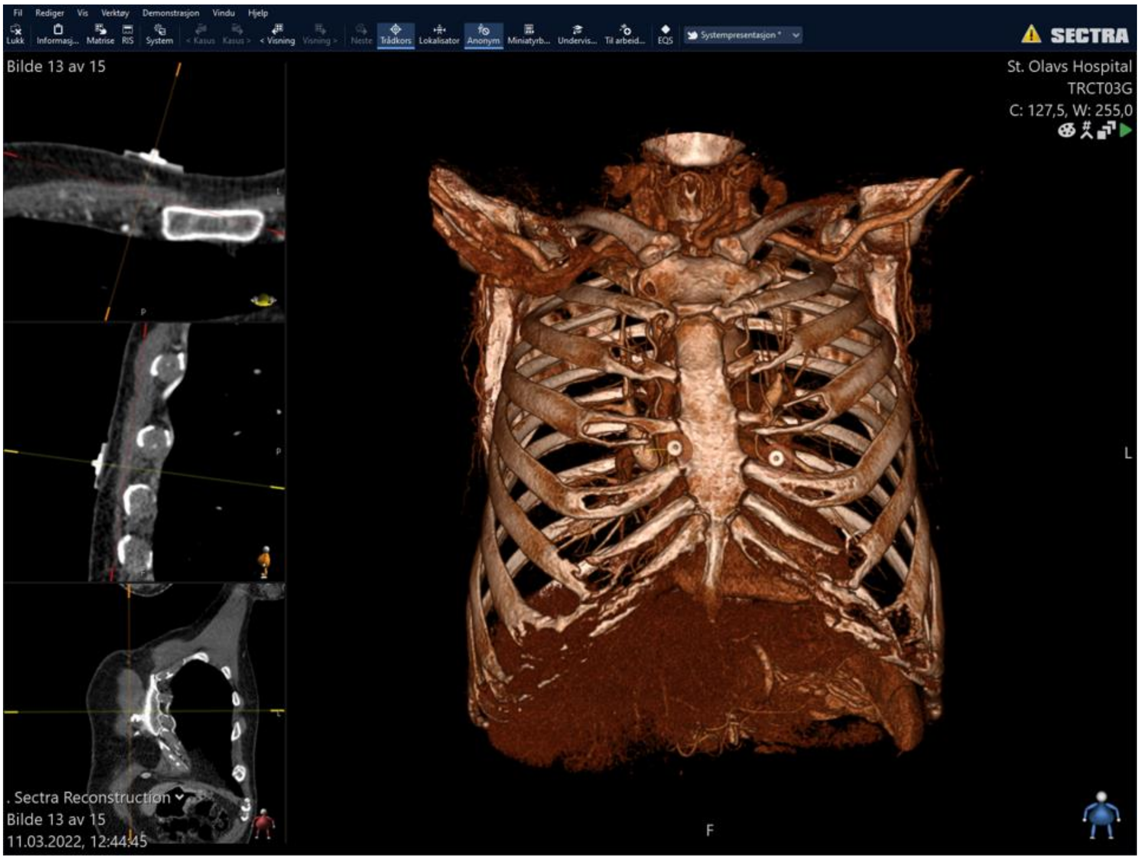


Figure 5. A processed CT-image of one of the patients (written patient consent and permission for publication obtained).

The resulting scores were that 22 (44%) patients had both the electrodes placed in the fourth intercostal space. Five (10%) patients had both electrodes in the third intercostal space and 11 (22%) patients had both electrodes in the fifth intercostal space. Two (4%) patients had both electrodes in the sixth intercostal space.

Ten (20%) of the patients had the electrodes V1 and V2 placed in different intercostal spaces. When the electrodes were attached to the skin, they were placed on the horizontally same level. In four of the CT images, the corresponding ribs were not attached to the sternum at the same level.

The V2 electrode placements were positioned far more laterally away from the sternum than V1 in 22 of the 50 patients. Thirty (60%) of the patients had at least one electrode in their fourth intercostal space. Forty-six (92%) of the patients had the electrodes placed in the third, fourth or fifth intercostal space. Of the four (8%) placements that missed with more than one space, one patient had severe thorax deformities and one was the patient the project coordinator forgot to ask the patient to raise his arms. Of the electrodes that are not in the fourth intercostal space, almost twice as many (13 vs 7) are located to low than to high. Using the Spearman's rank-order correlation in SPSS gave the values of Spearman's correlation (Spearman's Rho), 95% confidence intervals and p-values (*P*) for the correlation between intercostal space placement and other variables. These are shown in Table 6.

	Spearman's Rho	Confidence interval	Significance
Height	-0.049	- 0.33 to 0.24	*P* = 0.73
Weight	-0.208	- 0.47 to 0.083	*P* = 0.15
Sternum length	0.216	- 0.074 to 0.47	*P* = 0.13
Age	0.009	- 0.28 to 0.30	*P* = 0.95
Sex	0.240	- 0.049 to 0.49	*P* = 0.093

Table 6 Correlation between intercostal space and the other variables

As seen in Table 6, all confidence intervals include the value zero and none of the p-values reflect any statistical significance. This is interpretated as no obvious or significant correlation exists for the variables, compared to the placement of the electrodes V1 and V2. A linear correlation between intercostal space placement and sex might not make very much sense, but the numbers indicate some correlation. This is best explored in a cross table with numbers. The result is shown in Table 7.

Intercostal space	**Female**	**Male**	**Total**
2.5	2	0	2
3.0	5	0	5
3.5	3	0	3
4.0	11	11	22
4.5	3	2	5
5.0	5	6	11
6.0	2	0	2
Total	31	19	50

Table 7 Cross table of intercostal space placement vs sex.

Table 7 shows that no males have electrode placements above the fourth intercostal space.

Results – proportions in the CT images

As described in the method section, CT-images were also investigated to explore the proportions of anatomy and the theoretical basis of the ¼ - ½ method, independently of where the electrodes were placed.

The ¼ - ½ method advise that the nearest intercostal space should be chosen if the fingers end up on a rib. By defining the fourth intercostal space as from the centre of the fourth rib to the centre of the fifth rib, **45 of 47 (95,7%)** of the measurements on the CT images were then within the fourth intercostal space. On the 47 images that were analysed, the fourth ICS (centre fourth rib to centre fifth rib) was on average from 19,3% to 34% of the distance from where the costal margins meet to the top of the manubrium. The quarter mark was then within these limits on 45 of the 47 (95,7%) of the images. Taking the average for every pair of measurements, min-max fourth ICS, it was 26,6% of the distance from where the costal margins meet and to the top of the manubrium. The complete table of measurements can be seen in Appendix F

The boundaries for the fourth intercostal space have variations between individuals and were found in this study to be on average from 19,3% to 34% of the distance from the sternal notch to the point where the costal margins meet, for the minimum and maximum limits respectively. The measured boundaries had a range from 12% to 33% for the lower border and a range from 26,1% to 46,4% for the upper border. This is shown graphically in figure 6.

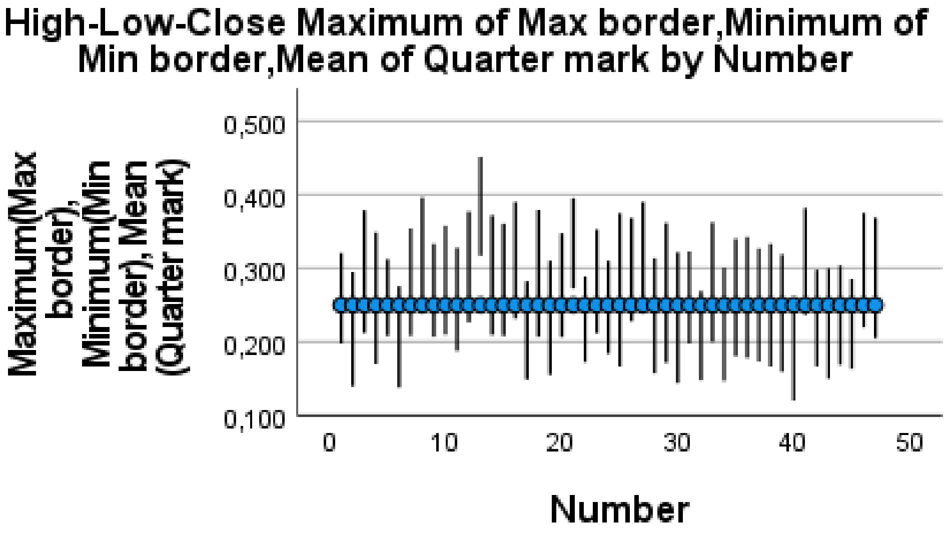


Figure 6. Distribution of the 4. ICS with the ¼ distance (quarter mark) in blue dots.

