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## Ergonomic factors and musculoskeletal pain in sonographers



# Ergonomic factors and musculoskeletal pain in sonographers

Jenny Gremark Simonsen



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DOCTORAL DISSERTATION

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To be defended at Segerfalkssalen at Biomedicinskt centrum, Lund

Date 26<sup>th</sup> of April at 9am.

Faculty opponent

*Professor, Susanne Wulff Svendsen, Arbejdsmedicinsk klinik,  
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| Abstract<br><p><b>Background:</b> Sonographers have a high risk of musculoskeletal disorders. Sonography involves strenuous postures in the neck and upper limbs, and is visually demanding. Echocardiography is especially challenging, with static postures and monotonous movements. <b>Aim:</b> The overall aim of this thesis was to identify ergonomic risk factors for pain in sonographers, and to propose actions for sustainable work conditions. <b>Method:</b> At baseline a questionnaire on occupational factors and perceived pain was distributed to all female sonographers in Sweden (N=291). A qualitative interview was performed in a subgroup (N=22). The physical workload was assessed by technical measurements of postures, movements and muscular load in another subgroup (N=33), comparing different tasks and different techniques for echocardiography. A follow up questionnaire concerning pain was distributed about 2.5 years after baseline. <b>Results:</b> At baseline neck/shoulder as well as elbow/hand pain were associated with computer related eye complaints, high mechanical exposure index (MEI) and high job demands. To perform echocardiography was associated with elbow/hand pain while transducer handling with a two-handed/alternating grip and straight wrist was associated with a low prevalence of elbow/hand pain. The patient's comfort was often prioritised to the disadvantage of working posture. Suggested improvements included reducing the manual handling of the transducer and to alternate hands. Echocardiography was static with awkward wrist postures and a lack of forearm muscular rest. In comparison, none of the techniques explored was optimal. The prevalence of neck/shoulder pain increased during the follow up period. Computer related eye problems, high MEI, high job demands and pain at baseline predicted neck/shoulder pain at follow up in both regions. Full time work and high job demands were associated with a high incidence of pain during the follow up period, whereas full time work was associated with a low recovery of neck/shoulder pain. For elbows hands, high sensory demands and pain at baseline were predictors for pain at follow/up and high sensory demands were associated with a high incidence of pain during the follow up period. <b>Conclusions:</b> We recommend improved visual ergonomics and optimal adjustability of the equipment. For echocardiography, we recommend that the equipment should be arranged so that a variation in work postures is enabled, as none of the techniques was optimal.</p> |   |       |
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# Ergonomic factors and musculoskeletal pain in sonographers

Jenny Gremark Simonsen



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Winston Churchill



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## List of papers

This thesis is based on the following four papers, which are included at the end and referred to in the text by their roman numerals.

- I. Gremark Simonsen J, Nordander C, Axmon A, Arvidsson I. Neck and upper extremity pain in sonographers - Associations with occupational factors. *Applied Ergonomics*, 2017; 58: 245-253.
- II. Gremark Simonsen J, Gard J. Swedish Sonographers' Perceptions of Ergonomic Problems at Work and their Suggestions for Improvements – A Qualitative Study. *BMC Musculoskeletal Disorders*, 2016; 17:391-401.
- III. Gremark Simonsen J, Dahlgvist C, Nordander C, Enquist H, Axmon A, Arvidsson I. Assessments of physical workload in sonography tasks using inclinometry, goniometry and electromyography. *Safety and Health at Work*, *in press*.
- IV. Gremark Simonsen J, Nordander C, Axmon A, Arvidsson I. Predictors of musculoskeletal pain in female sonographers – A follow up study. *Manuscript*.

# Populärvetenskaplig sammanfattning

Ultraljudet introducerades som en undersökningsmetod inom kardiologin på 1950-talet. Den kliniska användningen har därefter expanderat. Ultraljudsdiagnostik används nu inom hälso- och sjukvården inom många olika områden, bland annat inom obstetrik, gynekologi, ortopedi och kärldiagnostik. Biomedicinska analytiker (BMA) är en yrkesgrupp som utför ultraljudsundersökningar av hjärta (ekokardiografi) och/eller kärl. Det är väl känt att yrkesgruppen har besvär i muskler och leder. De relaterar ofta sina besvär till de ergonomiska förhållandena i ultraljudsundersökningen.

En speciell ultraljudsapparat används för undersökningen. Förutom maskinvaran består apparaten av en ställbar bildskärm, ett reglerbart tangentbord och en probe som är fäst vid apparaten med en sladd. Undersökaren sitter framför apparaten och kontrollerar proben med den ena handen, tangentbordet med den andra handen samtidigt som bilderna läses av på skärmen. Belysningen är dämpad i undersökningsrummet för att underlätta tolkningen av bilderna. Patienten ligger eller sitter på en brits. I undersökningen projicerar och trycker BMA:n ultraljudsproben mot patientens hud. Förutom ultraljud utför BMA:n andra undersökningar som till exempel, pacemaker kontroller, administration samt ergometercykeltester.

Huvudsyftet med denna avhandling var att ta reda på vilka de ergonomiska riskfaktorerna var för smärta/besvär i denna yrkesgrupp, samt att föreslå åtgärder för hållbara arbetsförhållanden. Den består av fyra delstudier som tillsammans tillför kunskap om den fysiska arbetssituationen för yrkesgruppen BMA inom ultraljud.

Vid baslinjen deltog 291 kvinnliga BMA anställda på samtliga 45 sjukhusbaserade kardiolog- eller klinisk fysiologi kliniker i Sverige. De besvarade en enkät om individ faktorer, hälsotillstånd i muskler och leder i nacke/övra extremitet, arbetsrelaterade faktorer, fysisk arbetsbelastning och psykosocial arbetsmiljö. En uppföljande enkät skickades till samtliga deltagare efter cirka 2.5 år. Denna besvarades av 209 BMA. En subgrupp (N=22) deltog i fördjupade semistrukturerade intervjuer, baserade på en intervjuguide med frågor om upplevelser av ergonomiska problem samt förslag på förbättringar.

Fysisk belastning registrerades genom tekniska mätningar av arbetsställningar, rörelser och muskelaktivitet i en annan subgrupp (N=33). Armens rörelser registrerades med inklinometri, handledsrörelser registrerades med goniometri och muskelaktiviteten i kappmuskeln och i underarmens sträckarmuskler registrerades med elektromyografi. Vi jämförde den fysiska belastningen i ekokardiografi med andra undersökningar som till exempel kärlundelser, spirometri och administration. Dessutom jämfördes den fysiska belastningen i tre olika tekniker

som användes i ekokardiografi (T1,T2,T3, se figur:2-4; sid:19), för att ta reda på om någon teknik var ergonomiskt mer fördelaktig.

Vid baslinjen var både nack/axelsmärta och armbåge/handsmärta associerade med datorrelaterade ögonbesvär, ett högt mekaniskt index (dvs. bristfällig ergonomi) och höga arbetskrav. Att hålla proben med två händer eller att byta mellan händerna, liksom att hålla proben med rak handled, var associerat med lägre förekomst av armbåge/handsmärta.

De tekniska mätresultaten visade att andel vila i underarmens muskler och rörelsehastigheten i handleden var låga i ultraljudsarbetet. Ekokardiografi var särskilt statistiskt med lägre hastigheter i överarm och handled jämfört med andra ultraljudsundersökningar och andra arbetsuppgifter. Underarmsvilan var extremt låg i probehandlen i ekokardiografi. I arbetet med proben hölls handleden i en ensidigt flekterad (T3) eller ensidigt extenderade position (T1,T2), beroende på arbetsteknik. Andelen vila i kappmuskeln var betydligt högre i T3 jämfört med T1 och T2. Det fanns således skillnader i fysisk belastning i de olika teknikerna i ekokardiografi, men ingen av dem var optimal ur ergonomisk synvinkel.

Resultat från baslinjen visade att ekokardiografi var associerat med en högre prevalens av armbåge/hand smärta och vid intervjun framkom att personalen också upplevde ekokardiografi som mer fysiskt ansträngande än andra ultraljudsundersökningar.

Resultaten visade att obekväma arbetsställningar och rörelser samt krav på precision och koncentration predikterade smärta vid uppföljningen. Möjlighet att anpassa utrustningen predikterade lägre förekomst av nacke/axel smärta. Optimala inställnings möjligheter av ultraljudsapparaten föreslogs som en ergonomisk förbättringsåtgärd vid intervjuerna. Trots detta prioriterade BMA:n patientens välmående framför en bra arbetsställning vid undersökningen.

Otillräckligt justerbar belysning i undersökningsrummet var risk faktor för nacke/axel smärta som också upplevdes som ett problem.

Sammanfattningsvis rekommenderar vi justerbar utrustning, förbättrad synergonomi och variation mellan arbetsuppgifter. Eftersom ingen arbetsteknik i ekokardiografi var mer fördelaktig, föreslår vi att man arrangerar undersökningsrummet så att man kan alternera mellan de olika teknikerna.

## Abstract

**Background:** Sonographers have a high risk of musculoskeletal disorders. Sonography involves strenuous postures in the neck and upper limbs, and is visually demanding. Echocardiography is especially challenging, with static postures and monotonous movements. **Aim:** The overall aim of this thesis was to identify ergonomic risk factors for pain in sonographers, and to propose actions for sustainable work conditions. **Method:** At baseline a questionnaire on occupational factors and perceived pain was distributed to all female sonographers in Sweden (N=291). A qualitative interview was performed in a subgroup (N=22). The physical workload was assessed by technical measurements of postures, movements and muscular load in another subgroup (N=33), comparing different tasks and different techniques for echocardiography. A follow up questionnaire concerning pain was distributed about 2.5 years after baseline. **Results:** At baseline neck/shoulder as well as elbow/hand pain were associated with computer related eye complaints, high mechanical exposure index (MEI) and high job demands. To perform echocardiography was associated with elbow/hand pain while transducer handling with a two-handed/alternating grip and straight wrist was associated with a low prevalence of elbow/hand pain. The patient's comfort was often prioritised to the disadvantage of working posture. Suggested improvements included reducing the manual handling of the transducer and to alternate hands. Echocardiography was static with awkward wrist postures and a lack of forearm muscular rest. In comparison, none of the techniques explored was optimal. The prevalence of neck/shoulder pain increased during the follow up period. Computer related eye problems, high MEI, high job demands and pain at baseline predicted neck/shoulder pain at follow up in both regions. Full time work and high job demands were associated with a high incidence of pain during the follow up period, whereas full time work was associated with a low recovery of neck/shoulder pain. For elbows hands, high sensory demands and pain at baseline were predictors for pain at follow/up and high sensory demands were associated with a high incidence of pain during the follow up period. **Conclusions:** We recommend improved visual ergonomics and optimal adjustability of the equipment. For echocardiography, we recommend that the equipment should be arranged so that a variation in work postures is enabled, as none of the techniques was optimal.

## Abbreviations

|        |   |
|--------|---|
| BMI    | Body Mass Index                                       |
| CI     | Confidence Interval                                   |
| COPSOQ | Copenhagen Psychosocial Questionnaire                 |
| JCQ    | Job Content Questionnaire                             |
| EMG    | Surface electromyography                              |
| MEI    | Mechanical exposure index                             |
| MSDs   | Musculoskeletal disorders                             |
| MVC    | Maximal voluntary contraction                         |
| MVE    | Maximum voluntary EMG activity                        |
| N      | Number of participants                                |
| NIOSH  | National Institute for Occupational Safety and Health |
| NRS    | Numeric Rating Scale                                  |
| PHYI   | Physical exposure index                               |
| PR     | Prevalence ratio                                      |
| SD     | Standard deviation                                    |
| SULMA  | Sustained low level of muscle activity                |
| T      | Technique   |
| VAS    | Visual Analog Scale                                   |





# Introduction

## Ultrasound

Since the introduction of ultrasound in clinical diagnosis of the heart in the 1950s [1] its use has increased. Inge Edler, a cardiologist professional in Lund hospital and Hellmuth Hertz, a physicist together performed the first successful ultrasound cardiogram (UCG) later renamed echocardiography. Echocardiography is probably the most important non-invasive tool for cardiac diagnosis since the invention of the electrocardiograph machine. The clinical use of the ultrasound in health care has expanded to include not only adult and paediatric cardiology but also for example obstetrics, gynaecology and vascular diseases [1]. Diagnostic medical ultrasound is the most dynamic growth area [2]. More than one-quarter of all imaging procedures uses ultrasound and between 1987 and 2005 the number of ultrasonic scans increased from 33 to 53 scans/1000 inhabitants in Sweden[1, 3]. We estimate that more than 100 000 cardiovascular sonography examinations are performed yearly in Sweden. The health care professionals who usually perform ultrasound imaging in Sweden are doctors in different specialties, midwives [4-6] and biomedical scientists (BMA). The occupational title varies in different countries depending on education. The BMAs in our study are denoted sonographers.

## Sonographers

In Sweden, sonographers in physiology clinics and cardiology clinics perform ultrasound imaging of the heart (echocardiography) and vessels (arteries and veins). Often, other tasks are included in the sonographer's work such as spirometry, pacemaker controls, electrocardiography, ergometer exercise test on a bike, and computer work.

The ultrasound examination usually takes place in a special room which is darkened and the artificial light in the room is low to facilitate the viewing of images on the screen.

A special ultrasound device is used (Fig. 1). The device is usually mobile on wheels and consists of a screen, a keyboard and a transducer attached to a cable. The ultrasound device is either positioned to the right or to the left of the examination table. The sonographer sits in front of the device. She handles the keyboard with one hand and the transducer with the other.



**Figure 1**  
Ultrasound device.

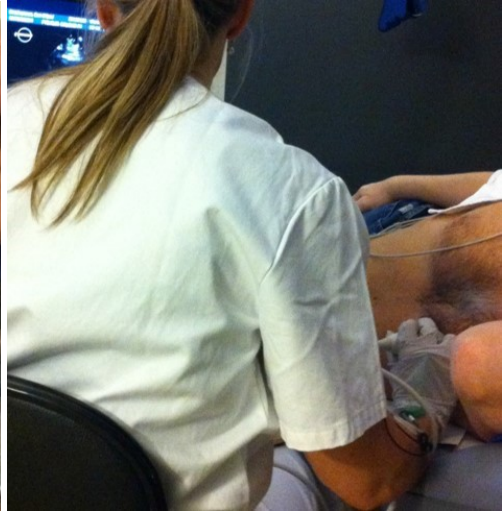
In echocardiography the sonographer usually handles the transducer with one hand and is not comfortable to switch hands, whereas in vascular examinations she usually changes hands. In echocardiography a precise pressure is applied with the transducer to the patient's chest to achieve optimal contact with the skin. The hand is held rather still during the scanning, whereas in the vascular examinations the sonographer moves the transducer along the vessel and due to the superficial location of the vessel a low grip force is applied [7].

In echocardiography examinations the sonographer usually applies one of three different working techniques, which of the techniques depends on local hospital practice. The sonographer either handles the transducer with the left hand (Technique 1, Fig. 2) or with the right hand (Technique 2, Fig. 3). The patient lies on the table facing the examiner in both these techniques. In a third technique the patient lies on the table facing away from the examiner who handles the transducer

with the right hand (Technique 3, Figure 4). In the third technique the limb handling the transducer is more elevated compared to the other two techniques. It is not known if any of the techniques is preferable as concerns risk of musculoskeletal pain.



**Figure 2**  
Technique 1.



**Figure 3**  
Technique 2.



**Figure 4**  
Technique 3.

In other sonography examinations the patient's position depends on the examination, for example in vein mapping the patient sits or is sometimes positioned on a tilting board. The results are analysed by the sonographer either at the ultrasound machine or at a separate computer workstation.

## Risk factors for musculoskeletal disorders

The background for work-related disorders is known to be very multifaceted and the interactions between the individual and workplace risk factors are complex [8]. Physical loads, are usually more obvious work-related causes of MSDs [9]. These loads involve physically demanding postures and movements. Long durations of repetitive movements, work postures with elevated arms above the shoulder level and postures with the back twisted or bent are examples of physically demanding movements and postures [10]. In addition, sustained or high muscular exertions are risk factors. The equipment and workstation design influence on the physical load.

Poor psychosocial support, low job control and high job demands are factors that will increase the risk of MSDs [10]. Further, Unge et al. reported that higher decision latitude and lower work demand was associated with lower physical workload and musculoskeletal disorders in female hospital cleaners [11]. Also, individual factors such as age and gender influence on the exposure. Even if women and men work in the same workplace different exposure and symptoms can be reported depending on gender [12]. Work-related skills, personality and genetic conditions are other individual factors that may influence on the exposure [9].

## Ergonomic risk factors in sonography

Among sonographers, the ergonomic risk factors that have been shown to be associated with musculoskeletal disorders include force, repetition, high velocities, awkward postures, extended duration and muscular load [13]. These risk factors are common in the different work postures in sonography examinations.

Several studies have shown that the handling of the transducer with sustained applied pressure against the patient, awkward wrist postures, shoulder abduction and twisting of the neck and trunk were the key risk factors in sonography [14-16]. Also differences in the sonographers anthropometrics influenced the workload [17].

## **Work postures**

### *The head*

The head is often held in a static and twisted position in sonography [14, 15]. Especially, echocardiography involves an isometric posture of the head to facilitate to read the images on the screen. A review study on neck pain in workers showed that most neck pain results from interactions between the individual and the workplace risk factors [8, 18].

Long durations of static neck postures have also been reported in laparoscopic surgery, another example where precise movements are required. These postures were closely associated with low-level muscle tension, which contributed to an increased risk for the surgeons to develop musculoskeletal disorders [19].

Sonography is also computer intense. In a study by Arvidsson et al. female computer workers had a high prevalence of neck disorders and higher compared to male computer workers with similar work tasks [20].

### *The upper arm*

Scanning with an elevated transducer arm is an often occurring work posture. This especially occurs when the sonographer has to reach over the patient to apply the transducer [17], but also the handling of the keyboard involves some arm elevation. Svendsen et al. showed that quantitative exposure-response relations were established between current work with highly elevated arms and clinically verified shoulder disorders [21]. Also, prolonged elevation entails less time for recovery. Constant trapezius muscle activity, a risk factor according to the Cinderella hypothesis, has been reported in tasks involving a visual and keyboard related work situation [22, 23].

### *The wrist*

The use of the transducer involves awkward wrist postures [24, 25]. That is the wrist is held in an extremely extended or flexed posture. Also sustained bending and twisting are common wrist postures in the transducer handling [17].

Extreme wrist angles have been identified as risk factors for various types of wrist problems such as carpal tunnel syndrome [26-28]. Rempel et al. found that alternative keyboards may prevent or reduce arm pain or disorders probably by reducing the awkward arm and wrist postures [29].

### *Muscular load*

Yet another risk factor was insufficient recovery time between examinations [30, 31]. Sonography involves high and sustained grip forces depending on for instance the type of examination, professional experience and the patients' constitution [7].

Burnett et al. reported that sonographers spend as much as 72% of the scanning time with their scanning arm in a static position [25]. A sustained static handgrip, especially in elevated arm positions, increases the load on the shoulder muscles [32]

Feurstein et al. found that office workers who generated higher keyboard force reported higher upper extremity symptoms [33]. A strong association was seen between high perceived exertion and the development of neck/shoulder and arm/hand symptoms among computer users [34].

### *Visual conditions*

Insufficient lighting and glare appear to be common factors associated with visual troubles [35, 36]. Also, to perform sonography is associated with a high level of concentration when reading and interpreting the images and thus visually demanding, which is known to increase the trapezius muscle activity [37].

Computers have become a part of our everyday life, and as a consequence more people experience eyestrain, tired eyes and irritation [38]. Also, both individual and work-related factors were related to the incidence of eye-symptoms among professional computer users [39].

## Psychosocial workload in sonography

To perform sonography is associated with a high level of concentration in order to achieve good pictures and also a responsibility for the patient, that is to provide an accurate reply to the referral. Hill et al. reported that sonographers were exposed to high demands and low control in the work environment [40]. Low control and increase in the demand of performed examinations place the sonographers at a risk for a high psychosocial workload [15]. High job demands were identified as a risk factor for pain in the neck and upper limbs in a large population [41].

## Work related disorders in sonography

It has been shown in several cross-sectional studies that neck/shoulder, hand and upper back were the sites where pain was most often reported among the sonographers [14, 15, 24]. According to the National Institute for Occupational Safety and Health (NIOSH) sonographers are at risk of developing work-related musculoskeletal disorders in the upper extremities, neck and back [42]. An increase in reported pain has also been shown since the late 1990s [43]. Tendonitis and carpal tunnel syndrome [44] are examples of reported diagnoses.

## Associations between physical work load and pain in the neck and upper extremities among sonographers

The sonographers' work situation has been studied for at least the last two decades [13] and associations between physical work load and pain in the neck and upper extremities have been found in several cross sectional studies [16, 44, 35, 45]. Especially, in echocardiography associations between static postures and monotonous movements in the scanning and pain have been reported [44, 46]. Recommendations have been made concerning how to reduce the risks for musculoskeletal disorders, and it is of great interest to explore which associations that are still in place, in order to propose relevant preventive actions. Further, to date, there are no longitudinal studies in ultrasound.

The knowledge about sonographers' own perception of their work situation is scarce. To our knowledge, only one qualitative study has been performed. To gain a deeper understanding of what can be done it is time that they are given a voice [47]. As echocardiography has been pointed out as especially harmful, in depth analyses of physical exposure including postures, movements and muscular load during sonography in the different techniques for echocardiography are called for.





# Aims and Objectives

The overall aim of this thesis was to identify ergonomic risk factors for pain in sonographers, and to propose actions for sustainable work conditions.

*Specific aim of each paper was*

- To explore associations between physical and psychosocial conditions in pain in neck/shoulders and elbows/hands
- To explore, describe and assess the sonographers' perceptions of ergonomic problems and their suggestions for improvement strategies
- To compare the physical workload in the neck and upper extremities between echocardiography and other work tasks, as well as among different echocardiography techniques
- To identify physical and psychosocial working conditions that predict pain after a follow-up period in neck/shoulders and elbows/hands



# Materials and methods

## *Design overview*

|                     | <b>Paper I</b>   | <b>Paper II</b>   | <b>Paper III</b>   | <b>Paper IV</b>  |
|---------------------|--|---|--|--|
| Title               | Neck and upper extremity pain in sonographers - Associations with occupational factors | Swedish sonographers' perceptions of ergonomic problems at work and their suggestions for improvement | Assessments of physical workload in sonography tasks using inclinometry, goniometry and electromyography | Predictors of musculoskeletal pain – A follow up study |
| Female sonographers | 291  | 22  | 33   | 209  |
| Age: mean (range)   | 44 (24-65)   | 45 (24-59)  | 47 (28-66)   | 46 (24-65)   |
| Study design        | Cross - sectional  | Qualitative   | Technical measurements   | Longitudinal   |
| Analysis method     | Poisson regression, McNemar's test   | Content analysis  | Mann Whitney U-test, Wilcoxon matched-pairs signed rank test   | Poisson regression                                     |

## Data collection

Data was collected from March 2010 until March 2015 (Table 1). The baseline questionnaire was distributed from 2010 until 2012. The sonographers were a part of a larger study population [41] including four different professions (teachers, nurses, assistant nurses and sonographers) and the questionnaires were distributed according to a list. The sonographers were employed in clinical physiology and cardiology clinics in the whole of Sweden. The technical measurements started in 2011 and went partly on at the same time as the baseline data collection. Sonographers employed in four County Councils of the southern Sweden (Skåne, Halland, Blekinge and Kronoberg) participated in the measurements. The interviews went on at the same time as the measurements and a larger part of the informants also participated in the measurements. The follow up questionnaire was distributed between 2012 and 2015. There was some variation in distribution (mean: 29 months; range: 21 – 34 months) due to the distribution in the larger population.

**Table 1.**

Overview of data collection of papers I-IV.

| 2010                                     | 2011 | 2012                                     | 2013                                      | 2014                                 | 2015 |
|--|------|--|---|--------------------------------------|------|
| Baseline questionnaire 2010 03 – 2012 10 |      |  |   |                                      |      |
|  |      |  |   | Interview<br>2014 06<br>– 2015<br>01 |      |
|  |      | Technical measurements 2011 11 – 2015 03 |   |                                      |      |
|  |      |  | Follow up questionnaire 2012 09 – 2015 03 |                                      |      |

## Paper I

*Neck and upper extremity pain in sonographers – Associations with occupational factors*

### Materials

The sonographers included in **Paper I** was a part of a larger study population including assistant nurses, theatre nurses, anaesthetic nurses and teachers (N= 1591) [41]. Female sonographers who worked at least 20 hours per week and performed sonography at least four hours per week during the past three months were included in the analyses (N=291). The sonographers performed echocardiography examinations and/or other sonography examinations, including diverse vascular examinations and screening for hip dislocation. Most of the sonographers also performed other work tasks for example spirometry, ergometer exercise tests on a bike and computer work.

### Methods

Sonographers employed in clinical physiology and cardiology departments in hospitals throughout the whole Sweden received a questionnaire. A subgroup of 117 sonographers (those who worked in county councils of the southern Sweden) was also given a clinical examination of the neck and upper limbs. Symptoms and findings were noted and diagnoses set by the examiners according to criteria for predefined diagnoses [48, 49].

The questionnaire included questions on personal and lifestyle factors, workload, general working conditions, physical and psychosocial working conditions and musculoskeletal pain from the neck and upper limb.

Personal and lifestyle factors included questions on age, height, smoking habits, personal recovery time, exercise, household work and number of children < 15 living at home.

General working conditions comprised questions on seniority as a sonographer, working hours per week, number of hours of sonography, number of examinations per week. Questions were also asked about the work equipment including the screen, the keyboard, the work chair and the examination table. The visual conditions during computer work were also questioned. Physical workload was assessed using a mechanical exposure index (MEI) and a physical exposure index (PHYI). The MEI is based on 11 items concerning awkward postures, static workload and precise movements. The PHYI is based on seven items concerning material handling including lifting [50]. The participants were also asked about satisfaction with ergonomic conditions during computer work.

Psychosocial working conditions were assessed with three dimensions (job demands, job control and job support) of Karasek's Job Content Questionnaire (JCQ) [51]. Further, one dimension of the Copenhagen Psychosocial Questionnaire (COPSOQ) [52] was used, that is "sensorial demands" which concerns eyesight, precision, attention, focus and control of body movements.

Sonographers who performed at least 10 hours of echocardiography per week answered detailed questions about the echocardiography examinations for example the number of examinations performed per day and which hand was used to handle the transducer. Additionally, we asked if the patient was lying facing the examiner on the table or facing away. This led to three possible working techniques (Fig. 2-4). We also obtained information about hand and wrist postures during the examination that is how the transducer was held.

The participants were asked about subjective musculoskeletal complaints (ache, pain or discomfort) in the neck, shoulders, elbows and hands during the preceding 12 months according to the Nordic Questionnaire [53]. Additionally, information about the frequency as well as the intensity of complaints during the past year was asked for. A person was considered to have considerable musculoskeletal pain (subsequently referred to as pain) if reporting any combination that is marked with blue in Figure 5 [41]. The condition was defined separately for the neck/shoulders and elbows/hands.

| Intensity of complaints | Frequency of complaints during the past year |        |           |       |            |
|-------------------------|--|--------|-----------|-------|------------|
|                         | Never  | Seldom | Sometimes | Often | Very often |
| 0 None at all           |  |        |           |       |            |
| 0.5 Very, very slight   |  |        |           |       |            |
| 1 Very slight           |  |        |           |       |            |
| 2 Slight/mild )         |  |        |           |       |            |
| 3 Moderate              |  |        |           |       |            |
| 4 Fairly severe         |  |        |           |       |            |
| 5 Severe                |  |        |           |       |            |
| 6                       |  |        |           |       |            |
| 7 Very severe           |  |        |           |       |            |
| 8                       |  |        |           |       |            |
| 9                       |  |        |           |       |            |
| 10 Very, very severe    |  |        |           |       |            |

**Figure 5.** Combinations within the blue field where defined as *pain* (Arvidsson 2016).

## Statistical methods

To assess associations between the exposure and pain, the prevalence ratios (PRs) with 95% confidence intervals (CIs) were estimated by Poisson regression. PRs were given according to indexes or fixed categories used in the questionnaire. Continuous variables were trichotomized, so that any exposure effect relationship could be assessed. If the number per category was  $\leq 5$  it was merged with an adjacent one.

Personal factors were assessed as potential confounders. We calculated each variable with each outcome variable and considered variables with overall p-values  $\leq 0.2$  as possible confounders. We calculated associations between work factors and pain using crude PRs as well as PRs adjusted for possible confounders. Pain was analysed separately for each region. For neck/shoulders age was a possible confounder and for elbows/hands Body Mass Index (BMI) and children < 15 living at home were possible confounders.

McNemar’s test was used to evaluate paired categorical outcomes, that is pain only in the hand or shoulder that handled the transducer (“transducer shoulder/transducer hand”) compared to the other hand or shoulder (“computer shoulder/computer hand”).

# Paper II

## *Swedish sonographers perceptions of ergonomic problems at work and their suggestions for improvement*

### **Materials**

Twenty-two female sonographers employed in cardiology and clinical physiology departments in hospitals in the County Councils of the southern Sweden participated in the in depth interviews. The heads of the different departments told the sonographers about the interview study and those who were interested contacted the author. The group was then selected.

To achieve a variety in the data collection the following inclusion criteria was used: female sonographers with a variation in age and seniority as a sonographer. Also a variation in workplace, and examinations performed (echocardiography and vascular examinations for example mapping of veins or aorta scanning) were considered in the inclusion procedure.

### **Methods**

Individual qualitative interviews were performed to explore and assess sonographers' perceptions of ergonomic, psychosocial and organisational problems at work. The interviews were performed as in depth interviews to generate all possible perceptions about their problems and strategies at work as well to deepen the awareness and knowledge about the sonographers' work situation. Three content areas were identified in the interviews and the data was used as three separate units of analysis. In this study the ergonomic content of the interviews that is the ergonomic problems and suggestions for improvements was selected as one unit of analysis.

To catch the participants' unique and different perceptions, and to gain direct information without imposing preconceived categories, an interview following a semi-structured guide was performed [54]. It contained open-ended questions concerning ergonomic, psychosocial and organisational problems at work as well as possible solutions to these problems including improvement strategies. The interview was performed as a conversation. We had a dialogue with a reference group consisting of two experienced sonographers during the preparation of the interview guide to ascertain that the most important issues were included in the guide. To get started the interview began with an open question: "How do you perceive your sonography work?"



The interview guide was developed and structured to answer the research questions. In this paper, the addressed research questions were: 1. “What are the perceived ergonomic problems in echocardiography and vascular sonography?” and 2. “How can the working situation be improved ergonomically?”

To ensure that the research questions were answered, follow up questions were used when needed. The interviews took place at the sonographer’s workplace in a separate room and lasted for one hour. The interviews were recorded and transcribed. Pre-interviews and two pilot interviews were performed.

## **Analysis**

Content analysis was used to analyse the transcribed interviews [54]. Content analysis is widely used in studies where the aim is to explore and assess a new research area.

First the interviews were read through several times to get a sense of the whole and to select the unit of analysis. Further meaning units were identified, that is all possible quotes that answer the research questions. Then the meaning units were condensed, to shorten the text but preserving the signification and labelled with a code. The codes were kept close to the text to keep the manifest expression of the text and “let the text talk” [54]. Then preliminary sub categories and categories were developed. The two authors discussed the codes, subcategories and categories until consensus was reached. Finally a number of categories emerged which answered the research questions. [54]. The first step of the analysis was manifest, but labelling the categories required abstraction of the manifest content and could be seen as a latent step in the content analysis.

## **Paper III**

*Assessments of physical workload in sonography tasks using inclinometry, goniometry and electromyography*

### **Materials**

Thirty-three experienced sonographers employed at clinical physiology and cardiology clinics in hospitals in southern Sweden participated in the study. All sonographers were right handed and none reported musculoskeletal pain of such intensity that it influenced on their working technique.

### *Work tasks*

We explored three types of work tasks: echocardiography, other sonography examinations and non-sonography tasks. In echocardiography, work load in technique 1, 2 and 3 were recorded.

Computer work such as administration, interpreting Holter (long-term registration of electrocardiogram) and cardiac stress test were examples of non-sonography tasks. During the cardiac stress test the patient sat on an ergometer bike and the sonographer stood by and registered the heart rate.