To better see where the 1/2-1/4 method places the 1/4-mark, the boundaries of the fourth ICS was expressed by the numbers zero and one. This was done mathematically by min-max normalization.

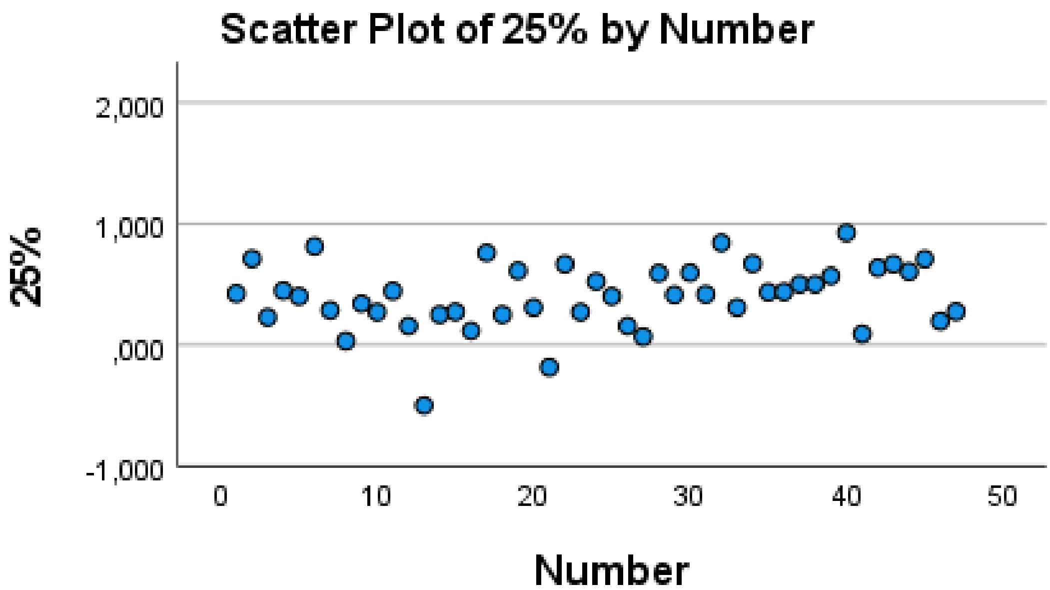


Figure 7. Distribution of the 25% distance. Fourth ICS borders are 0 and 1 (SPSS).

The blue dots in figure 7 are still the 25% distance from where the costal margins meet to the sternal notch. The boundaries for the fourth intercostal space are 0 and 1. Taking the average for every pair of measurements, minimum - maximum fourth intercostal space, it was 26,5% of the distance from where the costal margins meet and to the top of the manubrium. The 1/2-1/4 method presumes that the fourth ICS is at 25%.

	N	Minimum	Maximum	Mean	Std. Deviation
25%	47	- 0.500	0.925	0.402	0.271

Figure 8 Descriptive statistics for the values in figure 7 (SPSS).

From the data in figure 8 we can find a 95% confidence interval by expanding 1,96 standard deviations from the mean. There will then be a 95% probability that the values will be between – 0,129 and 0,933.

The complete table of measurements can be seen in Appendix F.

DISCUSSION

Technical errors in ECG acquirements have been described for a long time. These errors are misplacement errors, reversal errors, failure to reduce artefacts and noise, wrong use of filters and patient positioning errors. Many attempts have been made to improve the accuracy, including advise on repeated education and training, alternative methods for finding the landmarks, devices made to locate the landmarks and devices with prepositioned ECG electrodes on them.

In this thesis emphasis was made on ECG electrode misplacement of the electrodes V1 and V2, which is perhaps the most common mistake. As opposed to reversal of the two limb electrodes on each arm, which also is a common mistake, misplacement of V1 and V2 is not so easy to detect by reviewing the ECG [6].

No known alternative method to position the electrodes V1 and V2 has so far replaced the traditional method on a wider scale. The traditional method requires an ability to correctly identify anatomical landmarks like the ribs and intercostal spaces by counting. Failure to address this issue properly may be due to lack of attention to the problem and that failure to correctly identify the correct landmarks imply that the health care professionals lack knowledge of anatomy, which might be shameful. Emphasis on repeated training and education improves the results, but the core of the problem may be the traditional method itself. That the traditional method of counting is a suboptimal method given its proven lack of accuracy.

Main findings

Most of the patients were elderly, age ranking from 30 to 85 years, with mean and median age 65 and 70 respectively. This corresponds well with the age of patients receiving ECGs in the prehospital environment.

Twenty-two out of fifty (44%) of the patients in the trial had both electrodes placed in the fourth intercostal space, verified by computed tomography. Forty-four percent is not as accurate as initially expected, but 46 of 50 (92%) of the patients had the electrodes placed in within one rib of the proposed ideal. The V1 and V2 electrode placements that were within 2,5 cm from the centre of the fourth ICS would likely not have given significant diagnostic differences compared to an ECG with the V1 and V2 electrodes within the fourth ICS, according to several studies stating that more than 2 – 2,5 cm misplacement increase the risk of misdiagnoses [4,12,13,15,20,24,25,29].

Measurements made on the CT images demonstrated that the 1/2-1/4 method in theory places the 1/4 mark within the borders of the fourth ICS on 45 of 47 (95,7%) of the images if the fourth ICS is defined between the centre of the fourth rib to the centre of the fifth rib. This is an argument for the theoretical goodness of the 1/2-1/4 method. To become the method of choice, considerable practical accuracy also needs to be demonstrated,

Ten (20%) of the patients had the electrodes V1 and V2 placed in different intercostal spaces. When the electrodes were attached to the skin, they were placed on the horizontally same level. There may be two reasons why this displacement has occurred. Firstly, there was a positional change from the electrode placement while the patient was sitting, to the CT scan, where the patients were lying down. Positional change can alter the electrode position relative to inner structures [39].

Secondly, 22 of the images showed that V2 was positioned far more laterally away from the sternum than V1. The ribs meet the sternum at an oblique angle and the lateral distance from the sternum affects which intercostal space the electrodes end up in. The more lateral positioning of many of the V2 electrodes is probably due to a perspective misconception as the project coordinator (DUF) stood on the patients' right side when attaching many of the electrodes, and not in front of them.

Thirty (60%) of the patients had at least one electrode in their fourth intercostal space. In some patients, the electrodes may have ended up in different intercostal spaces because the ribs are not attached to the sternum at the exact same level. In this trial, the cause of the electrodes location in different spaces is mostly believed to be laterally placement of V2 and change in body position between electrode placement and the CT scan. This is because significant height differences between rib attachments to the sternum only occurred in four of the CT images.

Forty-six (92%) of the patients had the electrodes placed in the third, fourth or fifth intercostal space. In the four (8%) patients where the placement missed with more than one space, one patient had severe thorax deformities and one was the patient the project coordinator forgot to ask the patient to raise his arms. Very few of the electrode placements then missed with more than one intercostal space.

Of the electrodes that were not in the fourth intercostal space, almost twice as many (13 versus 7) were located to low rather than to high. This may indicate that the method should advice to choose the nearest intercostal space **upwards**, in the case of the fingers ending up on a rib.

As described in the method section, CT-images were also investigated to explore the proportions of anatomy and the theoretical basis of the ¼ - ½ method, independently of where the electrodes were placed.

Defining the fourth intercostal space as from the centre of the fourth rib to the centre of the fifth rib, 45 of 47 (95,7%) of the measurements on the CT images were within the fourth intercostal space. In the 47 images, the average level of the centre of the fourth intercostal space was 26,6% of the distance from where the costal margins meet and to the top of the manubrium. This number is close to 25%, a number which makes the use of symmetry applicable. The two outliers were examined for distinctive features, but none were found. The costal margins just met more inferiorly in these two images than in the others. The theoretical accuracy of 95,7% justifies further practical testing of the 1/2-1/4 method.