## **Methods**

### *Recordings of physical work load*

The participants carried portal loggers that recorded and stored data.

### *Inclinometry*

Inclinometry based on triaxial accelerometers was used to measure postures (relative to the line of gravity) and movements [55]. One inclinometer was placed on the forehead, one on the upper back (C7/Th1) and one on each upper arm. A reference posture was recorded for head, neck and upper back with the participant standing upright looking at a mark in eye level, which defined the 0° of inclination. To determine reference positions for the arms, the participant was seated with the side of the body leaning towards the back of a chair and the arm hanging vertically over the back of the chair with a 2-kg dumbbell in the hand.

### *Goniometry*

Wrist positions and movements were recorded bilaterally for both the flexion/extension and the deviation angles, using biaxial flexible electrogoniometers. The goniometers were attached bilaterally to the wrists, one block on the third metacarpal bone and the other one at the middle between the forearm bones. The reference position was defined with the forearm and hand resting on a table with the elbow flexed 90°. The hand was adjusted so that the third metacarpal bone of the middle finger and the forearm bones pointed along in the same direction, with a sight line between the ulna and third metacarpal bone [56].

### *Electromyography*

Bipolar surface electromyographic (EMG) registrations were recorded bilaterally for the trapezius muscles and the forearm extensor muscles. The electrodes were attached to the descending part of the upper trapezius muscle. The forearm electrodes were applied to the most prominent part of the muscle. The muscular

activity was normalized to EMG recorded during maximal voluntary contractions (MVE). Muscular rest was defined as % time below 0.5% MVE [57].

## **Statistical methods**

As some of the measures were skewed, nonparametric statistical tests were used, and group medians were therefore presented. Group means and standard deviation were presented to enable comparison with earlier studies. In comparisons among independent observations, that is the different echocardiography examinations (for the transducer limb as well as the keyboard limb) the Mann-Whitney U test was used. In comparison among dependent observations, that is echocardiography versus other sonography examination and versus non-sonography tasks, the Wilcoxon matched-pairs signed-rank test was used. As technique one (T1) is the most common technique in Sweden it was chosen for these analyses. As most pain has been reported from the transducer limb we considered it most relevant. We thus compared the recordings from the left limb during echocardiography with the right limb in other work tasks.

## **Paper IV**

*Predictors of musculoskeletal pain in female sonographers – a follow up study*

### **Materials**

The 291 female sonographers who participated in the baseline study (**Paper I**) received a follow-up questionnaire about 2.5 years after baseline (mean 29 months; range range: 21 – 34 months). We received 249 answers that is 42 did not respond. Of the 209 respondents, 43 were excluded for the neck/shoulders and 42 for the elbows/hands. Reasons for exclusion were: missing outcome data at follow up, retired or parental leave and no longer fulfilled the inclusion criteria which was to work at least 20 hours per week and to perform at least four hours of sonography per week.

## Methods

All data was collected at baseline (**Paper I**) except for pain which was collected at both baseline and follow up. All the questions included in the baseline questionnaire were included in the follow up questionnaire. Additionally, a number of questions about changes in the physical work situation in the sonography work and changes in work technique in sonography were added in the follow up questionnaire. Also if the changes had led to an improvement was asked for.

## Statistical methods

We estimated prevalence ratios (PRs) with 95% confidence intervals (CIs) by Poisson regression. Work-related factors were assessed at baseline and outcomes at baseline and follow up. All variables were categorized, preferably dichotomized.

Personal characteristics were assessed as potential confounders in a two-step procedure. In the first step, we assessed the associations pair-wise with each outcome variable. In a second step potential confounders that were related to any of the outcomes (as determined by  $p \leq 0.20$ ) were assessed for an association with the exposure variables. Those that were also associated with any of the exposure variables (again determined by  $p \leq 0.20$ ) were included in the multivariate models. As there were only four smokers we did not consider smoking.

Pain in each region was analysed independently of one another in three models; model I: crude model, model II: adjusted for confounders (BMI and physical exercise for neck/shoulders and height and physical exercise for elbows/hands), model III: adjusted for confounders and pain at baseline. In each of these models we investigated which work-related exposures at baseline predicted pain at follow up.



# Results and comments

## Paper I

*Neck and upper extremity pain in sonographers – Associations with occupational factors*

### **Main results**

Fifty eight percent of the sonographers met the criteria for neck/shoulder pain, and 30% met the criteria for elbow/hand pain. Positive associations with work-related factors and pain were found between eye complaints, a high MEI (poor ergonomics) and high job demands and pain in both regions (Table 2). High seniority in sonography (>15 - 36 years), dissatisfaction with the computer workplace as well as headache related to computer work and also high sensory demands were associated with reported neck/shoulder pain. Negative associations were found between an adjustable keyboard and chair and neck/shoulder pain.

During the study we got to know of a fourth technique (T4; Fig. 6) where two echocardiographers cooperated during the examination that is, one handled the keyboard and the other the transducer with an option of a two-handed/alternating transducer grip.



**Figure 6.**  
Technique 4

To perform echocardiography was associated with elbow/hand pain. Echocardiographers (N=175) reported on average five echocardiography examinations per day. A transducer grip with a straight the wrist and /or a two-handed/alternating grip was negatively associated with elbow/hand pain. More echocardiographers reported pain in the “transducer shoulder” only than in the “computer shoulder” only (33 vs 13,  $p=0.005$ ). Similar results were found for hand pain (30 vs. 4,  $p< 0.005$ ).

**Table 2.**

(short version from Paper I). Associations between pain in neck/shoulders (adjusted for age) and in the elbows/hands (adjusted for BMI and children living at home) and work-related factors in the total study population. The number of participants (N) and prevalence ratios (PR) with 95% confidence intervals (CI), calculated with Poisson regression.

|   | N   | Neck/shoulders<br>(N=289) | Elbows/hands<br>(N=290) |
|---|-----|---------------------------|-------------------------|
|   |     | PR (CI)                   | PR (CI)                 |
| Seniority as a sonographer              |     |                           |                         |
| 1.1 - 6                                 | 95  | 1                         |                         |
| 6.1 - 15                                | 96  | 1.2 (0.9 – 1.6)           |                         |
| 15.1 - 36                               | 96  | <b>1.5 (1.2 – 2.1)</b>    |                         |
| Type of examinations                    |     |                           |                         |
| Other examinations only                 | 70  |                           | 1                       |
| Echocardiography                        | 106 |                           | 1.7 (1.0 – 3.0)         |
| Echocardiography and other examinations | 112 |                           | <b>1.9 (1.1 – 3.3)</b>  |
| Possibility to adjust keyboard          | 233 | <b>0.8 (0.6 – 1.0)</b>    |                         |
| Possibility to adjust chair             | 262 | <b>0.7 (0.6 – 0.9)</b>    |                         |
| Eye complaints related to computer work |     |                           |                         |
| Never                                   | 158 | 1                         | 1                       |
| Seldom                                  | 45  | 0.9 (0.6 – 1.2)           | 0.9 (0.5 – 1.7)         |
| Sometimes                               | 59  | <b>1.3 (1.0 – 1.6)</b>    | 1.3 (0.9 – 2.0)         |
| Often/very often                        | 25  | <b>1.8 (1.6 – 2.2)</b>    | <b>2.2 (1.4 – 3.6)</b>  |
| Headache related to computer work       |     |                           |                         |
| Never                                   | 170 | 1                         |                         |
| Seldom                                  | 60  | <b>1.3 (1.0 – 1.7)</b>    |                         |
| Sometimes                               | 34  | <b>1.8 (1.5 – 2.2)</b>    |                         |
| Often/very often                        | 22  | <b>2.0 (1.7 – 2.4)</b>    |                         |
| Eye sight                               |     |                           |                         |
| Good or adequately corrected            | 238 | 1                         |                         |
| Inadequately corrected                  | 47  | <b>1.4 (1.1 – 1.7)</b>    |                         |
| Mechanical exposure index score         |     |                           |                         |
| Unexposed/low (11 - 15 p)               | 44  | 1                         | 1                       |
| Medium (16 - 19 p)                      | 131 | <b>1.8 (1.1 – 2.7)</b>    | 1.7 (0.9 – 3.4)         |
| High (20 - 33 p)                        | 100 | <b>2.2 (1.4 – 3.3)</b>    | <b>2.0 (1.0 – 3.9)</b>  |
| Compure work- station                   |     |                           |                         |
| Very satisfied                          | 35  | 1                         |                         |
| Rather satisfied                        | 146 | 1.0 (0.7 – 1.4)           |                         |
| Neutral                                 | 67  | 1.0 (0.7 – 1.4)           |                         |
| Rather/very dissatisfied                | 34  | <b>1.5 (1.1 – 2.1)</b>    |                         |
| Job demands                             |     |                           |                         |
| Lowest tertile                          | 85  | 1                         | 1                       |
| Middle tertile                          | 97  | 1.3 (1.0 – 1.8)           | 1.4 (0.8 – 2.3)         |
| Highest tertile                         | 105 | <b>1.6 (1.2 – 2.1)</b>    | <b>1.7 (1.1 – 2.8)</b>  |
| Sensory demands                         |     |                           |                         |
| Lowest tertile                          | 87  | 1                         |                         |
| Middle tertile                          | 113 | 1.3 (1.0 – 1.7)           |                         |
| Highest tertile                         | 84  | <b>1.7 (1.3 – 2.2)</b>    |                         |



## Comments

In comparison with a larger population assessed with the same definition of pain, the sonographers reported a higher prevalence of shoulder pain compared to female teachers (PR 1.3; CI 1.1 – 1.6) [41]. Thus, they are a relevant group for in depth studies in workload and associations with pain.

Among the men (N=30), who were excluded due to a low number of participants, 27% met the criteria for neck/shoulder pain and 20% that for elbow/hand pain. Thus, they had a lower prevalence of pain compared with the female sonographers.

In the female sonographers who underwent a standardized clinical examination 22% fulfilled the criteria for at least one neck/shoulder diagnosis which was higher than among females in varied work, but lower than among females in repetitive/constrained work according to Nordander et al. [48]. The most common neck/shoulder diagnosis was acromioclavicular syndrome (Table 3). For the elbows/hands 7% fulfilled the criteria for at least one diagnosis, which is just above that of females with varied/mobile work, but lower than females with repetitive/constrained work. For elbows/hands carpal tunnel syndrome and ulnar nerve entrapment were the most common diagnoses.

**Table 3 .**  
Clinical diagnoses from 103 of the sonographers.

| Diagnoses                                     | N  | (%)  |
|---|----|------|
| Tension neck                                  | 5  | (5)  |
| Cervical syndrome                             | 9  | (9)  |
| Frozen Shoulder                               | 3  | (3)  |
| Supraspinatus tendinitis                      | 3  | (3)  |
| Infraspinatus tendinitis                      | 5  | (5)  |
| Bicipital tendinitis                          | 7  | (7)  |
| Acromioclavicular syndrome                    | 14 | (14) |
| Lateral epicondylitis or medial epicondylitis | 2  | (2)  |
| Carpaltunnelsyndrome                          | 3  | (3)  |
| Frohe´s syndrome                              | 1  | (1)  |
| Ulnar nerve entrapment/cubital syndrome       | 3  | (3)  |
| Ulnar nerve entrapment at the wrist           | 2  | (2)  |

The questionnaire included a total of 30 questions of work exposure factors and seven detailed questions about echocardiography examinations. We found associations between a number of the ergonomic factors and pain. Some of the exposure measures were objective and some subjective.

The MEI is a subjective variable which reflects awkward work postures, static load or high muscular strain during precise movements [50]. These are often occurring

work postures in the sonographers' work situation [58] and thus, important to ask for. The MEI is validated and has shown to predict neck/shoulder pain prevalence in a population study [59]. Eighty percent of the sonographers reported medium to high MEI scores which in the other study population meant a double to threefold risk for developing neck/shoulder pain.

As we have confirmed the high ergonomic workload with our technical measurements we find the sonographers' perceptions of a high MEI trustworthy. However, since MEI is subjective there may be some overestimation of the association between a high MEI and pain. Still we consider it reliable. The fact that there were dose-response relationships further strengthens this assumption. Based on this we recommend optimization of ergonomic conditions. Adjustable equipment seems to be important as associations with pain were shown.

When stratifying for age (dichotomization by the median 45 years) we found that the youngest worked the most hours per week and performed the most hours of sonography per week. This might explain why higher age was associated with a lower prevalence of neck/shoulder pain. Among the older sonographers the PRs increased with increasing number of hours of sonography per week, though not statistically significant. Among the younger there was no obvious pattern (not in table).

Echocardiography is hand intense including simultaneous transducer and keyboard handling. Quite relevant an association between performing echocardiography and prevalence of elbow/hand pain was found. Echocardiography is also visually demanding, that is observing images during the examination and afterwards analyzing images at a computer work place. Accordingly, we found several associations between pain and visual conditions.

In comparison with the larger population, sonographers together with assistant nurses reported the lowest job control [41], but no association with pain was found. For job demands the sonographers reported the lowest job demands compared to all groups in the larger population. However, an association between job demands in the highest tertile and pain was found [60].

The sonographers reported high sensory demands (e.g. visual demands, attention, control of body movements and precision) in comparison with the other occupational groups [41]. An association was seen between high sensory demands (highest tertile) and pain. Thus, sonographers primarily have a high physical workload, but mentally stressful work tasks may affect the workload which increase the trapezius muscle activity [61] and probably increase the risk.

# Paper II

## *Swedish sonographers perceptions of ergonomic problems at work and their suggestions for improvement*

### **Main results**

The sonographers perceived their work stimulating, but physically exhausting. The main perceived ergonomic problems were echocardiography examinations as they were performed with little variation in posture. Insufficiently adjustable equipment for example if the buttons on the control panel and keyboard were not within comfortable reach was an ergonomic problem. The patient's health and constitution had negative effects on workload and postures.

A common beginner's problem was to press too hard with the transducer forgetting about the physical risks. Also, to obtain good pictures were prioritized to good ergonomics.

A suggested ergonomic improvement strategy was to vary postures during scanning. For example to swap hands and to alter between sitting and standing during the examination. To be two examiners and to have a possibility to consult a colleague if the examination took a long time were other strategies.

Access to optimal equipment adjustability including the table, screen, keyboard and transducer were suggested as an ergonomic improvement strategy. Ergonomic aids were perceived useful if located close at hand.

An encouragement of a broader skill of the sonographers, would increase the possibility to alternate between different kinds of examinations and work tasks, which in turn would contribute to more variation.

The sonographers perceived eyestrain due to poor lighting during the examination and to avoid glare on the screen the ceiling light was only switched on when the patient entered the room. A dimmer was perceived to be a possibility to adjust the artificial light and also to increase the level of luminosity.

To get high quality images was perceived as a higher priority than adjusting the equipment to achieve a comfortable working posture, which enlightened the need to optimize the equipment, which also was a proposal for the ergonomic improvements. More experience in the scanning situation also facilitated a more relaxed work posture especially in the transducer handling. One suggestion to be able to work in a more relaxed posture was to get an opportunity to practice on the equipment to improve and be more accustomed.

The participants perceived that the patient's constitution had negative effects on their workload and posture. This was particularly true as the number of corpulent patients was increasing in number.

## **Comments**

The in depth interview generated important data about the sonographers' perceptions such as the patient's well-being was prioritized before good ergonomics. It is known from other studies that health care professionals put the patients' needs before their own [62]. These problems involve both the importance of safe patient handling and the sonographer's exposition to repeated strain and exertion during the examination [63, 64]. Also, to obtain good pictures were prioritized to good ergonomics.

The study contributed to more in depth information about the ergonomic problems and the strategies to handle these problems. For example, in the interview we asked more specifically about the perception of the lighting and equipment and strategies of how to improve it. This information contributed to valuable insight of the importance of visual ergonomic improvements, to achieve a good working environment for the sonographers.

Also, the participants perceived that the patient's constitution had negative effects on their workload and posture. This was particularly true as the number of corpulent patients was increasing in number.

## **Paper III**

*Assessments of physical workload in sonography tasks using inclinometry, goniometry and electromyography*

### **Main results**

During echocardiography the upper arm of the transducer limb was elevated  $>30^\circ$  93% of the time in T3 (where the arm was held around the patient) (Table 4) which was twice as long as in the other two techniques (T1, T2). In contrast the proportion of muscular rest was noticeably higher in T3 (18%) than in the two other techniques (6%). In T1 and T2 the wrist was extended during the whole examination and in awkward posture about 50% of the time. In T3 the wrist was flexed more than half of the examination time, and in awkward posture 81% of the time, significantly

more than in T1. The wrist velocities were  $< 2^\circ/\text{s}$  and the proportion of time the forearm extensor muscles were at rest was  $< 1\%$  of the time in all techniques.

**Table 4.**

(short version from Paper III) Physical workload in the neck and transducer limb during echocardiography transducer time in 33 female sonographers using three different techniques; p-values from Mann-Whitney U-tests.

|   | T1                         | T2                        | T3                           |
|---|----------------------------|---------------------------|------------------------------|
|   | N = 10                     | N = 13                    | N = 10                       |
|   | Mean (SD)                  | Mean (SD)                 | Mean (SD)                    |
| Upper arm                                     |                            |                           |                              |
| elevation ( $^\circ$ , 50th percentile)       | 28 (4.4) <sup>bbb</sup>    | 22 (12) <sup>ccc</sup>    | 47 (9.4) <sup>bbb,ccc</sup>  |
| elevation above $30^\circ$ (% time)           | 41 (20) <sup>bbb</sup>     | 36 (32) <sup>cc</sup>     | 93 (5.5) <sup>bbb,cc</sup>   |
| Trapezius muscle                              |                            |                           |                              |
| rest ( $<0.5\%$ MVE % time)                   | 6.1 (5.0)                  | 5.6 (10) <sup>c</sup>     | 18 (15) <sup>c</sup>         |
| Wrist flexion/extension****                   |                            |                           |                              |
| 10th percentile ( $^\circ$ )                  | -49 (5.9) <sup>a,bbb</sup> | -57 (10) <sup>a,ccc</sup> | -25 (12) <sup>bbb,ccc</sup>  |
| 50th percentile ( $^\circ$ )                  | -31 (8.2) <sup>bbb</sup>   | -37 (12) <sup>ccc</sup>   | 8.8 (8.4) <sup>bbb,ccc</sup> |
| 90th percentile ( $^\circ$ )                  | -4.2 (13) <sup>bbb</sup>   | -14 (10) <sup>ccc</sup>   | 26 (10) <sup>bbb,ccc</sup>   |
| velocity ( $^\circ/\text{s}$ , 50 percentile) | 1.3 (0.7)                  | 1.0 (0.3)                 | 1.2 (0.1)                    |
| awkward postures (% of time)                  | 46 (15) <sup>b</sup>       | 53 (21)                   | 81 (17) <sup>b</sup>         |
| Forearm extensor muscles                      |                            |                           |                              |
| peak load (% MVE, 90th percentile)            | 18 (6) <sup>b</sup>        | 17 (8) <sup>c</sup>       | 14 (12) <sup>b,c</sup>       |
| rest ( $<0.5\%$ MVE % time)                   | 0.2 (0.4)                  | 0.1 (0.4) <sup>c</sup>    | 0.6 (1.0) <sup>c</sup>       |

<sup>a</sup>T1 vs T2, <sup>b</sup>T1 vs T3, <sup>c</sup>T2 vs T3.

For the keyboard limb no major differences were found in physical workload between the three techniques. The upper arm was elevated above  $30^\circ$  half of the time in all three techniques. The wrist was dorsally extended during the whole transducer time and the proportions of forearm extensor muscles rest were  $< 2\%$ .

In comparison between transducer limb and keyboard limb the proportion of time the extensor muscles were at rest was overall lower in the transducer forearm than in the keyboard forearm and significantly lower in T2 ( $p = 0.002$ ).

Echocardiography was more static compared to other work tasks characterized by low velocities of the head, upper arm and wrist, awkward wrist postures and a lack of forearm muscular rest.

## Comments

In the technical measurements we focused on echocardiography examinations as the number of such examinations increase [60] and are more standardized performed compared to the different vascular examinations. Also, echocardiographers

experienced more work-related pain in a recent study compared to peer employees [46].

During echocardiography the muscular rest in the forearm extensor muscles was 8% which is not extremely low. However, during the transducer time it was below 1% in all techniques. A low muscular rest is considered to be an important risk factor for muscular pain [65, 66]. The transducer time, in our measurements, lasted 15-40 minutes during each examination, and the echocardiographers performed a mean of five such examinations per day. Therefore we suspect this exposure to be a risk factor for pain.

We know that the transducer handling requires precision. Factors that may have influenced the transducer handling were the experience as a sonographer and the patient's constitution [67]. We also know that the sonographers prioritized the patient's wellbeing and to get good images before good ergonomics [67]. In summary the forearm muscular load during transducer time implied an extreme static workload which needs to be mixed with more muscle relaxation. One strategy would be to introduce a variety of work tasks in the schedule.

The trapezius muscular rest was also almost twice as long during the entire echocardiography examination (11%) compared to during transducer time (6%) with the exception of T3 (18%). In T3 the sonographer supported the arm on the patient. However, we consider the trapezius portion of rest within acceptable limits [68].

The head was held in a close to upright position and the head velocity was low, which is typical for computer work [68]. However, we observed that the head was often rotated as the sonographer had to read the images on the screen and the screen was placed to the side of the table. Unfortunately, our measurements do not catch neck rotation.

Concerning awkward wrist postures during transducer time there were large differences between the three techniques (~ 40% - ~ 80% of time). In T3 the wrist was in an awkward posture 80 % of the time, dominated by flexion, whereas in T1 and T2 the wrist was predominantly extended. A neutral posture is preferred [69, 70].

None of the techniques had such ergonomic advantages that we can recommend it. We therefore suggest a rotation between techniques. A rotation between T2 and T3 is preferable as no refurbishment of the examination room will be needed. By changing the patient's position on the table, this can be achieved.

During the baseline study we got to know of a fourth technique (T4) where two echocardiographers cooperated during the examination. Unfortunately we did not have resources to perform measurements on this technique.

## **Robot operated ultrasound**

We performed two technical measurements in echocardiography on the transducer limb when a robot assisted transducer was used [71, 72]. The transducer was attached to a holder and located on the patient. The echocardiographer examined the patient handling the transducer with a joystick. At first the echocardiographer examined the patient manually with the transducer in her right hand. Then she attached the transducer to the holder and repeated the examination, handling the transducer with the joystick in the right hand. The measurements showed that as for the dorsal extension (50th percentile:  $-41^{\circ}$ ) and the upper arm elevation (50th percentile:  $23^{\circ}$ ) the robot assisted transducer examination was performed similarly to T2. Also, the robot assisted transducer handling was performed with low wrist velocities and low proportions of forearm extensor rest. However, the sonographers were not so used to handle the joystick which might have affected the muscular load. Thus, we cannot draw firm conclusion concerning these measurements. Robot-assisted laparoscopy has been shown to be less physically stressful, concerning trapezius muscle activity, compared to standard laparoscopy [73]. Hence, as the handling of the transducer is an ergonomic problem the robot assisted sonography should be further investigated and developed.

## **Paper IV**

*Predictors of musculoskeletal pain in female sonographers – a follow up study*

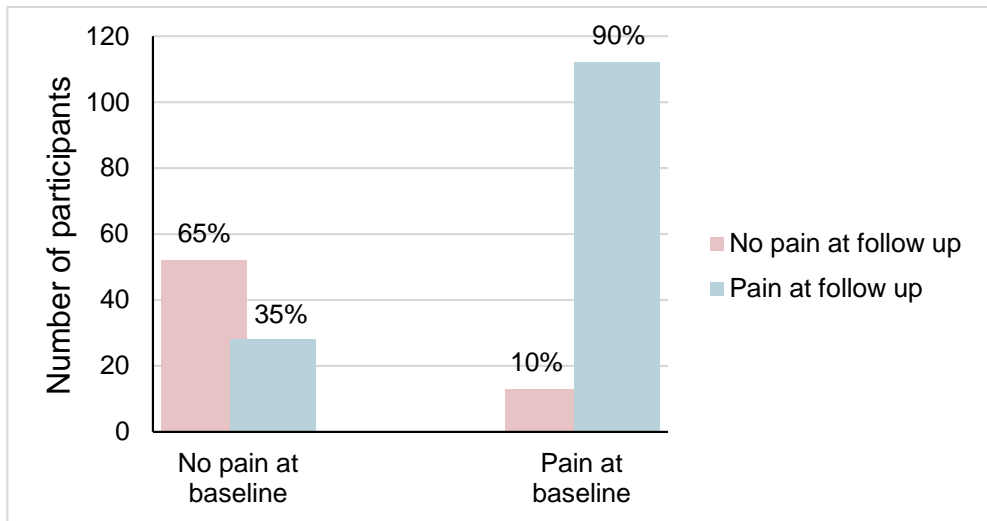
### **Main results**

#### *Neck/shoulder pain*

At baseline 125 of the sonographers had neck/shoulder pain among these 112 still reported pain at follow up (Fig. 7). Among the 80 participants who did not report pain at baseline, 28 developed pain during the follow up period thus, an increase in neck/shoulder pain prevalence from 61% to 68%. Eye complaints and headache related to computer work as well as inadequately corrected eyesight and dissatisfaction with the computer work station were predictors for neck/shoulder pain. The same was true for a high MEI, working with the wrist bent forwards (in echocardiography) and high job demands.

When taking pain at baseline into account, full time work and the possibility to tilt the screen were associated with a lower incidence of pain/or a higher recovery

during the follow up period. Though, high job demands and transducer handling with a forward bent wrist (in echocardiography) were associated with a higher incidence of pain and/or a lower recovery during the follow up period.



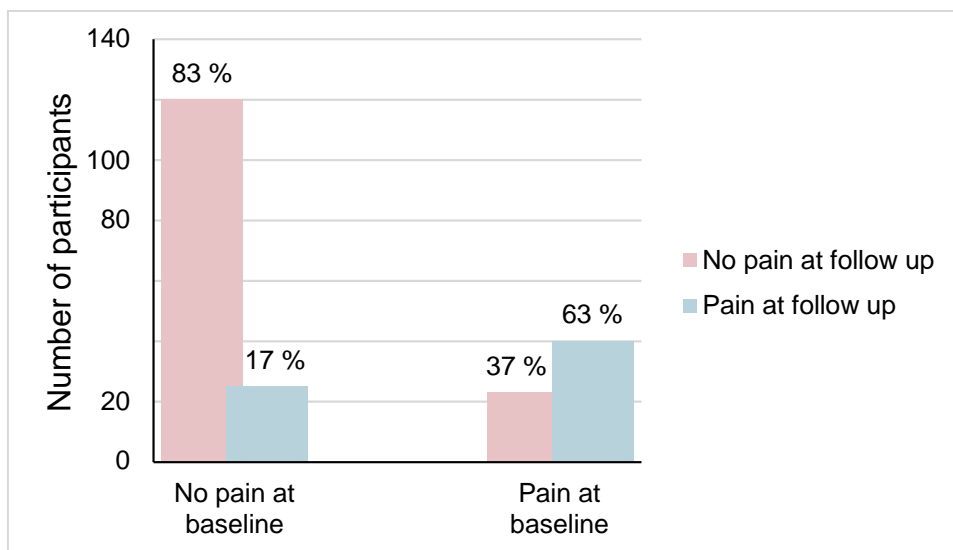
**Figure 7.** Health status at follow up among participants without (N = 80) and with (N = 125) pain at baseline in neck/shoulders.

### *Elbow/hand pain*

At baseline 63 of the sonographers had elbow/hand pain among these 40 still reported pain at follow up (Fig. 8). Among the 145 participants who did not report pain at baseline, 25 developed pain. The pain prevalence increased with 1% (from 30 % to 31%) from baseline to follow up. High sensory demands was a predictor for elbow/hand pain. When taking pain at baseline into account the possibility to adjust screen height and high sensory demands were associated with a lower incidence of pain/or a higher recovery during the follow up period.

Pain at baseline was the strongest predictor for pain at follow up in both body regions.





**Figure 8.** Health status at follow up among participants without (N = 145) and with (N = 63) pain at baseline in elbows/hands.

## Comments

The population was followed on average during two and a half years with a range of 13 months. It would be optimal to have had the same follow up time for all participants, but this was not possible due to logistic reasons. However, when adjusting for follow up time no significant changes in associations between exposures were seen.

One fifth of the study population was excluded at follow up, of these 27 participants no longer fulfilled the inclusion criteria concerning the time in sonography. Of these, only one participant reported pain as a reason for changing jobs. Thus, no healthy worker selection was suspected.

Of the baseline responders, 41 did not answer at follow up. A selection mechanism may be assumed, that is individuals with pain are more likely to answer. They may also be more inclined to experience the workload to be demanding and thus exaggerate the exposure [74]. In fact, the non-responders had less pain in neck/shoulders at baseline.

In comparison with the larger population (Table 5) [75] the sonographers (not exactly the same population of sonographers because of different inclusion criteria, N=217) showed the highest prevalence of neck/shoulder pain at baseline and the prevalence increased more than for any of the other professions from baseline to

follow up. The majority of the sonographers with pain at baseline still reported pain at follow up which is remarkable since these conditions normally fluctuate [76, 77].

Contrary, the prevalence of pain in elbows/hands was almost the same at baseline as at follow up. However, different participants were affected. The prevalence was as high as 31% almost twice as high as among the teachers. This further supports the importance of studying the effect of work conditions in sonography.

**Table 5.**

Neck/shoulder and elbow/hand pain prevalence in a larger population at baseline and at follow up (Arvidsson et al to be published.)

|                   | Neck/shoulder pain |     |           |     | Elbow/hand pain |     |           |     |
|-------------------|--------------------|-----|-----------|-----|-----------------|-----|-----------|-----|
|                   | Baseline           |     | Follow up |     | Baseline        |     | Follow up |     |
|                   | N                  | (%) | N         | (%) | N               | (%) | N         | (%) |
| Teachers          | 244                | 49  | 242       | 46  | 245             | 20  | 244       | 19  |
| Anesthetic nurses | 213                | 48  | 209       | 46  | 214             | 24  | 213       | 25  |
| Theatre nurses    | 209                | 55  | 202       | 59  | 208             | 28  | 207       | 32  |
| Assistant nurses  | 223                | 55  | 217       | 53  | 223             | 42  | 220       | 40  |
| Sonographers      | 222                | 61  | 217       | 67  | 221             | 31  | 221       | 31  |

Among the studied body regions pain in the neck was most common. Figure. 9 shows the reported intensity and prevalence at baseline and at follow up. The most common combination was moderate pain sometimes. This is also where the largest change between baseline and follow up occurred. This combination is included in our definition of pain. This definition of pain has so far only been published in two studies [41, 78] and we consider it relevant as it catches important aspects.

|                         | Frequency of complaints |        |           |       |            |
|-------------------------|-------------------------|--------|-----------|-------|------------|
| Intensity of pain       | Never                   | Seldom | Sometimes | Often | Very often |
| None at all (0)         | 35/33                   | 3/0    |           |       |            |
| Very, very slight (0.5) | 0.5/0.5                 | 0.5/0  | 0/0.5     |       |            |
| Very slight (1)         | 0/0.5                   | 2/1    | 1/0.5     | 0.5/0 |            |
| Slight/mild (2)         |                         | 4/3    | 4/6       | 1/1   | 0.5/0      |
| Moderate (3)            | 0.5/0.5                 | 3/2    | 9/13      | 6/6   | 2/2        |
| Fairly severe (4)       |                         | 1/0.5  | 4/5       | 2/3   | 1/0        |
| Severe (5)              |                         | 0/0.5  | 0.5/3     | 5/2   | 3/1        |
| 6                       |                         |        | 0.5/1     | 4/3   | 3/2        |
| Very severe (7)         |                         | 0.5/0  | 0.5/0     | 1/4   | 1/1        |
| 8                       |                         |        | 0/0.5     | 0.5/1 | 0/1        |
| 9                       |                         |        |           |       | 0/0.5      |
| Very, very severe (10)  |                         |        | 0/0.5     |       |            |

Figure 9.

Prevalence of of neck pain during the past year (%; Baseline/Follow up). Red figures indicate increasing prevalence, blue decreasing and black unchanged. Empty cells indicate 0% at baseline and follow up.

We used the exposure at baseline in the analyses and because of a lower number of participants at follow up we dichotomized the variables when possible. Thus, we lost the possibility to discover exposure-response relationships.

Eye complaints, poor eyesight, headache, high MEI and high job demands were predictors for neck/shoulder pain at follow up and also associated with pain at baseline, which strengthens the assumptions that these factors are of importance.