Relation to prior studies

Incidence of ECG electrode misplacement among paramedics is not described in many studies. But by looking at the numbers for other health care professional, there is no reason to believe that paramedic prehospital practice is any better. Incidence in studies suggest that misplacement of the ECG electrodes V1 and V2 is widespread among all health care professionals, except possibly cardiac technicians who do this procedure frequently. Cardiac technicians perform many ECGs, and their work conditions are often well facilitated. Prehospital working conditions often imply urgency and suboptimal environments. Paramedics may have a greater need for methods that are fast and simple.

Medical consequences of precordial ECG electrode misplacement are well described in studies and may lead to false diagnoses, overlooked diagnoses and delay of other treatment. Two of the studies [14,23] have tried to estimate the cost of precordial electrode misplacement. It is difficult to produce an accurate estimate of the unnecessary cost related to this issue, but it has been shown to be considerable [14,22,23]. In addition to the medical consequences, focus on cost will have the advantage of making more people working in health care business interested in the problem. More studies should perhaps focus on cost as an issue to increase the interest in this topic. Alternative methods have been explored by reviewing some of the existing literature. Belts with prepositioned electrodes and slidable plastic rulers have so far not produced convincing and credible results. They may not fit every patient and they represent an additional expense. None of them are in widespread use. All of the studies describing these devices have used expert or experienced clinician opinion when deciding what is the “correct” location in these trials. While these persons undoubtedly are skilled professionals, McCann et al [15] outlined and showed with numbers that this might not be a reliable reference point.

Two of the studies [31,33] describe what seems to be the same trial, exploring the proportions of human anatomy and ratios of the sternum. The difference from their method and this one is that is dependent on a sliding ruler and that they looked at the proportion of length between sternal notch to fourth ICS compared to the total length of sternum, including the xiphoid process. The 1/2-1/4 method does not include the length of the xiphoid process, but the felt lower edge of the sternum right where the two costal margins meet. The use of a sliding ruler and possibly a pillow to identify the tip of the xiphoid process takes away the simplicity of the method and makes it less feasible for prehospital use.

Lehman et al [34] proposed a manual method for finding the second intercostal space in patients. They lay the patient’s hand to the front of the neck and visualized a horizontal line from the base of the thumb to the base of the fifth finger. This level was directly over the second rib or the second intercostal space in 89,3% of the patients. This method has some similarities to a method described by Rautaharju et al [32] where they advise that the sternal angle can be found three fingers width down from the suprasternal notch. Their methods still require counting ribs and spaces downwards to find the fourth intercostal space and they used expert opinion to decide the correct location. Despite a high degree of accuracy in described in the study by Lehman et al [34], this method will probably not revolutionize the process of placing the precordial electrodes V1 and V2. But it is probably useful as an alternative method and in addition to other methods.

The results concerning placement of electrodes using the 1/2-1/4 method in this thesis showed a result equivalent to many other’s studies referred to. However, the exact measurement of anatomic proportions supports the proposed hypothesis that the 1/4-length mark on the sternum represents the insertion point of the fourth intercostal space.

Methodological considerations

In testing of methods, the real placement of the electrodes needs to be confirmed by a reliable source. Other studies have used invisible ink marked by expert opinion. This was originally the method of choice in this thesis, but this test method has the weakness of representing just a few different body statures. The vast variation of body statures and increasing obesity in the population is one of the reasons that the traditional method of counting downwards may not work very well. Bias could be expected in educating the participants in using the new method. There is also a methodological issue in using just a few test persons with invisible ink having 100 persons do ECG on them. It would not test the accuracy of the method because if every participant followed the instructions, they would find the same location, right or wrong. The method would have little variation on one to three specific persons. One person doing the method the same way on many different patients, however, would state something about how good the method really is.

The 1/2 -1/4 method was not tested exactly the way it would be done in the field. Instead of dividing the distances by eyesight and palpate for the closest intercostal space, the method was tested by using measuring tape and placing the electrodes according to the measurements, irrespective of this placement was over a rib or over a space. In the assessment of the CT images, the placement was decided by assessing which intercostal space it would have landed in depending on if the line from the electrode perpendicular to the rib cage hit over or under the centre of the rib. This way of testing the method is not considered inferior to doing the actual method. On one side, the use of measuring tape ensures reproducibility and accuracy to the placements, not relying purely on eyesight and judgement of symmetry. On the other side, the use of eyesight, symmetry and palpation is a part of the method, including its possible weaknesses

The trial was performed in the CT laboratories at St. Olav's University Hospital. The patients were approached prior to their CT scan, but while they were in the same room as the CT machine. Information about the trial was given, consent was obtained, and the two electrodes were placed while the patients were sitting on a chair with their arms raised. They then went up, walked to the CT machine, and lied down. All 50 patients were sitting when the electrodes were attached.

In six of the 50 CT-images, the V1 and V2 positions are vertically displaced compared to each other. They were placed on the horizontally same line on the patient's chest prior to the CT scan. Even if the patients sat on a chair with their arms raised, the change in position from sitting on a chair to lying on the CT board have displaced some of the electrodes. It is not known how many of the electrodes have been displaced because of change in body position, except for the six patients where this obviously has happened because of the very visible vertical displacement compared to each other seen on the CT images. The body positional change is likely to have caused the displacement of the electrodes. Literature describes this effect. One study reported that 14% of their subjects had so significant changes due to mobilization that they were visible on ECG [39]. The measurements and electrode placements of the trial should have been done after the patients were lying at the CT machine, just prior to their scan. This unfortunate circumstance was probably caused by a lack of awareness of this issue and that the project coordinator was in a, for him, unfamiliar environment and did not want to be in the radiographer's way. Change of body position between electrode placement and the CT scan has altered the result, but to what extent is unknown.

None of the 50 patients in the electrode trial were excluded from the analysis of the results. Two of them could be excluded on the basis that one of them had an extremely untypical thorax and the other one did not have raised arms while placing the electrodes. The main result would then be that 22 of 48 (46%) patients had both their electrodes located in the fourth intercostal space and that only two (4%) missed with more than one intercostal space. On the other hand, not excluding anyone does not alter the result significantly, the trial could still claim 50 consecutive patients and strictly following the inclusion/exclusion list determined before the trial. In the review of proportions in the CT images, three of the images had to be excluded. Missing landmarks made it impossible to accurately measure the proportions in these images.

Strengths and limitations

This study of the 1/2-1/4 method was done on 50 consecutive patients not selected in any other way than that they would have an elective CT scan of the thorax. This ensured a variation in age, body statures, weight, and height. Age varied from 30 to 85 years, with a median age of 70. Even if the patient sample did not include any patient from 18 to 29 years of age, it does reflect well the age group typically having ECGs performed on them by the prehospital emergency medical services.

Computed tomography appears to be an accurate method to visualize the structures of the thorax and to verify electrode placement. CT. Many studies have used expert opinion to verify correct placement, but this may not be a reliable standard [15].

Location of the initial anatomical landmarks was done according to the 1/2-1/4 method by palpating the sternal notch (top edge of the manubrium) and the point where the costal margins meet. Dividing the distance by 4, was done by a millimetre rated measuring tape, instead of using eyesight and symmetry. This is not believed to have affected the results significantly, but it is considered a limitation, as the actual method of dividing the distance was not used.

The electrodes were placed at the measured 1/4 distance on each side of the sternum, irrespectively of being on a rib or in an intercostal space. The actual method advised that the closest space to the fingers should be chosen. This was compensated by classifying a placement as within an intercostal space if the location seen on the CT image was between the centre lines of the adjacent ribs. It is unknown whether using the actual method by palpating for the closest could have prevented the electrodes from ending up in different intercostal spaces. The electrode placement was done by only one person. Having several persons performing the electrode placement could possibly have brought more diversity and credibility to the test results.

The electrodes should be placed facing the front of the patient. In this trial, most of the placements were done from the patient's right side. This may have contributed to the 22 images demonstrating a V2 placement more laterally away from the sternum than V1, due to perspective misconception. A more lateral placement from the sternum is not according to the guidelines and may affect which intercostal space the electrode is located. This is because the ribs and intercostal spaces are attached to the sternum in an oblique angle.

The electrodes were placed on sitting patients while the CT imaging were done on the patients lying supine in the CT machine. The electrode placement procedure and the verification method should be done consecutively with patients in the exact same position. This may have altered the result significantly.