Full time work, though not associated with pain at baseline, was associated with pain at follow up after adjustment for pain at baseline. This was because among the sonographers with pain at baseline, those who worked full time did not recover as often as those who worked part time (Table 6). Job demands were a risk factor for developing pain among those who were unaffected at baseline.

**Table 6.**

Associations between pain in neck/shoulders and work-related factors. Number of participants with no pain (N=80) and with pain (N=125) and prevalence ratios (PR) with 95% confidence intervals (CI), adjusted for possible confounders and calculated with Poisson regression and adjusted for BMI and physical exercise.

|                        | No pain at baseline (N=80) |       |                        | Pain at baseline (N=125) |       |                        |
|------------------------|----------------------------|-------|------------------------|--------------------------|-------|------------------------|
|                        | N                          | N (%) | PR (CI)                | N                        | N (%) | PR (CI)                |
| Working hours (h/week) |                            |       |                        |                          |       |                        |
| .20 - 36               | 40                         | (50)  | 1                      | 56                       | (45)  | 1                      |
| 37 - 41                | 40                         | (50)  | 0.9 (0.4 – 1.8)        | 69                       | (55)  | <b>1.2 (1.0 – 1.3)</b> |
| Job demands            |                            |       |                        |                          |       |                        |
| Low                    | 49                         | (62)  | 1                      | 56                       | (45)  | 1                      |
| High                   | 30                         | (24)  | <b>1.8 (1.0 – 3.1)</b> | 69                       | (55)  | 1.1 (1.0 – 1.3)        |

A high MEI was associated with elbow/hand pain at baseline but surprisingly not a predictor for pain at follow up. A possible explanation is that those who reported pain at baseline had received a better ergonomic work situation due to their symptoms. In fact several of the sonographers reported ergonomic improvements concerning equipment during the follow up period. However, only two of the sonographers who had recovered since baseline reported ergonomic improvements as the reason for recovery.

High sensory demands were a predictor for elbow/hand pain after taking pain at baseline into account. This was explained by a higher incidence among sonographers without pain at baseline (Table 7). This is reasonable as high sensory demands lead to precise and static postures, confirmed by low muscular rest in the forearm extensors and low wrist velocities registered in our measurements.

At baseline medium long transducer time was associated with a high prevalence of elbow/hand pain, whereas transducer time above 135 minutes per day was associated with a lower prevalence. This might be an effect of healthy worker selection. Also at follow up, when taking pain at baseline into account, longer transducer time was a predictor for pain with a PR of 1.6 (CI 1.0 – 2.7). When data was split into no pain at baseline/pain at baseline (Table 7) we saw the effect in both groups. Therefore, we recommend a limited transducer time per day.

**Table 7.**

Associations between pain in elbows/hands and work-related factors. Number of participants with no pain (N=145) and with pain (N=63) and prevalence ratios (PR) with 95% confidence intervals (CI), adjusted for possible confounders and calculated with Poisson regression and adjusted for height and physical exercise.

|                               | No pain at baseline<br>(N= 145) |      |                        |    | Pain at baseline<br>(N= 63) |                 |         |
|-------------------------------|---------------------------------|------|------------------------|----|-----------------------------|-----------------|---------|
|                               | N                               | N(%) | PR (CI)                |    | N                           | N(%)            | PR (CI) |
| Sensory demands               |                                 |      |                        |    |                             |                 |         |
| Low                           | 82                              | (57) | 1                      | 30 | (48)                        | 1               |         |
| High                          | 62                              | (43) | <b>3.3 (1.5 – 7.3)</b> | 33 | (52)                        | 0.9 (0.6 – 1.3) |         |
| Transducer time (min per day) |                                 |      |                        |    |                             |                 |         |
| 45 - 120                      | 39                              | (51) | 1                      | 34 | (77)                        | 1               |         |
| 121 - 400                     | 38                              | (49) | 1.9 (0.8 – 4.9)        | 10 | (23)                        | 1.5 (0.9 – 2.5) |         |

In summary we consider both visual and physical ergonomics important in prevention for the sonographers' health and a sustainable work situation. We agree with the Industry Standards for the Prevention of Work Related Musculoskeletal Disorders in Sonography first published in 2003 [79] and updated in 2016 [63] which contains detailed recommendations for the reduction of pain prevalence for users of sonography equipment.

# Discussion and conclusions

## General discussion

It is well known that sonographers experience musculoskeletal pain and discomfort in the neck and upper limbs which they relate to their workload. To prevent risk of disorders, adequate risk assessments of the physical workload are required. In this project we wanted to deepen the knowledge. To get as complete a picture as possible of the sonographers' work environment/work situation we used three different research methods that is epidemiological and qualitative methods and technical measurements. Each piece contributes with valuable knowledge. As a whole the result high lightens and adds important information about the ergonomic determinants for pain.

Through the baseline study we got information about associations between exposure and pain. The baseline study contributed to the awareness of what questions should be asked for in the semi structured interview. The interview included a question on suggestions on improvement strategies as we did not catch these aspects in the questionnaire. The in depth interviews deepened our knowledge and understanding of the results. The technical measurements contributed with objective data about the ergonomic conditions which we had only so far observed. By conducting a follow-up study we were able to comment on predictions of pain and possible associations for recovery/incidence of pain.

The technical measurements objectively confirmed that sonography and especially echocardiography involved strenuous and demanding postures. In line with the results from the technical measurements, a high MEI and high sensory demands (questions about work postures and movements) were found as predictors for a high prevalence of pain at follow up in the epidemiological studies. Further, the qualitative study confirmed that the sonographers perceived the work posture in echocardiography as extremely demanding. Thus, the same ergonomic risk factors were found in all three methods which strengthens the results.

Clear ergonomic rules are needed in a context of physical workload in relation to risk of musculoskeletal disorders.

To prevent that workers are affected by work related diseases there are, for most exposures, measurable threshold limit values that should not be exceeded [80]. Unfortunately, the regulation of ergonomic load is unclearly formulated and based on assessment models, checklists and observational methods [10]. However, our research group has recently proposed action levels for ergonomic load and exceeding such levels means unacceptable physical workload and a high risk of work related musculoskeletal disorders [80]. These action levels concern whole day measurements.

These action levels are relevant for our results in the forearm extensor muscular rest (< 5% of time for recovery). In Paper III we did not include whole day measurements. Thus, the comparison with the action levels is not fully applicable, but several tasks showed very low values. However, whole day measurements have been published by Arvidsson et al [41]. The sonographers had 7% muscular rest in mean (SD 5%) indicating that some of them had a lack of recovery. Low recovery and static workload are known risk factors for musculoskeletal disorders [81]. This point to the need of variation in work task.

To perform echocardiography was associated with a higher prevalence of elbow/hand pain and also perceived physically demanding by the informants, in line with the results from the technical measurements. About 70% of the echocardiographers reported one and a half hour to six and a half hours transducer time per day, and transducer time >1.5 hour per day was associated with a higher prevalence of elbow/hand pain. The handling of the transducer is an ergonomic problem. Robot assisted sonography needs to be further developed, and accepted by the sonographers. In laparoscopy the robotic arm is considered the surgeon's "third hand" [82].

We did not measure or ask specifically about luminaires, but we know that incorrect lighting can cause eyestrain and in turn MSDs [36]. Several factors concerning visual ergonomics were associated with pain.

High job demands were a predictor for pain at follow up, including both physical and psychosocial exposures (hard work, a high work force pace or stressful work).

In this thesis we identified a number of areas for prevention. Adjustable equipment, echocardiography and visual ergonomics were the most important. The sonographers should be involved to take an active part in their work situation considering these areas. A holistic and participatory approach is recommended in the risk assessment that is taking into account the combination of risk factors and their interactions [9, 83], and to involve professional experts such as ergonomists and optometrists.

## Generalizability

The results can be generalised to other health professionals who perform ultrasound imaging approximately as many examinations per day as the sonographers. Their ergonomic and visual conditions are similar. Midwives and radiologists are examples of other health professionals. The recommendations also apply to these groups.

## Novelty

Part of the result confirms previously reported associations. However, two factors have previously not been highlighted, that is that the sonographers prioritize the patient's comfort to the disadvantage of working posture, and that to achieve good visual ergonomics a multidisciplinary approach including ergonomists and optometrists is recommended.

## Ethical considerations

For **Paper I, III and IV** ethical approval was included in the application for the larger study [41] as the sonographers studied in **Paper I, III and IV** constitute a part of the larger population. For **Paper II**, the qualitative study, a separate ethical approval was attained. All four studies were approved by the regional ethical review board in Lund.

## Methodological discussion

### Selection bias

In **Paper I** a questionnaire was sent to all female sonographers employed in physiology and cardiology departments in all hospitals in Sweden. Also, sonographers on sick leave received a questionnaire, and the response rate was as high as 86%. Any important selection bias is therefore not suspected. Still, a healthy worker selection cannot be ruled out [84], that is those who have developed disorders may have changed jobs while healthy workers have stayed. Such a selection could possibly obscure associations between exposure and pain, but it is



unlikely that false associations would show up due to healthy worker selection. Hence, we do not think that our conclusions are affected by selection bias.

In **Paper IV** the response rate at follow up was 70% and the non-responders had a lower prevalence of pain. Thus, there may be some selection bias if those participants with pain were more inclined to answer the questionnaire than those without pain which could influence on the results. That is the PR of the exposure could be overestimated if for example participants who experience pain also experience high job demands while participants with no pain and lower job demands are less likely to answer the questionnaire. On the other hand, among the respondents who were excluded because they no longer fulfilled the inclusion criteria only one participant stated MSDs as the reason for changing jobs or work tasks. We find it unlikely that selection bias have had a large impact on the results.

## **Information bias**

In **Paper I** and **Paper IV** there was a risk that participants with pain overestimated their exposure due to the pain, or participants without pain underestimated the exposure resulting in an incorrect association between exposure and pain (so called single source bias) [85]. This comes into play when the reported exposure is subjective, such as job demands and reported transducer time (the time when the sonographers is holding the probe). However, several of the reported associations concerned more objective factors, such as adjustable equipment, and as we saw patterns of risk factors (for example concerning echocardiography) and also confirmed the exposure by technical measurements, we do not think that information bias significantly influenced our results.

The participants were asked questions about intensity and frequency of pain the last 12 months in **Paper I and IV**. Normally pain is fluctuant, and in periods without pain it can be difficult to recall [86]. However, we have no reason to believe that there was a that systematic lack of recalling.

In **Paper III** there was no information bias as technical measurements are objective.

## **Confounding**

Confounding occurs if the exposed and unexposed differ with regard to other factors that affect the risk of developing the disease. Such a factor may introduce an error when estimating the effect of the exposure by comparing the occurrence of disease in the exposed and unexposed. If the factor affects the risk of disease only among the exposed the effect of the exposure is modified but no confounding is introduced [87].

In **Paper I** we selected a number of variables that we thought could be related to the outcome and associations with each outcome variable were assessed pairwise in one step with overall p values  $\leq 0.2$  as possible confounders. In **Paper IV** a second step was performed and potential confounders related to any of the outcomes were also assessed for an association with the exposure variables with overall p values  $\leq 0.2$ . Those that were associated were included in the models. By using the overall p value  $\leq 0.2$  the possibility of catching potential confounders increased.

There may be additional factors with a risk of confounding. However, we think we have taken care of the confounding in our model, though the ultimate would have been to use a two-step model also in **Paper I**.

There are also other ways of handling confounding. Directed acyclic graphs (DAGs) could have been a different way to identify the presence of confounding [88]. However, the number of variables was too many to perform a DAG.

## Exposure assessments

Physical and ergonomic exposure can be measured by self-report in interviews or questionnaires. In self-reports there is a risk of an over- or underestimation of the exposure [89] and a risk of low response validity [74] because of ignorance of what to ask about. The questionnaire used in **Paper I** and **Paper IV** included several questions about the work station some of which were objective while others were subjective with a risk of over- or underestimating the responses. A question about the perception of the computer workplace was added as the sonographer's work is computer intense. The questions about physical and mechanical exposures are validated [90] and the MEI score confirmed previous knowledge of the sonographers' perceptions of static postures.

Psychosocial factors were assessed with the Job Content Questionnaire (JCQ, Karasek and Theorell 1990) [51] which is the mostly used questionnaire for assessing psychological demands in the workplace [91]. We chose to add one dimension of the COPSOQ questionnaire [52] relevant for this study, that was including a dimension containing physical precision and concentration, as the JCQ could not capture the precisions of the physical demands which affect both physical and visual ergonomics.

Observation methods are time consuming and there is none of the available ones that fulfill the requirements for a valid exposure assessment concerning reliability [92] also the inter-rater and intra-rater reproducibility are low [93]. Thus, none was applicable in our study.

Technical measurements are direct high precision recordings of work postures and movements [57, 55]. In **Paper III** technical measurements including assessment of

postures, movement velocity and muscular load were used. The three methods used, inclinometry, goniometry and electromyography (EMG) are well documented, validated and frequently used [55, 94, 57] and representative to measure the physical workload in sonography [24, 95]. Unfortunately, we do not catch neck rotation which would have been adequate to study as we have noticed that work positions with a twisted neck occurs. The number of participants measured was limited due to resources. However, measurements was performed a whole workday and we believe to have caught the variation in work tasks performed [96]. Measurements of sustained low level of muscle activity (SULMA) [97], defined as continuous muscle activity above 0.5% of the maximal EMG activity and quantified into ten predetermined duration (1.5 s – 20 min) intervals, would have provided in depth information of the muscular activity during different work tasks.

In **Paper III** we defined awkward postures for the wrist in percent of time the wrist is flexed  $>5^\circ$  or extended  $>40^\circ$ . Others have chosen other parameters [98]. However we based our definition on a long clinical experience of measurements [99].

## Outcome assessments

In **Paper I** and **Paper IV** we used a novel way to classify pain which has advantages taking into account both frequency and intensity of pain the last 12 months. So far only a few studies have been published [78, 41]. The cut off was set to the best of our knowledge that is participants who had suffered from considerable pain the preceding 12 months represented the pain group. Other alternatives to ascertain severity of pain could have been the Visual Analog Scale VAS [100] or the Numeric Rating Scale (NRS) [101]. However, we believe the model to be relevant taking two important aspects of pain into account and will use it in future studies.

In our study we combined neck and shoulders into one region and elbows/hands into another. We considered it enough to fulfil the pain criteria in one of the two body parts in each region to suffer from considerable pain as our main interest was study which risk factors were associated with pain rather than which body part was most affected.

## Statistical considerations

Though, we included all female sonographers employed in Swedish hospitals, the study groups were rather small in **Paper I** and **Paper IV**. However, we considered it large enough to handle our aims, that is the associations in **Paper I** and further in **Paper IV** the predictions between pain and exposure. For statistical analyses in **Paper I** and **Paper IV** we used the Poisson regression which provides the prevalence

ratio (PR), which we generally think is easier to interpret compared to logistic regression which provides odds ratios. **Paper III** in comparison between techniques in echocardiography and in comparison between echocardiography and other sonography tasks we considered the amount of measurements sufficient to demonstrate statistically significant differences. **In Paper III** we chose non-parametric tests (Mann-Whitney *U test* and Wilcoxon matched-pairs signed-rank test) as some of our data was not normally distributed.

**In Paper IV** we had limited possibility to study associations between risk factors and incidence of new cases, as one fourth of the study population was lost to follow-up and as the prevalence of neck/shoulder pain was already high at baseline. By utilizing the information in the whole study population we were able to assess which factors were predictors in the follow up. In addition by adjusting for pain at baseline we were able to assess how much of the association between exposure and pain that was present already at baseline and how much was due to an association between exposure and in pain from baseline to follow up (either incidence or recovery).

## Qualitative methods

Qualitative research methods are being used increasingly in health science [102]. In **Paper II** an in depth- interview was used to generate data about the sonographers' perceptions. We chose to perform this study in the later part of the project to deepen our knowledge and to get new insights about the sonographers physical work situation. To catch the participants' unique perspective, and to gain direct information without imposing preconceived categories, an interview following a semi structured guide was performed [54].

A selection of the unit of analysis was performed as we had a focus on ergonomic factors and the text was divided into meaning units, coded and categorized [54]. The categories derived from each individual's unique perceptions as in inductive content analysis. That is the categories were developed through reflection and discussion [54, 103].