Educational considerations

A minor proportion (8%) of the study population had their placements more than one space away from the fourth intercostal space. This could be an argument for the goodness of the method, as studies suggest that deviations become clinically important if the precordial electrodes miss with more than 2 - 2,5 cm [4,12,13,15,20,24,25,29]. Twice as many misses (13 versus 7) were placed to low rather than to high. This could imply that in teaching the method, if the fingers end up on a rib, the nearest intercostal space should be found searching upwards**.**

Given the extent and consequences of V1 and V2 electrode misplacement, one could argue that the method would improve the accuracy of precordial electrode placement in many systems, but this depends on how precise they are today. The 1/2-1/4 method results suggest that it can be recommended as an alternative for inexperienced personnel in emergency situations or whenever the traditional method makes it difficult to find the fourth intercostal space with traditional methods. This could be less than ideal working conditions, patient obesity or other body stature issues. The results from the patient CT trial and the CT image proportions show that the 1/2-1/4 method may advise a low placement more often than a high placement. Ideally, the lower boundary should all be below 25%. The method description should include that if the fingers end up on a rib, the closest rib searching **upwards** should be chosen.

A reasonable approach could be to apply several strategies as suggested in the literature. The literature review also shows that there is a need for raised awareness of the extent and consequences of ECG electrode misplacement. An important step is to enable sufficient focus on this subject in educational activities Continued education and reminders among professionals might also be beneficial. Alternative methods should be applied where finding the sternal joint is difficult, including the method suggested in this thesis. The findings in this thesis and in other studies could be of help in further studies, attempting to find an easy and accurate method for placing the precordial ECG electrodes, especially V1 and V2.

CONCLUSION

There is a need for raised awareness of the technical acquisition of ECGs. Special consideration should be given to the placement of the ECG electrodes V1 and V2, as misplacement of them is very frequent and their placement will have impact on how the other precordial ECG electrodes are placed.

Misplacement of the precordial electrodes V1 and V2 have consequences because of false diagnoses and missed diagnoses. This may lead to diagnostic delays, personal consequences, and a considerable financial burden on the health care system.

The prehospital environment requires a method that is easy, fast, and accurate. The method of choice should be to precisely locate the sternal angle as the second rib is attached to this joint. In this thesis a new alternative method using symmetry and assumptions of the proportions of human anatomy was investigated. Half of all patients had correct placement of V1 and V2. By exact measurements, the method proved the theoretical basis of the method in nine out of ten patients. By using findings in this thesis, further investigations using the theoretical basis of this method and applied knowledge from the field combined, a more accurate method should be further validated.

REFERENCES

1. Zègre Hemsey JK, Drew BJ. Prehospital electrocardiography: A review of the literature. J Emerg Nurs [Internet]. 2012;38(1):9–14. Available from: http://dx.doi.org/10.1016/j.jen.2011.09.001
2. Trivedi K, Schuur JD, Cone DC. Can paramedics read ST-segment elevation myocardial infarction on prehospital 12-lead electrocardiograms? Prehosp Emerg Care [Internet]. 2009;13(2):207–14. Available from: http://dx.doi.org/10.1080/10903120802706153
3. Barnes AR, Pardee HEB, White PD, Wilson FN, Wolferth CC: Joint Recommendations of the American Heart Association and the Cardiac Society of Great Britain and Ireland: Standardization of precordial leads. American Heart J, 1938 15: 107
4. Kerwin AJ, Mclean R, Tegelaar H. A method for the accurate placement of chest electrodes in the taking of serial electrocardiographic tracings. Can Med Assoc J. 1960;82:258–61.
5. Ilg KJ, Lehmann MH. Importance of Recognizing Pseudo-septal Infarction due to Electrocardiographic Lead Misplacement. The American Journal of Medicine. 2012 Jan;125(1):23-7.
6. García-Niebla J, Llontop-García P, Valle-Racero JI, Serra-Autonell G, Batchvarov VN, de Luna AB. Technical mistakes during the acquisition of the electrocardiogram. Ann Noninvasive Electrocardiol [Internet]. 2009;14(4):389–403. Available from: http://dx.doi.org/10.1111/j.1542-474X.2009.00328.x
7. Harrigan RA, Chan TC, Brady WJ. Electrocardiographic electrode misplacement, misconnection, and artifact. J Emerg Med [Internet]. 2012;43(6):1038–44. Available from: http://dx.doi.org/10.1016/j.jemermed.2012.02.024
8. Khunti K. Accurate interpretation of the 12-lead ECG electrode placement: A systematic review. Health Educ J [Internet]. 2014;73(5):610–23. Available from: http://dx.doi.org/10.1177/0017896912472328
9. Hadjiantoni A, Oak K, Mengi S, Konya J, Ungvari T. Is the correct anatomical placement of the electrocardiogram (ECG) electrodes essential to diagnosis in the clinical setting: A systematic review. Cardiol Cardiovasc Med [Internet]. 2021;05(02). Available from: http://dx.doi.org/10.26502/fccm.92920192

10. Gregory P, Kilner T, Lodge S, Paget S. Accuracy of ECG chest electrode placements by paramedics: an observational study. British Paramedic Journal. 2021 May 1;6(1):8-14.
11. Rajaganeshan R, Ludlam CL, Francis DP, Parasramka SV, Sutton R. Accuracy in ECG lead placement among technicians, nurses, general physicians and cardiologists. International Journal of Clinical Practice. 2007 Aug 31;62(1):65-70.
12. Wenger W, Kligfield P. Variability of precordial electrode placement during routine electrocardiography. J Electrocardiol [Internet]. 1996 [cited 2022 Oct 5];29(3):179–84. Available from: https://pubmed.ncbi.nlm.nih.gov/8854328/
13. Kligfield P, Gettes LS, Bailey JJ, Childers R, Deal BJ, Hancock EW, et al. Recommendations for the Standardization and Interpretation of the Electrocardiogram. Journal of the American College of Cardiology. 2007 Mar;49(10):1115-22.
14. Rehman M, Rehman NU. Precordial ECG Lead Mispositioning: Its Incidence and Estimated Cost to Healthcare. Cureus. 2020 Jul 7; 12(7).
15. McCann K, Holdgate A, Mahammad R, Waddington A. Accuracy of ECG electrode placement by emergency department clinicians. Emerg Med Australas [Internet]. 2007;19(5):442–8. Available from: http://dx.doi.org/10.1111/j.1742-6723.2007.01004.x
16. Medani SA, Hensey M, Caples N, Owens P. Accuracy in precordial ECG lead placement: Improving performance through a peer-led educational intervention. J Electrocardiol [Internet]. 2018;51(1):50–4. Available from: https://www.sciencedirect.com/science/article/pii/S0022073617301218
17. Ferrie EP, Collum N, McGovern S. The right place in the right space? Awareness of site for needle thoracocentesis. Emergency Medicine Journal. 2005 Nov 1;22(11):788-9.
18. Abobaker A, Rana RM. V1 and V2 pericordial leads misplacement and its negative impact on ECG interpretation and clinical care. Ann Noninvasive Electrocardiol. 2021 Jul;26(4); 26:e12844.
19. García-Niebla J. Comparison of P-Wave Patterns Derived From Correct and Incorrect Placement of V1-V2 Electrodes. Journal of Cardiovascular Nursing. 2009 Mar;24(2):156-61.

20. Kania M, Rix H, Fereniec M, Zavala-Fernandez H, Janusek D, Mroczka T, et al. The effect of precordial lead displacement on ECG morphology. Med Biol Eng Comput [Internet]. 2014;52(2):109–19. Available from: http://dx.doi.org/10.1007/s11517-013-1115-9

21. Bond RR, Finlay DD, Nugent CD, Breen C, Guldenring D, Daly MJ. The effects of electrode misplacement on clinicians' interpretation of the standard 12-lead electrocardiogram. Eur J Intern Med [Internet]. 2012;23(7):610–5. Available from: http://dx.doi.org/10.1016/j.ejim.2012.03.011

22. Walsh B. Misplacing V1 and V2 can have clinical consequences. The American Journal of Emergency Medicine. 2018 May;36(5):865-70.

23. Ajmal M, Marcus F. Standardization in performing and interpreting electrocardiograms. Am J Med [Internet]. 2021 [cited 2022 Oct 5];134(4):430–4. Available from: https://www.amjmed.com/article/S0002-9343(20)31106-2/fulltext

24. Soliman EZ. A simple measure to control for variations in chest electrodes placement in serial electrocardiogram recordings. Journal of Electrocardiology. 2008 Sep;41(5):378-9.

25. Herman MV, Ingram DA, Levy JA, Cook JR, Athans RJ. Variability of electrocardiographic precordial lead placement: a method to improve accuracy and reliability. Clin Cardiol [Internet]. 1991 [cited 2022 Oct 5];14(6):469–76. Available from: https://pubmed.ncbi.nlm.nih.gov/1810683/

26. Roy SK, Shah SU, Villa-Lopez E, Murillo M, Arenas N, Oshima K, et al. Comparison of electrocardiogram quality and clinical interpretations using prepositioned ECG electrodes and conventional individual electrodes. Journal of Electrocardiology. 2020 Mar;59:126-33.

27. Baas LS, Beery TA, Allen GA, Ware S, Lamba S, Abraham WT. Accuracy of the precordial V-Quick patch in persons with cardiac or pulmonary disease. J Emerg Med [Internet]. 2003 [cited 2022 Oct 5];24(2):131–9. Available from: https://pubmed.ncbi.nlm.nih.gov/12609641/

28. Bell SJ, Clifton J, Pease J, Greenfield JC, Leggett S, Maynard C, et al. The evaluation of a precordial ECG BELT: technologist satisfaction and accuracy of recording. J Electrocardiol [Internet]. 2001;34(2):155–9. Available from: https://www.sciencedirect.com/science/article/pii/S0022073601700210

29. Bond RR, Finlay DD, McLaughlin J, Guldenring D, Cairns A, Kennedy A, et al. Human factors analysis of the CardioQuick Patch®: A novel engineering solution to the problem of electrode misplacement during 12-lead electrocardiogram acquisition. Journal of Electrocardiology. 2016 Nov;49(6):911-8.
30. Luc M, Fintel DJ, Klein HO, Childers R, Mor-Avi V, Tzivoni D, et al. Comparison of twelve-lead electrocardiogram using a glove-based recording system with standard methodology. Am J Cardiol [Internet]. 2013;112(6):895–903. Available from: http://dx.doi.org/10.1016/j.amjcard.2013.05.018
31. Day K, Oliva I, Krupinski E, Marcus F. Identification of 4th intercostal space using sternal notch to xiphoid length for accurate electrocardiogram lead placement. J Electrocardiol [Internet]. 2015;48(6):1058–61. Available from: http://dx.doi.org/10.1016/j.jelectrocard.2015.08.019
32. Rautaharju PM, Park L, Rautaharju FS, Crow R. A standardized procedure for locating and documenting ECG chest electrode positions: consideration of the effect of breast tissue on ECG amplitudes in women. J Electrocardiol [Internet]. 1998 [cited 2022 Oct 5];31(1):17–29. Available from: https://pubmed.ncbi.nlm.nih.gov/9533374/
33. Marcus F, Hughes T, Barrios P, Borgstrom M. Clinical location of the fourth and fifth intercostal spaces as a percent of the length of the sternum. J Electrocardiol [Internet]. 2018;51(1):55–9. Available from: http://dx.doi.org/10.1016/j.jelectrocard.2017.05.006
34. Lehmann MH, Katona AM. Proposed bedside maneuver to facilitate accurate anatomic orientation for correct positioning of ECG precordial leads V1 and V2: a pilot study. J Emerg Med [Internet]. 2012 [cited 2022 Oct 5];43(4):584–92. Available from: https://pubmed.ncbi.nlm.nih.gov/22504082/
35. Barold SS. Willem Einthoven and the birth of clinical electrocardiography a hundred years ago. Card Electrophysiol Rev [Internet]. 2003;7(1):99–104. Available from: http://dx.doi.org/10.1023/a:1023667812925
36. Wilson FN, Kossmann CE, Burch GE, Goldberger E, Graybiel A, Hecht HH, et al. RECOMMENDATIONS for standardization of electrocardiographic and vectorcardiographic leads. Circulation [Internet]. 1954 [cited 2022 Oct 5];10(4):564–73. Available from: https://www.semanticscholar.org/paper/da0bb92a3488fbdd9330fa0f53b34250dfc7df01

37. Treder MS. Behind the Looking-Glass: A Review on Human Symmetry Perception. Symmetry. 2010 Jul 22;2(3):1510-43. 1535.

38. Wallen R, Tunnage B, Wells S. The 12-lead ECG in the emergency medical service setting: how electrode placement and paramedic gender are experienced by women. Emerg Med J [Internet]. 2014;31(10):851–2. Available from: http://dx.doi.org/10.1136/emermed-2013-202826

39. Nelwan SP, Meij SH, van Dam TB, Kors JA. Correction of ECG variations caused by body position changes and electrode placement during ST-T monitoring. J Electrocardiol [Internet]. 2001;34 Suppl:213–6. Available from: http://dx.doi.org/10.1054/jelc.2001.28895

APPENDIX A - Abbreviations

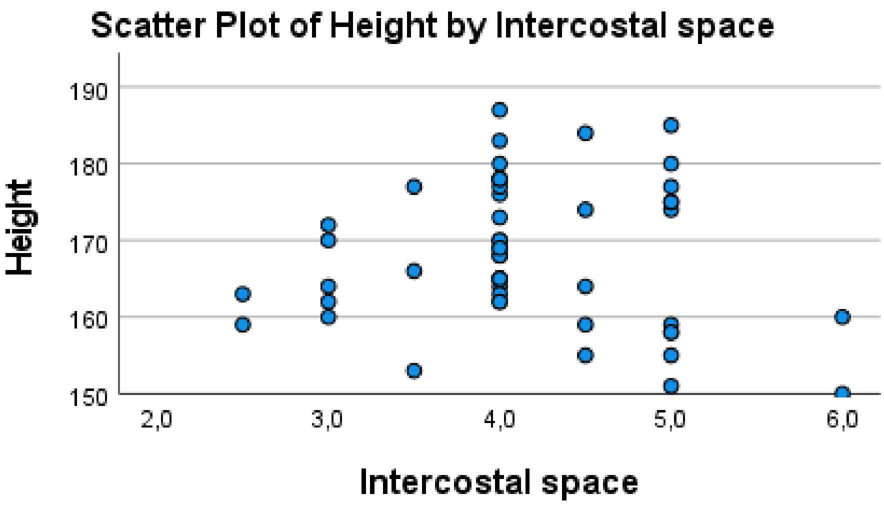
BSPM	Body Surface Potential Mapping
CT	Computer tomography
ECG	Electrocardiogram
EMS	Emergency Medical Services
ICS	Intercostal space
MI	Myocardial infarction
MPR	Multi Planar Reconstructions
PACS	Picture Archive Communication Systems
RBBB	Right bundle branch block
STEMI	ST-elevation myocardial infarction
V1	The first precordial ECG electrode, both the electrode and lead, placed on the chest immediately to the right of the sternum in the fourth intercostal space.
V2	The second precordial ECG electrode, both the electrode and lead, placed on the chest immediately to the left of the sternum in the fourth intercostal space.