Terms such as validity and reliability are usually not used in qualitative research instead the term trustworthiness is used including credibility, confirmability, dependability and transferability according to Elo et al. developed by Lincoln and Guba in 1985 [104].

Content analysis is widely used in studies where the aim is to explore and assess a new research area. It is a qualitative method that not requires a specific and deep theoretical base, but is common to use when exploring and assessing a new area.

Successful content analysis requires that the researcher can analyse and simplify data and form categories that reflect the aim of the study in a reliable manner. The

credibility of the research findings also deals with how well the categories cover the data. To achieve credibility the choice of participants and the most appropriate method for data collecting is important. The reader must be given appropriate information to understand the analysis process [54]. We chose the content analysis method to be applicable to our research questions.

Conformability refers to the researcher's ability to be neutral to data. To achieve conformability both authors were involved in the analysis process discussing forth and back between the whole and the parts of the text [54].

Dependability in qualitative studies refers to that the researcher and the informants are interrelated and interacting with each other, thus influencing each other. As perceived realities are constantly changing, questions of replicability are not in focus. Dependability relates to the ability of the researcher to be flexible and change perspective in accordance with the emerging process [102].

Transferability deals with how well the results can be generalized and applied to other similar contexts. Through the in depth interviews we believe that the perceptions expressed are applicable to other health care professionals performing ultrasound imaging.

## Gender aspects

The majority of the sonographers who answered the questionnaire at baseline were females (=291). Only 30 were males and were thus excluded due to the low number of participation. The option to include the men and to stratify by gender was no alternative. Men and women have different biological prerequisites to cope with physical workload since their skeletal anatomy and muscle characteristics differ [105]. Also, in identical work tasks female showed considerably higher muscle activity in relation to capacity, and a higher prevalence of musculoskeletal complaints of the neck and upper extremity than the males did [106, 107]. It is not recommended to simply adjust for gender as gender may be an effect modifier [108].

The male sonographers performed on average 19 hours of echocardiography per week, whereas the female sonographers performed 16 hours per week. Still, the males showed less pain than the females. In general women seem to more vulnerable to musculoskeletal disorders, yet they dominate in this occupation.

We find our recommendations to be applicable to both female and male sonographers as the examination involves visual attention, control of body movements and precision which are risk factors for MSDs regardless of gender if performed without variation in postures and movements.

## Causal inference

We found a number of associations and we believe that several of them are causal. To address causal inference one may use Hill's criteria [108]:

*The strengths of the association.* Some of the associations showed PRs around 2.0 with confidence intervals well above 1.0, which we consider at least moderate strength.

*Consistency.* Many cross-sectional surveys confirm the associations between perceived pain and physical work environment factors among sonographers.

*Specificity.* Though, the prevalence of pain is high, this may also occur in other occupational groups.

*Temporality.* For most of our associations we do not know whether exposure preceded pain, though we suspect so. Only concerning job demands for neck/shoulders and sensory demands for elbows/hands we found an additional association in **Paper IV** after adjusting for pain at baseline.

*Biological gradient.* In **Paper I** we found exposure-response relationships for several risk factors.

*Plausibility.* Most of our associations are plausible for the questionnaire. For the questionnaire we selected exposure factor that we suspected to be risk factors.

*Coherence.* Our associations are in line with knowledge in the ergonomic field. Specifically static and awkward postures are well-known risk factors for pain.

*Experiment.* We are not aware of any experiment concerning sonography work.

*Analogy.* In the 1990s, the introduction of personal computers with poor ergonomics similar to sonography triggered an epidemic of musculoskeletal disorders.

Hence, several of Hill's criteria are fulfilled, and our belief of causality remains.

## Conclusions

At baseline, positive associations were found between eye complaints, a high MEI (poor ergonomics) and high job demands and pain in both regions.

Dissatisfaction with the computer workplace as well as headache related to computer work and also high sensory demands were associated with reported neck/shoulder pain at baseline. Negative associations were found between an adjustable keyboard and chair and neck/shoulder pain.

To perform echocardiography was associated with elbow/hand pain at baseline. More echocardiographers reported pain in the “transducer limb” than in the “computer limb”. In echocardiography, a transducer grip with the wrist bent backwards was positively associated with elbow/hand pain while holding the transducer in a two-handed/alternating grip was negatively associated with elbow/hand pain.

The patient’s comfort and obtaining good images were often prioritized to the disadvantage of working posture. Some participants perceived poor lighting as a problem. Optimal equipment adjustability was suggested. Echocardiography was perceived as less varied in posture compared to vascular examinations.

Echocardiography was static with lower velocities in the upper arm and wrist, compared to other sonography examinations and other work tasks.

The echocardiography techniques had different ergonomic disadvantages. None was optimal. To alternate between the techniques should be better.

A high MEI, eye complaints, dissatisfaction with the computer work station and high job demands predicted neck/shoulder pain. After adjustment for pain at baseline, full time work was associated with a lower recovery and high job demands was associated with a higher incidence of neck/shoulder pain.

Adjustable equipment predicted a lower neck/shoulder pain prevalence, also after adjustment for pain at baseline.

High sensory demands predicted a higher prevalence of elbow/hand pain also after adjustment for pain at baseline.

## Compliance with existing standards and regulations

In summary we consider both visual and physical ergonomics important in prevention for the sonographers' health and a sustainable work situation. We agree with the Industry standards for the prevention of work related musculoskeletal disorders in sonography first published in 2003 [79] and updated in 2016 [63] which contain detailed recommendations for the reduction of pain prevalence for users of sonography equipment.

Our recommendations are represented in the standards. In the future we want them to be a part in the systematic environment work [109]. We believe our recommendations to be relevant to improve and maintain a sustainable working environment [10].

## Recommendations

A multidisciplinary approach considering both physical and visual ergonomics.

Improved logistics in terms of supporting better planning for resources especially for prolonged examinations and complicated patients, and scheduled variation in work tasks.

In echocardiography, arrange the room to make it possible to vary work posture and work technique.

To improve and develop the ergonomic equipment used in sonography, especially the transducer and keyboard with a special focus on echocardiography, and to involve manufacturers in the ergonomic development of the ultrasound device.

To further develop robot assisted sonography.

## Future research

To further identify which are the perceived negative and positive psychosocial and organisational factors in sonography work.

To further explore the use of the robotic-assisted arm in sonography by assessment of the physical workload in sonographers experienced in the use of the robotic arm



To investigate the physical exposure and health among the sonographers after proposed ergonomic interventions in the examination room, especially in echocardiography.

To assess gender differences in physical workload using technical measurements, as our results showed that male sonographers reported a lower prevalence of pain compared to the females.

To further explore and analyse associations in the trapezius muscle activity and reported neck/shoulder pain by calculating the sustained low level of muscle activity (SULMA).

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Paper I







## Neck and upper extremity pain in sonographers e Associations with occupational factors



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### abstract

Sonographers have a high risk of musculoskeletal disorders. This study explores the associations between working conditions and musculoskeletal pain based on the frequency and intensity of pain in the neck and upper extremities. A questionnaire was answered by 291 female sonographers. High prevalence of neck/shoulder pain was associated with eye complaints and headache related to work on the computer, dissatisfaction with the computer workstation, high mechanical exposure index (MEI) and high demands. The possibility to adjust the keyboard and chair, and adequately corrected eyesight were positive factors. High prevalence of elbow/hand pain was associated with performing echocardiography, computer-related eye complaints, high MEI and high job and sensory demands. In echocardiography, working with a straight wrist and holding the transducer with a two-handed grip or alternating hands was associated with a low prevalence of elbow/hand pain. Thus, further improvements in the working conditions are possible and are recommended.

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### 1. Introduction

Many sonographers experience musculoskeletal pain and discomfort in the neck, upper limbs and back (Morton and Delf, 2008; Muir et al., 2004; Pike et al., 1997; Roll et al., 2012; Russo et al., 2002). Sonographic scanning involves static postures and precise movements of the upper limbs (Kim and Roh, 2014; Pike et al., 1997; Wihlidal and Kumar, 1997), which are well known risk factors for neck and upper limb pain (Hagberg, 1996). Furthermore, it involves considerable computer work, in itself a risk factor for pain (Tornqvist et al., 2009). The scanning usually takes place in a dark room, which may lead to eye strain (Wihlidal and Kumar, 1997). However, the extent to which visual ergonomics affects the prevalence of work-related musculoskeletal disorders (WMSDs) is not known.

Sonography yields information on composition of i.a. internal organs, muscles, blood flow and is used in several specialities, such as cardiology, obstetrics, gynecology and radiology. It provides precise information and there is very little risk of adverse events for the patient (Douglas et al., 2007; Frank et al., 2015). Sonographic examinations have become more common over the past decades

(Baker and Coffin, 2013; Schoenfeld et al., 1999), with an increase in the number of examinations and hours of scanning per day for sonographers (Baker and Coffin, 2013; Russo et al., 2002). This may lead to higher prevalence of WMSDs.

Sonography of the heart (echocardiography) has become an invaluable diagnostic tool in daily cardiology practice (Badano et al., 2009; Douglas et al., 2007). Echocardiography requires high grip forces in the transducer hand due to the depth of the scanned organ (Bastian et al., 2009). Increased force in the hand grip may lead to an additionally increased risk of developing musculoskeletal disorders (Vanderpool et al., 1993). Due to the set up in the examination room, echocardiography is performed in one of a limited number of working techniques, but it is not known whether any of these is more favourable in terms of the risk of WMSDs.

The aim of this study was to explore associations between physical and psychosocial working conditions and pain in the neck, shoulders, elbows and hands, in order to propose recommendations for improved working conditions for sonographers. Special attention was paid to the working conditions in echocardiography.

### 2. Participants and methods

#### 2.1. Study design and population

This cross-sectional study comprised sonographers employed in

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clinical physiology and cardiology departments in hospitals throughout Sweden. A self-administered questionnaire was sent to all sonographers in all hospital departments where biomedical scientists performed sonography (45 departments). Female sonographers who worked at least 20 h per week and performed sonography for a minimum of four hours per week since at least three months were included in the analyses (N = 291, participation rate 86%). Male sonographers (N = 28) were excluded, due to the low number of participants.

For the studied population the ultrasonic equipment consists of a screen, a keyboard or a control panel and a transducer attached to a cable. The examiner usually sits on a chair during the examination and holds the transducer in one hand. With the other hand, she operates the keyboard and at the same time she watches the screen. The patient normally lies on an adjustable table and pressure is applied with the transducer to achieve optimal contact with the skin. During vein mapping of the legs the patient usually sits or stands. The transducers are usually palm sized (Lyon et al., 1997).

The examination room is darkened and the artificial light is low to facilitate viewing the images on the screen. The results are analysed by the sonographer, either on the ultrasound machine or on a separate computer workstation. Examinations are sometimes carried out in a ward with the patient in bed (bedside examination).

This study included echocardiography and other sonographic examinations. Other examinations involved mapping of veins, abdominal aorta scanning, examination of the neck vessels and screening for hip dislocation.

The study was approved by the Regional Ethics Committee at Lund University.

## 2.2. Data collection

### 2.2.1. Personal characteristics

The questionnaire included questions on personal characteristics: age, height, body mass index (BMI), smoking habits, personal recovery time, exercise, household work, children under 15 living at home and civil status.

### 2.2.2. General working conditions

The questionnaire included questions on seniority as a sonographer, working hours per week, number of hours of sonography per week, types of examinations and whether bedside examinations were performed. Questions were also asked about the equipment, for example the possibility of adjusting the position of the screen, the keyboard and the chair, the use of a specially designed examination table and where the analysis and reporting were carried out. We also asked about the use of and need for glasses or contact lenses and about eye strain and headache related to computer work.

Physical workload was assessed using a mechanical exposure index (MEI) and a physical exposure index (PHYI) (Balogh et al., 2001; Östergren et al., 2005). The MEI is based on 11 items concerning awkward work postures, static workload and precise movements. The PHYI is based on 7 items concerning material handling including lifting (Balogh et al., 2001). The participants answered each item on a three-point scale 1 = "hardly anything/not at all", 2 = "somewhat" or 3 = "a great deal". The total scores were calculated for each scale (MEI: 11e33; PHYI: 7e21) for each individual. The participants were then categorized according to the level of mechanical exposure: unexposed (11e12), low (13e15), medium (16e19) and high (20e33) and for physical score: unexposed (7e8), low (9e10), medium (11e13) and high (14e21), according to the recommendation of Balogh et al. (2001). The participants were also asked about satisfaction with ergonomic conditions during computer work.

We assessed the psychosocial conditions in terms of *job demands*, *job control* and *job support* using a Swedish version of the Job Content Questionnaire (JCQ) (Karasek et al., 1998; Karasek and Theorell, 1990). Job demands, job control and job support were calculated as the means of nine, nine and eight items, respectively. Each item was assessed using a four-point scale indicating the degree of agreement with various statements concerning conditions at work. Higher values on the scale indicated higher demands, better control and better support.

One dimension of the Copenhagen Psychosocial Questionnaire (COPSOQ) (Kristensen et al., 2005) was used to obtain an estimate of sensory demands, by the five questions that concern eye sight, precision, attention, focus and control of body movements. The participants answered the questions on a five-point scale (0 = "hardly ever/to a very little extent, 25 % seldom/to little extent, 50 % sometimes/to some extent, 75 % often/to a large extent and 100 % always/to a very large extent) and the mean value was calculated for each participant.

### 2.2.3. Working conditions in echocardiography

Through the questionnaire, echocardiographers, i.e. sonographers who performed echocardiography at least ten hours per week, were identified. The questionnaire included detailed questions about echocardiographic examinations, such as the number of hours worked per week, the number of examinations per day and transducer time (the time during which the echocardiographer uses the transducer during an examination).

We also asked which hand was used to hold the transducer, dominant, non-dominant or two-handed/alternating grip. Further we asked whether the patient was lying towards or away from the examiner on the table. This led to four possible working techniques:



Fig. 1. Working technique 1: the patient was facing the examiner, who held the transducer in the left hand.

1, the patient was facing the examiner, who held the transducer in the left hand (Fig. 1), or 2, in the right hand (Fig. 2), or 3, the patient was facing away from the examiner, who held the transducer in the right hand (Fig. 3). In technique 4, the patient was facing the examiner, and either two sonographers examined the patient: one held the transducer with both hands and the other operated the ultrasound equipment (Fig. 4), or the sonographer alternated between hands.

Through the questionnaire, we also obtained detailed information on hand and wrist postures during examinations, such as how the transducer was held in different projections: apical (the heart tip), parasternal (left side of the sternum) and subcostal (below the ribcage). Four alternatives were considered: "like a pen", "between the index and middle finger", "with all fingers around the transducer" or "other grip". Three alternatives were used for wrist position: "straight wrist", "bent forwards" or "bent backwards".

#### 2.2.4. Musculoskeletal pain

The participants were asked about musculoskeletal troubles (ache, pain or discomfort) in the neck, shoulders, elbows and hands during the preceding 12 months following the Nordic Questionnaire (Kuorinka et al., 1987). In addition, for each body region, information was collected about the frequency of complaints during the past year using a 5-point scale (never, seldom, sometimes, often or very often) (Holmström and Moritz, 1991), as well as the intensity of complaints on a ten-point scale from 0 (none at all) to 10 (very, very severe) (Borg, 1990). A participant was considered to have considerable musculoskeletal pain (subsequently referred to simply as "pain") if reporting complaints at least "seldom" with an intensity of at least 7 (very severe), or "sometimes" with an



Fig. 3. Working technique 3: the patient was facing away from the examiner, who held the transducer in the right hand.



Fig. 4. Working technique 4: the patient was facing the examiner who held the transducer with both hands.



Fig. 2. Working technique 2: the patient was facing the examiner, who held the transducer in the right hand.

intensity of at least 3 (moderate), or "often" or "very often" with an intensity of at least 2 (slight/mild) (Arvidsson et al., 2016). The condition was defined separately for the neck/shoulders and elbows/hands.

#### 2.3. Statistics

The prevalence ratios (PRs) with 95% confidence intervals (CIs), estimated by Poisson regression, were used to assess associations with neck/shoulder and elbow/hand pain. PRs are given for personal, as well as work-related factors according to indexes or fixed categories used in the questionnaire. If the number of participants per category was  $\leq 5$  it was merged with an adjacent one. For working techniques and wrist positions a few participants reported divergent conditions that could not be merged with another one and were thus excluded. Continuous variables were trichotomized as there were no consistent linear effects. We calculated univariable PRs for personal factors and considered variables with overall  $p$ -values  $\leq 0.20$  for any outcome possible confounders. We then calculated associations between work factors and pain using crude PRs as well as PRs adjusted for possible confounders.