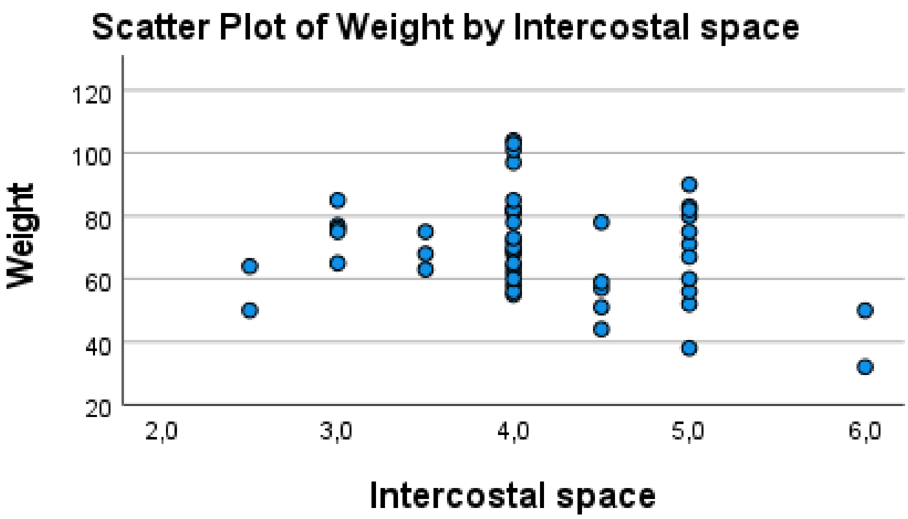
APPENDIX B - Results from the 50 CT images

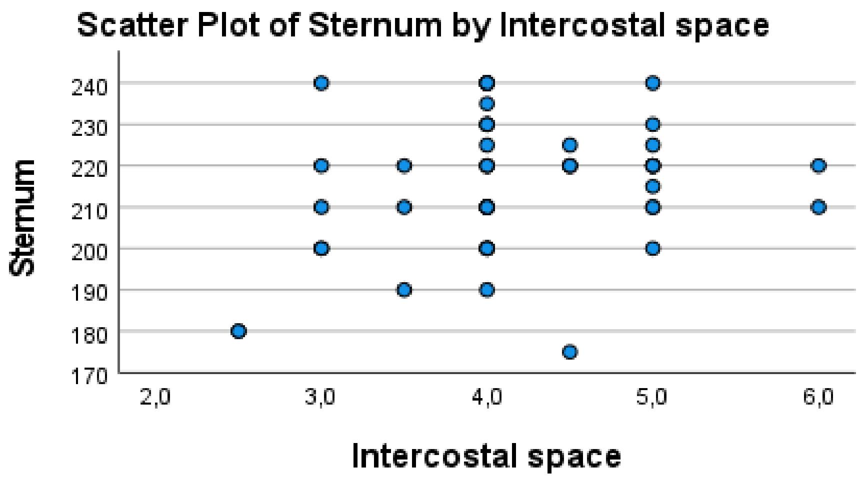
Patient Number	Sex [M/F]	Age [Year]	Weight [kg]	Height [cm]	Sternum [mm]	V1 [ICS]	V2 [ICS]
1	M	65	71	185	220	**5**	**5**
2	F	80	44	159	175	**4**	**5**
3	F	74	52	155	210	**5**	**5**
4	M	54	82	178	220	**4**	**4**
5	M	67	82	183	200	**4**	**4**
6	F	31	32	150	220	**6**	**6**
7	M	82	55	170	225	**4**	**4**
8	M	78	68	168	200	**4**	**4**
9	F	70	62	164	200	**4**	**4**
10	F	62	77	164	200	**3**	**3**
11	F	75	64	163	210	**4**	**4**
12	M	83	69	165	210	**4**	**4**
13	F	47	97	169	240	**4**	**4**
14	M	30	80	174	215	**5**	**5**
15	F	78	85	172	200	**3**	**3**
16	F	77	64	163	180	**2**	**3**
17	M	79	83	175	230	**5**	**5**
18	F	77	56	151	200	**5**	**5**
19	F	65	76	170	220	**3**	**3**
20	M	74	81	176	220	**4**	**4**
21	F	80	50	160	210	**6**	**6**
22	F	59	65	162	200	**4**	**4**
23	F	58	82	170	240	**4**	**4**
24	F	74	65	162	210	**3**	**3**
25	F	71	38	159	220	**5**	**5**
26	F	82	67	158	210	**5**	**5**
27	F	72	58	165	220	**4**	**4**
28	M	51	82	177	225	**5**	**5**
29	M	62	104	187	240	**4**	**4**
30	F	51	51	155	225	**5**	**4**
31	F	61	101	168	230	**4**	**4**
32	F	85	56	165	210	**4**	**4**
33	F	61	85	169	230	**4**	**4**
34	F	38	68	153	190	4	**3**
35	M	68	72	173	210	4	**4**
36	M	70	78	184	220	**5**	**4**
37	F	66	60	158	220	5	**5**
38	M	72	103	180	190	**4**	**4**
39	F	74	63	166	210	4	**3**
40	F	43	75	177	220	3	**4**
41	M	75	78	177	235	**4**	**4**
42	F	41	57	164	220	5	**4**
43	F	62	75	160	240	3	**3**
44	M	76	75	175	220	**5**	**5**
45	M	62	90	180	240	5	**5**
46	F	71	50	159	180	**3**	**2**
47	F	54	70	178	240	4	**4**
48	M	54	73	178	210	**4**	**4**
49	M	72	59	174	220	**5**	**4**
50	F	81	60	162	230	4	**4**

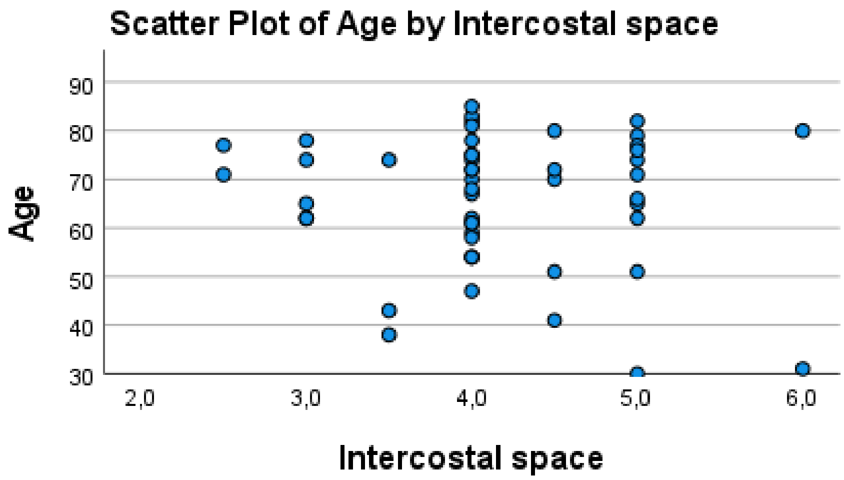
APPENDIX C - Scatter plots of correlation of variables

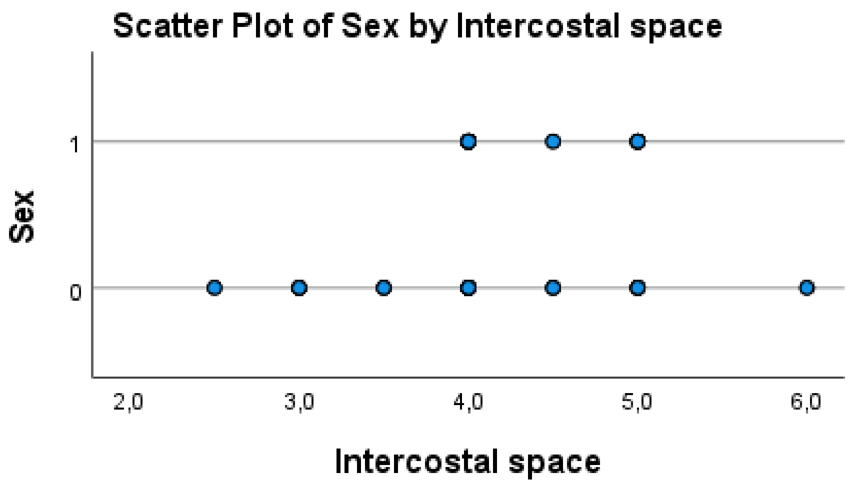
Sex is converted to numbers for statistical use. Digit 0 = female. Digit 1 = male. The intercostal space placement is described by the digits 2 to 6, corresponding to the intercostal spaces respectively. If one electrode was in the third intercostal space and one in the fourth space, it was assigned the value 3,5.






Scatter Plot of Sternum by Intercostal space
Sternum
240
230
220
210
200
190
180
170
2,0
3,0
4,0
5,0
6,0
Intercostal space


Scatter Plot of Age by Intercostal space
Age
90
80
70
60
50
40
30
2,0
3,0
4,0
5,0
6,0
Intercostal space


Scatter Plot of Sex by Intercostal space
Sex
1
0
2,0
3,0
4,0
5,0
6,0
Intercostal space

APPENDIX D - Consent form

Vil du delta i forskningsprosjektet

Ny metode for å plassere EKG-elektroder

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å teste en ny metode for å plassere 2 av elektrodelappene som brukes i et EKG (hjerteprøve). I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål
Vi skal teste om en ny metode for plassering av to av elektrodelappene i et EKG er mer presis enn den som brukes i dag. Dette er en del av en masteroppgave på en videreutdanning innen ambulansefag.

Hvem er ansvarlig for forskningsprosjektet?
Universitetet i Stavanger er ansvarlig for prosjektet, i samarbeid med St. Olavs hospital.

Hvorfor får du spørsmål om å delta?
Du får spørsmål om å delta fordi du som en del av de undersøkelsene skal gjennomgå på sykehuset, skal ta et CT røntgenbilde av brystkassen din. Plasseringen av de to EKG-lappene eller markørene vil synes på røntgen-bildet slik at man ser hvor presist de er plassert. Inni EKG lappen befinner det seg en metallring som sees på røntgenbildet.

Hva innebærer det for deg å delta?

Du får plassert to markører eller EKG-lapper tilsvarende en vanlig hjerteundersøkelse på brystkassen din etter at det har blitt målt med linjal hvor de bør sitte. Disse tas av etter at røntgenbildet er tatt, dersom du ikke allerede har EKG-lapper på deg. Ditt bidrag vil bli registrert som et nummer og hvorvidt plasseringen av lappene var korrekt eller ikke. I tillegg ønsker vi å spørre deg om din vekt, høyde, samt måle lengden av ditt brystben med en linjal. Disse dataene vil bli lagret på et sikret dataområde hvor kun prosjektleder og prosjektkoordinator har tilgang til disse dataene. Ved å delta i undersøkelsen vil dette ikke på noen måte påvirke noen av de andre undersøkelser eller behandlinger som er planlagt i forhold til de symptomer du skal utredes for.

Vi ønsker også å lage en artikkel som beskriver funnene, samt presentere funnene for fora innen akuttmedisin. Vi vil da kun presentere funnene i sin helhet og ditt bidrag vil ikke kunne spores spesifikt til deg.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Det vil ikke ha noen negative konsekvenser for deg

hvis du ikke vil delta eller velger å trekke deg. Du kan når som helst velge å trekke deg fra undersøkelsen.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Ingen identifiserbare pasientopplysninger vil bli registrert, kun data om høyde, vekt, den målte lengden av brystbenet, og om plasseringen av EKG-lappene var korrekt eller ikke.

Opplysningene anonymiseres når prosjektet avsluttes/oppgaven er godkjent, noe som etter planen er 30. juni 2022.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra St. Olavs Hospital og Universitet i Stavanger har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter

Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- å få rettet opplysninger om deg som er feil eller misvisende
- å få slettet personopplysninger om deg
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med en av nedenstående.

Med vennlig hilsen

Oddvar Uleberg
(Forsker/veileder)
Oddvar.uleberg@stolav.no
Mobil: +47 – 482 66 455

Dag Uno Furuknap
(Prosjektkoordinator/Masterstudent)
dufuruknap@hotmail.com
Mobil: +47 – 993 61 413

Jeg har mottatt og forstått informasjon om prosjektet, og har fått anledning til å stille spørsmål. Jeg samtykker til at det måles med linjal på brystkassen min og det plasseres to EKG-elektroder der som kun har til formål å vise plasseringen av dem på røntgenbildet. Lappene vil bli fjernet etter røntgenundersøkelsen dersom du ikke allerede har EKG-elektroder plassert.

Ingen identifiserbare personopplysninger vil bli registrert eller brukt i prosjektet. Kun de data som er beskrevet ovenfor vil bli lagret.

(Signert av prosjektdeltaker, dato)

APPENDIX E - Regional Ethics committee (REK)

REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Oddvar Uleberg

Prosjektsøknad: Ny metode for å plassere EKG elektroder

Søknadsnummer: 375816

Forskningsansvarlig institusjon: St. Olavs Hospital HF

Prosjektsøknad vurderes som utenfor helseforskningslovens virkeområde.

Søkers beskrivelse

Bruk av elektrokardiogram (EKG) er et svært viktig diagnostisk verktøy ved hjertemedisinsk sykdom. Formålet med prosjektet er å teste presisjonen til en ny metode for plassering av to av de 10 elektrodene som brukes ved et 12- avlednings diagnostisk EKG-elektrodene V1 og V2. Plasseringen av disse vil førende for plassering av øvrige prekordiale avledninger. Disse skal ideelt plasseres mellom 4. og 5. ribben (4. interkostalrom). I denne undersøkelsen er det ønskelig å gjøre dette gjøres ved å feste EKG-elektrodene V1 og V2 på pasienter i akuttmottaket på St. Olavs Hospital som skal gjennomgå røntgen toraks som en del av sin innkomstundersøkelse. Av disse inkluderes kun de som er over 18 år, samtykker i å delta i prosjektet, er samtykkekompetente og er triagert til grønn eller gul i henhold til RETTS triagesystem som brukes i akuttmottaket.

Metoden som skal brukes er å måle lengden av brystbenet med linjal. Topp og bunn av brystbenet er anatomiske landemerker som er lett å identifisere ved forsiktig berøring med fingrene. Denne avstanden deles på fire og det måles ut en posisjon som er nøyaktig en fjerdedel fra bunn til topp på brystbenet. Dette er den antatt riktige høydeposisjonen til elektrodene V1 og V2 etter metoden som skal testes. EKG-elektrodene som benyttes er standard EKG-elektroder som også benyttes i akuttmottaket. Disse har en liten rund metallknapp på seg som vil synes på røntgen toraks. Elektrodene plasseres slik at metallknappen er nøyaktig på utmålt sted. Den samtykkende pasienten vil bli spurt om vekt og høyde, slik at dette også registreres.

Røntgenbildene vil i etterkant bli vurdert med hensyn på den faktiske plasseringen av elektrodene i forhold til 4. interkostalrom. Plasseringen vil bli markert på et skjema med tegning av ribbena og mellomrommene.

100 pasienter er tenkt inkludert i studien. Man ønsker å se på hvor mange av dem som får riktig plassert elektrodene ved hjelp av ny metode og om variasjon i treffsikkerhet er systematisk for høy eller lavt eller om det er vilkårlig variasjon i presisjonen.

Litteratur antyder at minst 50 % av alle EKG som blir tatt har feilplasserte elektroder V1 og V2. Det vanligste er at de plasseres for høyt. Dette skyldes delvis at det er vanskelig å identifisere de anatomiske landemerkene som brukes i tradisjonell metode for å måle ut riktig plassering. Feilplasserte elektroder V1 og V2 gjør at de øvrige prekordialelektrodene V3 - V6 også plasseres feil, da disse følger plasseringen av V1 og V2. Konsekvenser av feilplasserte prekordialelektroder er falske funn på EKG som for eksempel hjerteinfarkt, atrie/ventrikkelhypertrofier og høyre grenblokk. Noen tilstander kan også overses dersom elektrodene er feilplassert. Unormale funn på EKG som ikke er reelle kan føre til unødvendige kardiovaskulære undersøkelser med økt risiko for pasienten og unødvendige kostnader for helsevesenet

En mer presis metode for plassering av elektrodene vil potensielt kunne bedre diagnostikk av pasienter og senke kostnadene til helsevesenet.

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK sør-øst C) i møtet 02.12.2021. Vurderingen er gjort med hjemmel i helseforskningsloven (hfl.) § 10.

REKs vurdering

Formålet med det omsøkte prosjektet er å undersøke presisjonen ved en alternativ metode for plassering av EKG elektroder. Etter komiteens vurdering er derfor ikke prosjektets formål å etablere ny kunnskap om sykdom og helse, men om den alternative plasseringsmetodens egnethet for optimal plassering av EKG elektroder. Komiteen konkluderte derfor med at prosjektet faller utenfor helseforskningslovens virkeområde, jfr. helseforskningsloven §2 og §4.

Prosjektet kan gjennomføres uten godkjenning av REK innenfor de ordinære ordninger for helsetjenesten med hensyn til for eksempel regler for taushetsplikt og personvern. Søker bør derfor ta kontakt med enten forskerstøtteavdeling eller personvernombud for å avklare hvilke retningslinjer som er gjeldende.

Vedtak

Etter søknaden fremstår prosjektet ikke som medisinsk og helsefaglig forskning, og det faller derfor utenfor helseforskningslovens virkeområde, jf. helseforskningsloven § 2.

Komiteens avgjørelse var enstemmig.