McNemar's test was used to evaluate paired categorical



outcomes, i.e. pain only in the hand or shoulder that handles the transducer ("transducer shoulder"), compared to the other hand or shoulder ("computer shoulder").

We used the statistical package for the social sciences SPSS 20 (SPSS Statistics, IBM and Armonk, New York, USA).

### 3. Results

The mean age was 44 years (standard deviation 13 years), mean height 167 cm (SD 6 cm), mean BMI 24 (SD 4) and mean seniority in sonography 12 years (SD 9 years). One hundred and sixty-nine participants (58%) met the criteria for neck/shoulder pain, 85 (30%) for elbow/hand pain and 189 (65%) in any or both body regions. Associations between personal factors and pain are shown in Table 1. Among personal factors only age showed an association with neck/shoulder pain. For elbow/hand pain, BMI and children at home were associated. These factors were used as possible confounders in the analyses.

#### 3.1. Associations with work-related factors

High seniority in sonography, dissatisfaction with the computer

work station and high MEI, were associated with reported pain in the neck/shoulders, as were high job demands and high sensory demands (Table 2). Associations were also found with inadequately corrected eye sight, as well as with eye complaints and headache related to computer work. The possibility to adjust the keyboard and chair was associated with less pain.

Echocardiographers showed a higher prevalence of pain in the elbows/hands than those who did not perform echocardiography. A high MEI, eye complaints and high job and sensory demands were also associated with pain in the elbows/hands (Table 2).

#### 3.2. Associations with work-related factors in echocardiographers

Echocardiographers (N = 175) reported on average five echocardiographic examinations per day. More echocardiographers reported pain in the "transducer shoulder" only than in the "computer shoulder" only (33 vs 13,  $p < 0.005$ ). Similar results were found for hand pain (30 vs 4,  $p < 0.001$ ).

After adjustment, no specific factor in echocardiography was associated with neck/shoulder pain (Table 3). For the elbows/hands, to perform echocardiography 91e135 min per day (transducer time) was associated with pain, while more than 135 min was not. A

Table 1

Associations between pain<sup>a</sup> in the neck/shoulders and in the elbows/hands and personal factors in the total study population, calculated with Poisson regression. Number of subjects in each category (N), overall p-values (p) and prevalence ratios (PR) with 95% confidence intervals (CI).

|                                      | N   | Neck/shoulders (N = 289) |      |             | Elbows/hands (N = 290) |      |              |
|--------------------------------------|-----|--------------------------|------|-------------|------------------------|------|--------------|
|                                      |     | p                        | PR   | CI          | p                      | PR   | CI           |
| Age (years)                          |     | 0.07                     |      |             | 0.24                   |      |              |
| 23e37                                | 97  |                          | 1    |             |                        | 1    |              |
| 38e53                                | 92  |                          | 0.87 | (0.70e1.09) |                        | 1.45 | (0.93e2.27)  |
| 54e66                                | 99  |                          | 0.76 | (0.60e0.97) |                        | 1.17 | (0.73e1.86)  |
| Height (cm)                          |     | 0.73                     |      |             | 0.56                   |      |              |
| 153e164                              | 93  |                          | 1    |             |                        | 1    |              |
| 165e169                              | 94  |                          | 0.94 | (0.74e1.21) |                        | 0.85 | (0.56e1.31)  |
| 170e183                              | 102 |                          | 1.04 | (0.83e1.31) |                        | 0.79 | (0.52e1.22)  |
| Body mass index (kg/m <sup>2</sup> ) |     | 0.60                     |      |             | <0.001                 |      |              |
| 17.8e24.9                            | 209 |                          | 1    |             |                        | 1    |              |
| 25e29.9                              | 62  |                          | 1.06 | (0.84e1.33) |                        | 1.32 | (0.87e2.00)  |
| 30e37.8                              | 16  |                          | 1.19 | (0.84e1.69) |                        | 2.43 | (1.56e3.79)  |
| Smoking habits                       |     | 0.35                     |      |             | 0.80                   |      |              |
| Never smoker                         | 220 |                          | 1    |             |                        | 1    |              |
| Former smoker                        | 58  |                          | 1.16 | (0.94e1.44) |                        | 1.11 | (0.73e1.70)  |
| Daily smoker                         | 10  |                          | 1.17 | (0.73e1.89) |                        | 0.77 | (0.22e2.65)  |
| Children living at home              |     | 0.74                     |      |             | 0.14                   |      |              |
| No                                   | 185 |                          | 1    |             |                        | 1    |              |
| Yes                                  | 104 |                          | 1.16 | (0.96e1.40) |                        | 1.06 | (0.74e1.54)  |
| Personal recovery time (h/day)       |     | 0.33                     |      |             | 0.71                   |      |              |
| Hardly any time at all               | 19  |                          | 1    |             |                        | 1    |              |
| <1                                   | 42  |                          | 0.89 | (0.60e1.32) |                        | 0.71 | (0.33e1.55)  |
| 1                                    | 55  |                          | 0.95 | (0.66e1.37) |                        | 0.71 | (0.34e1.49)  |
| 2                                    | 80  |                          | 0.81 | (0.57e1.17) |                        | 0.93 | (0.48e1.80)  |
| 3                                    | 48  |                          | 0.64 | (0.41e1.00) |                        | 0.62 | (0.28e1.36)  |
| 4                                    | 40  |                          | 0.91 | (0.61e1.35) |                        | 0.88 | (0.42e1.85)  |
| Physical exercise                    |     | 0.53                     |      |             | 0.69                   |      |              |
| Never                                | 22  |                          | 1    |             |                        | 1    |              |
| Occasionally                         | 9   |                          | 0.76 | (0.40e1.45) |                        | 0.54 | (0.15e2.04)  |
| Once a week                          | 49  |                          | 0.85 | (0.60e1.19) |                        | 0.65 | (0.33e1.29)  |
| 2 e 4 times/week                     | 163 |                          | 0.76 | (0.58e1.04) |                        | 0.73 | (0.42e1.27)  |
| 5 times/week                         | 46  |                          | 0.81 | (0.57e1.15) |                        | 0.64 | (0.32e1.28)  |
| Household work (h/week)              |     | 0.77                     |      |             | 0.49                   |      |              |
| 0e2                                  | 6   |                          | 1    |             |                        | 1    |              |
| 3e10                                 | 118 |                          | 1.14 | (0.50e2.57) |                        | 1.61 | (0.26e9.90)  |
| 11e20                                | 103 |                          | 1.15 | (0.51e2.61) |                        | 1.81 | (0.30e11.07) |
| 21e30                                | 34  |                          | 1.36 | (0.59e3.11) |                        | 2.45 | (0.40e15.45) |
| >31                                  | 26  |                          | 1.20 | (0.51e2.28) |                        | 1.62 | (0.24e10.78) |
| Civil status                         |     | 0.80                     |      |             | 0.60                   |      |              |
| Single                               | 44  |                          | 1    |             |                        | 1    |              |
| Married/Cohabitant                   | 242 |                          | 1.04 | (0.80e1.36) |                        | 0.60 | (0.31e1.15)  |

<sup>a</sup> Based on frequency and intensity of musculoskeletal complaints during the last 12 months.

Table 2

Associations between pain<sup>a</sup> in the neck/shoulders and in the elbows/hands, and work-related factors in the total study population. Number of participants (N) and prevalence ratios (PR) with 95% confidence intervals (CI), crude as well as adjusted for possible confounders, calculated with Poisson regression.

|  | N   | Neck/shoulders <sup>b</sup> (N ¼ 289) |             |          |             | Elbows/hands <sup>c</sup> (N ¼ 290) |             |          |             |
|--|-----|---------------------------------------|-------------|----------|-------------|-------------------------------------|-------------|----------|-------------|
|  |     | Crude                                 |             | Adjusted |             | Crude                               |             | Adjusted |             |
|  |     | PR                                    | CI          | PR       | CI          | PR                                  | CI          | PR       | CI          |
| Seniority as a sonographer (years)       |     |                                       |             |          |             |                                     |             |          |             |
| 1.1e6                                    | 95  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| 6.1e15                                   | 96  | 1.03                                  | (0.80e1.31) | 1.20     | (0.93e1.55) | 1.17                                | (0.75e1.81) | 1.14     | (0.74e1.77) |
| 15.1e36                                  | 96  | 1.08                                  | (0.85e1.37) | 1.51     | (1.17e2.08) | 1.07                                | (0.68e1.68) | 1.00     | (0.64e1.57) |
| Working hours (h/week)                   |     |                                       |             |          |             |                                     |             |          |             |
| 20e39                                    | 134 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| 40e41                                    | 155 | 1.07                                  | (0.89e1.30) | 0.73     | (0.51e1.04) | 1.02                                | (0.90e1.15) | 0.75     | (0.52e1.07) |
| Sonography (h/week)                      |     |                                       |             |          |             |                                     |             |          |             |
| 1e14                                     | 82  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| 15e23                                    | 107 | 1.03                                  | (0.79e1.35) | 1.01     | (0.77e1.31) | 0.80                                | (0.51e1.24) | 0.82     | (0.53e1.27) |
| 24e40                                    | 100 | 1.23                                  | (0.97e1.58) | 1.20     | (0.94e1.53) | 0.90                                | (0.59e1.38) | 0.90     | (0.60e1.11) |
| Type of examinations                     |     |                                       |             |          |             |                                     |             |          |             |
| Other examinations only                  | 70  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Echocardiography                         | 106 | 0.97                                  | (0.76e1.25) | 0.91     | (0.74e1.16) | 1.74                                | (0.99e3.07) | 1.71     | (0.96e3.02) |
| Echocardiography and other examinations  | 112 | 1.01                                  | (0.79e1.29) | 0.98     | (0.80e1.30) | 1.91                                | (1.10e3.32) | 1.92     | (1.11e3.32) |
| Possibility to adjust screen height      |     |                                       |             |          |             |                                     |             |          |             |
| No                                       | 56  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Yes                                      | 229 | 0.91                                  | (0.73e1.15) | 0.91     | (0.72e1.14) | 1.44                                | (0.84e2.47) | 1.43     | (0.84e2.42) |
| Possibility to tilt screen               |     |                                       |             |          |             |                                     |             |          |             |
| No                                       | 24  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Yes                                      | 263 | 0.85                                  | (0.63e1.14) | 0.86     | (0.65e1.14) | 0.90                                | (0.50e1.66) | 0.90     | (0.46e1.76) |
| Possibility to adjust keyboard           |     |                                       |             |          |             |                                     |             |          |             |
| No                                       | 51  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Yes                                      | 233 | 0.78                                  | (0.63e0.96) | 0.78     | (0.64e0.95) | 1.01                                | (0.64e1.77) | 1.18     | (0.74e1.87) |
| Possibility to adjust chair              |     |                                       |             |          |             |                                     |             |          |             |
| No                                       | 24  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Yes                                      | 262 | 0.70                                  | (0.57e0.88) | 0.72     | (0.57e0.91) | 0.80                                | (0.46e1.39) | 0.77     | (0.43e1.37) |
| Use of special examination table         |     |                                       |             |          |             |                                     |             |          |             |
| No                                       | 30  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Yes                                      | 255 | 1.13                                  | (0.80e1.57) | 1.12     | (0.80e1.58) | 0.84                                | (0.50e1.40) | 0.79     | (0.47e1.33) |
| Computer work after examination          |     |                                       |             |          |             |                                     |             |          |             |
| In the examination room                  | 186 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| A workplace outside the examination room | 71  | 1.16                                  | (0.94e1.43) | 1.17     | (0.95e1.45) | 1.17                                | (0.95e1.45) | 1.44     | (0.99e2.09) |
| None                                     | 15  | 0.82                                  | (0.47e1.44) | 0.82     | (0.46e1.46) | 0.82                                | (0.46e1.46) | 1.32     | (0.63e2.77) |
| Bedside examinations                     |     |                                       |             |          |             |                                     |             |          |             |
| No                                       | 50  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Seldom                                   | 149 | 1.03                                  | (0.78e1.36) | 1.02     | (0.77e1.35) | 0.99                                | (0.59e1.66) | 1.14     | (0.68e1.89) |
| A few times per week                     | 77  | 1.04                                  | (0.76e1.42) | 1.03     | (0.75e1.40) | 1.16                                | (0.67e2.01) | 1.31     | (0.76e2.27) |
| Daily                                    | 12  | 1.49                                  | (1.01e2.12) | 1.32     | (0.92e1.90) | 0.89                                | (0.31e2.62) | 0.97     | (0.36e2.61) |
| Eye complaints related to computer work  |     |                                       |             |          |             |                                     |             |          |             |
| Never                                    | 158 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Seldom                                   | 45  | 0.88                                  | (0.62e1.24) | 0.88     | (0.63e1.23) | 0.84                                | (0.46e1.53) | 0.91     | (0.50e1.65) |
| Sometimes                                | 59  | 1.28                                  | (1.01e1.60) | 1.30     | (1.03e1.63) | 1.21                                | (0.77e1.90) | 1.31     | (0.85e2.04) |
| Often or very often                      | 25  | 1.80                                  | (1.52e2.13) | 1.84     | (1.55e2.19) | 1.96                                | (1.24e3.01) | 2.22     | (1.38e3.57) |
| Headache related to computer work        |     |                                       |             |          |             |                                     |             |          |             |
| Never                                    | 170 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Seldom                                   | 60  | 1.35                                  | (1.05e1.73) | 1.29     | (1.00e1.65) | 0.90                                | (0.55e1.49) | 0.92     | (0.57e1.50) |
| Sometimes                                | 34  | 1.81                                  | (1.47e2.24) | 1.79     | (1.45e2.20) | 1.28                                | (0.76e2.14) | 1.26     | (0.76e2.07) |
| Often or very often                      | 22  | 2.03                                  | (1.69e2.44) | 2.00     | (1.66e2.41) | 1.64                                | (0.98e2.76) | 1.54     | (0.90e2.62) |
| Eyesight                                 |     |                                       |             |          |             |                                     |             |          |             |
| Good or adequately corrected             | 238 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Inadequately corrected                   | 47  | 1.34                                  | (1.10e1.64) | 1.39     | (1.13e1.71) | 1.12                                | (0.70e1.78) | 1.20     | (0.75e1.92) |
| Mechanical exposure index score          |     |                                       |             |          |             |                                     |             |          |             |
| Unexposed/low (11e15 p)                  | 44  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Medium (16e19 p)                         | 131 | 1.82                                  | (1.17e2.82) | 1.77     | (1.14e2.74) | 1.67                                | (0.84e3.31) | 1.72     | (0.88e3.38) |
| High (20e33 p)                           | 100 | 2.18                                  | (1.41e3.36) | 2.20     | (1.39e3.32) | 2.03                                | (1.03e4.03) | 2.00     | (1.02e3.90) |
| Physical exposure index score            |     |                                       |             |          |             |                                     |             |          |             |
| Unexposed (7e8 p)                        | 74  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Low (9e10 p)                             | 124 | 1.06                                  | (0.83e1.34) | 1.03     | (0.81e1.31) | 1.00                                | (0.63e1.58) | 0.95     | (0.61e1.49) |
| Medium (11e13 p)                         | 55  | 0.89                                  | (0.64e1.23) | 0.86     | (0.62e1.18) | 1.12                                | (0.66e1.92) | 1.14     | (0.67e1.94) |
| High (14e21 p)                           | 21  | 1.01                                  | (0.73e1.59) | 1.05     | (0.72e1.53) | 1.02                                | (0.47e2.20) | 1.02     | (0.47e2.18) |
| Computer work-station                    |     |                                       |             |          |             |                                     |             |          |             |
| Very satisfied                           | 35  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Rather satisfied                         | 146 | 0.95                                  | (0.69e1.31) | 0.99     | (0.72e1.36) | 1.25                                | (0.65e2.41) | 1.23     | (0.63e2.38) |
| Neutral                                  | 67  | 0.97                                  | (0.68e1.38) | 1.00     | (0.70e1.42) | 1.06                                | (0.51e2.21) | 1.07     | (0.52e2.24) |
| Rather/very dissatisfied/                | 34  | 1.49                                  | (1.09e2.01) | 1.54     | (1.11e2.13) | 1.86                                | (0.92e3.83) | 1.71     | (0.81e3.58) |
| Job demands (cut-offs: 2.25 and 2.63)    |     |                                       |             |          |             |                                     |             |          |             |
| Lowest tertile                           | 85  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Middle tertile                           | 97  | 1.27                                  | (0.95e1.70) | 1.32     | (0.99e1.77) | 1.53                                | (0.91e2.57) | 1.37     | (0.82e2.31) |