Komiteens vedtak kan påklages til Den nasjonale forskningsetiske komité for medisin og helsefag, jf. helseforskningsloven § 10, tredje ledd og forvaltningslovens § 28. En eventuell klage sendes til REK Sør-Øst. Klagefristen er tre uker fra mottak av dette brevet, jfr. forvaltningsloven § 29.

Klageadgang

Du kan klage på REKs vedtak, jf. forvaltningsloven § 28 flg. Klagen sendes på eget skjema via REK portalen. Klagefristen er tre uker fra du mottar av dette brevet. Dersom REK opprettholder vedtaket, sender REK klagen videre til Den nasjonale forskningsetiske komité for medisin og helsefag (NEM) for endelig vurdering, jf. forskningsetikkloven § 10 og helseforskningsloven § 10.

Med vennlig hilsen

Erik Fosse Prof.,
PhD. Leder REK
sør-øst C

Anders Strand
Seniorrådgiver

Kopi til:
St. Olavs Hospital HF

APPENDIX F - Norwegian Centre for Research Data (NSD).

Meldeskjema / Alternative method for finding correct placement of ECG electrodes V... / Vurdering

Vurdering

Referansenummer	Type	Dato
985474	Standard	12.01.202

Prosjekttittel

Alternative method for finding correct placement of ECG electrodes V1 and V2 / Ny metode for å plassere EKG elektrodene V1 og V2

Behandlingsansvarlig institusjon

St. Olavs Hospital

Felles behandlingsansvarlige institusjoner

Universitetet i Stavanger/ Det helsevitenskapelige fakultet

Prosjektansvarlig

Oddvar Uleberg

Student

Dag Uno Furuknap

Prosjektperiode

01.12.2021 - 30.06.2022

Kategorier personopplysninger

Alminnelige Særlige

Rettslig grunnlag

Samtykke (art. 6 nr. 1 bokstav a) Uttrykkelig samtykke (art. 9 nr. 2 bokstav a)

Behandlingen av personopplysningene kan starte sa fremt den gjennomføres som oppgitt i meldeskjemaet. Det rettslige grunnlaget gjelder til 30.06.2022.

Meldeskjema

Kommentar

Det er vår vurdering at behandlingen vil være i samsvar med personvernlovgivningen, så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet den 12.1.2022 med vedlegg, samt i meldingsdialogen mellom innmelder og Personverntjenester.

Behandlingen kan starte.

Prosjektet er vurdert av Regionale komiteer for medisinsk og helsefaglig forskningsetikk (REK) til å falle utenfor helseforskningslovens virkeområde i vedtak av 20.12.2021 (ref: 375816). Prosjektet kan derfor gjennomføres uten godkjenning fra REK.

Vi legger til grunn at rekruttering av deltakere til prosjektet foregår på en måte som ivaretar taushetsplikten til helsepersonellet.

TYPE OPPLYSNINGER OG VARIGHET

Prosjektet vil behandle alminnelige personopplysninger og særlige kategorier av personopplysninger om helse frem til 30.6.2022.

LOVLIG GRUNNLAG

Prosjektet vii innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 nr. 11 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse, som kan dokumenteres, og som den registrerte kan trekke tilbake.

For alminnelige personopplysninger vii lovlig grunnlag for behandlingen være den registrertes samtykke, jf. personvernforordningen art.

6 nr. 1 a.

For særlige kategorier av personopplysninger vii lovlig grunnlag for behandlingen være den registrertes uttrykkelige samtykke, jf. personvernforordningen art. 9 nr. 2 bokstav a, jf. personopplysningsloven § 10, jf. § 9 (2).

PERSONVERNPRINSIPPER

Personverntjenester vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen:

om lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen

formalsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formal, og ikke viderebehandles til nye uforenlige formål dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet

lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for a oppfylle formålet.

DE REGISTRERTES RETTIGHETER

Vi vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art.13.

Så lenge de registrerte kan identifiseres i datamaterialet vii de ha føgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18) og dataportabilitet (art. 20).

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned. FØLG DIN INSTITUSJONS RETNINGSLINJER

Personverntjenester legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

Universitetet i Stavanger er felles behandlingsansvarlig institusjon. Personverntjenester legger til grunn at behandlingen oppfyller kravene til felles behandlingsansvar, jf. personvernforordningen art. 26.

For å forsikre dere om at kravene oppfylles, må prosjektansvarlig følge interne retningslinjer/radføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER

Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til Personverntjenester ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilken type endringer det er nødvendig a melde:

https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema Du må vente på svar fra oss for endringen gjennomføres.

OPPFØLGING AV PROSJEKTET

Vi vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Kontaktperson hos oss:

Lisa Lie Bjordal

Lykke til med prosjektet!

APPENDIX G - Measurements from CT images

#	Total distance	1/4 distance	Centre 5. rib	Centre 4. rib	Min border	Max border	Where
1	53	13,25	10,5	17	19,8 %	32,1 %	4. ICS
2	61	15,25	8,5	18	13,9 %	29,5 %	4. ICS
3	33	8,25	7	12,5	21,2 %	37,9 %	4. ICS
4	53	13,25	9	18,5	17,0 %	34,9 %	4. ICS
5	48	12	10	15	20,8 %	31,3 %	4. ICS
6	29	7,25	4	8	13,8 %	27,6 %	4. ICS
7	48	12	10	17	20,8 %	35,4 %	4. ICS
8	53	13,25	13	21	24,5 %	39,6 %	4. ICS
9	87	21,75	18	29	20,7 %	33,3 %	4. ICS
10	81	20,25	17	29	21,0 %	35,8 %	4. ICS
11	64	16	12	21	18,8 %	32,8 %	4. ICS
12	53	13,25	12	20	22,6 %	37,7 %	4. ICS
13	82	20,5	26	37	31,7 %	45,1 %	5. ICS
14	86	21,5	18	32	20,9 %	37,2 %	4. ICS
15	72	18	15	26	20,8 %	36,1 %	4. ICS
16	82	20,5	19	32	23,2 %	39,0 %	4. ICS
17	94	23,5	14	26,5	14,9 %	28,2 %	4. ICS
18	58	14,5	12	22	20,7 %	37,9 %	4. ICS
19	58	14,5	9	18	15,5 %	31,0 %	4. ICS
20	92	23	19	32	20,7 %	34,8 %	4. ICS
21	110	27,5	30	43,5	27,3 %	39,5 %	5. ICS
22	90	22,5	15,5	26	17,2 %	28,9 %	4. ICS
23	85	21,25	18	30	21,2 %	35,3 %	4. ICS
24	87	21,75	16	27	18,4 %	31,0 %	4. ICS
25	72	18	12	27	16,7 %	37,5 %	4. ICS
26	57	14,25	13	21	22,8 %	36,8 %	4. ICS
27	73	18,25	17,5	28,5	24,0 %	39,0 %	4. ICS
28	70	17,5	11	22	15,7 %	31,4 %	4. ICS
29	105	26,25	18	38	17,1 %	36,2 %	4. ICS
30	59	14,75	8,5	19	14,4 %	32,2 %	4. ICS
31	96	24	19	31	19,8 %	32,3 %	4. ICS
32	78	19,5	11,5	21	14,7 %	26,9 %	4. ICS
33	80	20	16	29	20,0 %	36,3 %	4. ICS
34	71,5	17,875	10,5	21,5	14,7 %	30,1 %	4. ICS
35	72	18	13	24,5	18,1 %	34,0 %	4. ICS
36	73	18,25	13	25	17,8 %	34,2 %	4. ICS
37	52	13	9	17	17,3 %	32,7 %	4. ICS
38	66	16,5	11	22	16,7 %	33,3 %	4. ICS
39	69	17,25	11	22	15,9 %	31,9 %	4. ICS
40	71	17,75	8,5	18,5	12,0 %	26,1 %	4. ICS
41	76	19	18	29	23,7 %	38,2 %	4. ICS
42	84	21	14	25	16,7 %	29,8 %	4. ICS
43	80	20	12	24	15,0 %	30,0 %	4. ICS
44	89	22,25	15	27	16,9 %	30,3 %	4. ICS
45	49	12,25	8	14	16,3 %	28,6 %	4. ICS
46	102,5	25,625	22,5	38,5	22,0 %	37,6 %	4. ICS
47	61	15,25	12,5	22,5	20,5 %	36,9 %	4. ICS