(continued on next page)

Table 2 (continued)

|  | N   | Neck/shoulders <sup>b</sup> (N % 289) |             |          |             | Elbows/hands <sup>c</sup> (N % 290) |             |          |             |
|--|-----|---------------------------------------|-------------|----------|-------------|-------------------------------------|-------------|----------|-------------|
|  |     | Crude                                 |             | Adjusted |             | Crude                               |             | Adjusted |             |
|  |     | PR                                    | CI          | PR       | CI          | PR                                  | CI          | PR       | CI          |
| Highest tertile<br>Job control (cut-offs: 2.67 and 3.00) | 105 | 1.61                                  | (1.24e2.10) | 1.61     | (1.24e2.10) | 1.74                                | (1.06e2.86) | 1.72     | (1.10e2.79) |
| Lowest tertile   | 97  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Middle tertile   | 99  | 0.86                                  | (0.70e1.07) | 0.86     | (0.69e1.07) | 0.81                                | (0.55e1.19) | 0.87     | (0.58e1.26) |
| Highest tertile<br>Job support (cut-offs: 2.63 and 4.00) | 91  | 0.90                                  | (0.70e1.17) | 0.88     | (0.69e1.14) | 0.66                                | (0.39e1.12) | 0.70     | (0.41e1.17) |
| Lowest tertile   | 83  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Middle tertile   | 117 | 0.91                                  | (0.72e1.14) | 0.91     | (0.73e1.15) | 0.78                                | (0.52e1.19) | 0.74     | (0.49e1.11) |
| Highest tertile  | 86  | 0.93                                  | (0.73e1.19) | 0.90     | (0.71e1.15) | 0.77                                | (0.49e1.22) | 0.75     | (0.48e1.18) |
| Sensory demands (cut-offs: 70 and 87.5)                  |     |                                       |             |          |             |                                     |             |          |             |
| Lowest tertile   | 87  | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Middle tertile   | 113 | 1.35                                  | (1.01e1.79) | 1.30     | (0.98e1.73) | 1.24                                | (0.76e2.01) | 1.17     | (0.72e1.90) |
| Highest tertile  | 84  | 1.70                                  | (1.30e2.22) | 1.69     | (1.29e2.22) | 1.68                                | (1.05e2.69) | 1.49     | (0.93e2.40) |

Results in bold face are statistically significant.

<sup>a</sup> Based on the frequency and intensity of musculoskeletal complaints during the past 12 months.

<sup>b</sup> Adjusted for age.

<sup>c</sup> Adjusted for BMI and children <15 living at home.

transducer grip with the wrist bent backwards was associated with a high prevalence of elbow/hand pain, while holding the transducer in a two-handed/alternating grip was associated with a low prevalence of elbow/hand pain (Table 3). No statistically significant association was found in the other projections (data not

shown).

#### 4. Discussion

Two thirds of the sonographers met the criteria for pain in one

Table 3

Associations between pain<sup>a</sup> in the neck/shoulders and in the elbows/hands, and time and number of examinations and working techniques among echocardiographers (examinations: > 10 h/w). Numbers of subjects (N) and prevalence ratios (PR) and 95% confidence intervals (CI), crude as well as adjusted for possible confounders, calculated with Poisson regression.

|   | N  | Neck/shoulders <sup>b</sup> (N % 174) |             |          |             | Elbows/hands <sup>c</sup> (N % 175) |             |          |             |
|---|----|---------------------------------------|-------------|----------|-------------|-------------------------------------|-------------|----------|-------------|
|   |    | Crude                                 |             | Adjusted |             | Crude                               |             | Adjusted |             |
|   |    | PR                                    | CI          | PR       | CI          | PR                                  | CI          | PR       | CI          |
| Echocardiography (h/week)   |    |                                       |             |          |             |                                     |             |          |             |
| 10e14   | 52 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| 15e19   | 50 | 0.85                                  | (0.60e1.19) | 0.80     | (0.57e1.12) | 0.99                                | (0.60e1.65) | 1.00     | (0.60e1.65) |
| 20e40   | 73 | 1.02                                  | (0.76e1.33) | 0.95     | (0.72e1.26) | 0.80                                | (0.48e1.33) | 0.78     | (0.47e1.28) |
| Number of examinations/day  |    |                                       |             |          |             |                                     |             |          |             |
| 2e3   | 30 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| 4   | 64 | 1.04                                  | (0.74e1.48) | 1.04     | (0.74e1.48) | 1.38                                | (0.74e2.56) | 1.36     | (0.74e2.50) |
| 5   | 37 | 1.08                                  | (0.74e1.58) | 1.08     | (0.74e1.58) | 1.09                                | (0.55e2.22) | 1.13     | (0.55e2.31) |
| 6e10  | 44 | 0.80                                  | (0.52e1.22) | 0.81     | (0.53e1.23) | 0.83                                | (0.39e1.76) | 0.85     | (0.41e1.77) |
| Transducer time (minutes/day)   |    |                                       |             |          |             |                                     |             |          |             |
| 12e90   | 52 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| 91e135  | 58 | 1.03                                  | (0.79e1.34) | 1.04     | (0.80e1.35) | 1.54                                | (0.94e2.25) | 1.64     | (1.00e2.70) |
| 136e400   | 64 | 0.72                                  | (0.52e0.99) | 0.73     | (0.53e1.02) | 0.71                                | (0.38e1.32) | 0.75     | (0.41e1.38) |
| Working technique   |    |                                       |             |          |             |                                     |             |          |             |
| 1. Patient facing the examiner, transducer in left hand                   | 80 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| 2. Patient facing the examiner, transducer in right hand                  | 37 | 0.97                                  | (0.69e1.35) | 0.98     | (0.71e1.37) | 1.11                                | (0.66e1.85) | 1.17     | (0.70e1.91) |
| 3. Patient's back against the examiner, transducer in right hand          | 32 | 1.12                                  | (0.82e1.52) | 1.18     | (0.87e1.64) | 1.19                                | (0.71e1.98) | 1.16     | (0.68e1.95) |
| 4. Patient facing the examiner, two-handed or alternating transducer grip | 21 | 0.97                                  | (0.64e1.47) | 0.99     | (0.66e1.49) | 0.28                                | (0.07e1.08) | 0.29     | (0.08e1.06) |
| Hand used to hold the transducer  |    |                                       |             |          |             |                                     |             |          |             |
| Dominant  | 69 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Non dominant  | 83 | 1.04                                  | (0.80e1.50) | 1.01     | (0.77e1.31) | 0.94                                | (0.62e1.43) | 0.93     | (0.61e1.42) |
| Two handed/alternating  | 21 | 0.99                                  | (0.65e1.50) | 0.97     | (0.63e1.47) | 0.25                                | (0.07e0.98) | 0.26     | (0.07e0.94) |
| Transducer grip in parasternal projection                                 |    |                                       |             |          |             |                                     |             |          |             |
| Like a pen  | 74 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Between index/middle finger   | 10 | 0.30                                  | (0.09e1.05) | 0.31     | (0.09e1.07) | 0.72                                | (0.27e1.92) | 0.81     | (0.30e2.22) |
| All fingers around the probe  | 79 | 0.86                                  | (0.67e1.11) | 0.86     | (0.67e1.10) | 0.64                                | (0.41e1.01) | 0.63     | (0.40e1.00) |
| Other grips   | 8  | 0.95                                  | (0.54e1.65) | 0.87     | (0.49e1.52) | 0.90                                | (0.35e2.28) | 0.74     | (0.34e1.62) |
| Wrist position in parasternal projection                                  |    |                                       |             |          |             |                                     |             |          |             |
| Straight wrist  | 83 | 1                                     |             | 1        |             | 1                                   |             | 1        |             |
| Bent forwards   | 22 | 1.29                                  | (0.90e1.83) | 1.24     | (0.88e2.39) | 1.51                                | (0.72e5.94) | 1.52     | (0.79e2.91) |
| Bent backwards  | 62 | 1.19                                  | (0.90e1.57) | 1.12     | (0.85e1.78) | 1.70                                | (1.05e2.77) | 1.64     | (1.01e2.68) |

Results in bold face are statistically significant.

<sup>a</sup> Based on the frequency and intensity of musculoskeletal complaints during the past 12 months.

<sup>b</sup> Adjusted for age.

<sup>c</sup> Adjusted for BMI and children <15 living at home.

or both of the studied body regions. This cross-sectional study is one of the first and to date the largest, to provide estimates of associations between musculoskeletal disorders and work-related factors in sonography. Echocardiographers had higher prevalence of elbow/hand pain than those who performed only other kinds of examinations. Dissatisfaction with the computer workstation was associated with a higher prevalence of elbow/hand pain, while adjustable equipment was associated with a lower prevalence of pain. Higher MEI, higher job demands and higher sensory demands were associated with pain in both body regions. In echocardiographers, pain was more common in the arm/hand that held the transducer than in the other arm/hand.

As the study includes almost all echocardiographers in Sweden and they reported fulfilling five examinations per day, we estimate that at least 100 000 such examinations are performed yearly in Sweden.

#### 4.1. Methodological considerations

The present study is cross-sectional and based on self-reported exposure and on self-reported musculoskeletal pain. Overestimation of one or both of these may occur. Individuals with ongoing pain are prone to perceive their work to be more demanding than individuals without pain and therefore may overestimate the exposure (Hansson et al., 2001). Several of the exposure measures are objective (e.g. whether the chair can be adjusted) and thus unlikely to be misclassified. For those that are subjective, an overestimation of exposure among those with pain would lead to an overestimation of the association. The same effect would occur if subjects who perceive their work as too demanding overestimate bodily symptoms. However, in spite of these weaknesses, the observed associations are biologically plausible and in line with previous knowledge (Morton and Delf, 2008; Muir et al., 2004).

Several studies of sonographers have been reported in which various definitions of pain have been used (Horkey and King, 2004; Morton and Delf, 2008; Russo et al., 2002). Thus, comparisons with others studies must be made with caution. Pain may be troublesome both when it is severe and when it is frequent. Our definition of pain combines frequency and intensity, which we consider more relevant than most traditionally used definitions.

To the best of our knowledge we invited all clinical physiology and cardiology departments throughout Sweden where sonography is performed by biomedical scientists. They all agreed to participate. In each of these, the participation rate was high. Thus, we believe that there was no significant selection bias, neither on individual nor on regional level. However, since the study was cross-sectional, sonographers with pain may have left the profession and there may be selection towards more healthy workers (Shah, 2009). This would lower the prevalence of pain and possibly cause underestimation of the associations between occupational factors and pain.

Most of the sonographers also had other work tasks (e.g. spirometry, electroencephalography (EEG), work tests and administration). However, we judge from observations that these other activities in general caused a lower physical load and should not have influenced the results.

A previous study showed that discomfort of transducer design was a strong predictor of hand and wrist disorders (Vanderpool et al., 1993). We did not collect information on weight and dimensions of the transducers, thus we cannot draw any conclusion on the importance of the design of these.

Sonography is also used by other medical staff e.g. cardiologists, obstetricians, midwives and gynaecologists (Eindhoven et al., 2015; Green et al., 2015; Kim and Roh, 2014; Tegmänder and Eik-Nes,

2006). However, several work-related conditions are to a large extent similar to sonography performed in these specialities, e.g. light conditions, holding a transducer and watching a screen. Thus, the recommendations we propose are applicable also to other groups that perform sonography.

#### 4.2. Risk factors and recommendations

The sonographers who reported high job demands had a higher prevalence of neck/shoulder as well as elbow/hand pain, with clear exposure-response relationships. This is in line with previously published results for health care professionals (Bernal et al., 2015) and computer users (Torqvist et al., 2009). High job demands as a cause of neck and upper limb symptoms is partly mediated by the stress symptoms they might give rise to (van den Heuvel et al., 2005).

The majority of the sonographers reported a high or moderately high MEI. As in previous studies there was a strong association between increasing MEI and pain (Balogh et al., 2001; Östergren et al., 2005). High sensory demands in terms of small and very precise movements and high sight demands, may lead to long time static postures in neck and shoulders as well as in wrists and hands. This may be an explanation to the strong associations between high sensory demands and pain in these regions. High sensory demands seem to be unavoidable in sonography, thus it is important to optimize work conditions concerning ergonomics.

We found a strong association between eye strain and pain in both body regions. There was an association between neck pain and headache related to computer work. Working with poor lighting may cause eye strain (Hemphill et al., 2012), which in turn may increase trapezius muscle activity (Richter et al., 2015). This might be a causal factor for neck pain and headache. It is thus extremely important to ensure that all sonographers have adequate eye sight correction, and to optimize lighting conditions and contrast on the screen.

Dissatisfaction with the computer workstation was associated with neck/shoulder pain. This is most likely a proxy of poor ergonomics, including visual conditions. Indeed, similar associations were found for possibility to adjust chair and keyboard. Similar findings have been reported in two previous Swedish studies (Lindegård et al., 2012; Torqvist et al., 2009). Hence, to decrease pain prevalence it is important that all available recommendations for good computer ergonomics are met (Goodman et al., 2012).

Sonographers who performed echocardiography showed a higher prevalence of pain in the elbows/hands and pain was more prevalent in the hand and shoulder used to operate the transducer. Keeping the wrist straight when pressing the transducer against the patient seemed protective, in accordance with basic ergonomic principles (Kuo et al., 2001; You et al., 2014). Holding the transducer two-handed/alternating grip was associated with a lower prevalence of pain and this should be encouraged. By using techniques 1 and 2, i.e. with the patient facing the examiner, it is easier to hold the transducer with two hands when pressure is required in applying the transducer. Furthermore, voice activation has been shown to reduce the number of times the operator has to reach for the control panel (Bravo et al., 2005), and would make both hands available to handle the transducer. A robot arm holding the transducer has also been tested, which eliminates the problems with the handgrip (Arbeille et al., 2014; Boman et al., 2014).

Guidelines for prevention of work-related disorders in sonographers were developed more than ten years ago (Brown et al., 2003). These recommendations are well in line with the findings in this study, and should be more widely spread to encourage further improvements and interventions of the working environment. Since the prevalence of pain was high, we also suggest

regular health screening for early detection and prevention of pain related to the working environment (Hagberg et al., 2012).

#### 4.3. Conclusions

Ultrasonic examinations are becoming increasingly common. We estimate that at least 100 000 such are performed yearly in Sweden. This study has identified several ergonomic risk factors. Therefore it is important to ensure sustainable work conditions for sonographers. We recommend optimal visual conditions, adjustable components of the ultrasonic machine and the computer workstation, education concerning ergonomic guidelines and regular health screening, including eye sight. In echocardiography, other ways of holding and handling the transducer should be developed.

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Paper II







RESEARCH ARTICLE

Open Access



# Swedish Sonographers' perceptions of ergonomic problems at work and their suggestions for improvement

Jenny Gemark Simonsen<sup>1\*</sup> and Gunvor Gard<sup>2,3</sup>

## Abstract

**Background:** Sonographers' perceptions of ergonomic and work-related pain problems at work have so far mostly been researched in quantitative studies by questionnaires. There is a need of experience-based research to deepen the knowledge about how sonographers perceive ergonomic problems at work. Therefore, the aim of this qualitative study was to describe sonographers' perceptions of ergonomic problems at work, and their suggestions for improvement strategies.

**Methods:** Twenty-two female sonographers were individually interviewed regarding different aspects of their physical working environment. Content analysis was applied.

**Results:** The sonographers perceived different ergonomic problems in their working environment, but to offer patient comfort and to obtain the best possible images were often prioritized over working posture. Echocardiography was considered demanding as the examination is performed with little variation in posture. Ergonomic improvements included reducing the manual handling of the transducer, optimizing the adjustability of equipment, and taking the patient's physique and health into account. As some examinations were perceived to be more ergonomically demanding, variation between examinations was suggested, however, this requires broader skills.

**Conclusion:** Sonography, especially echocardiography is ergonomically demanding but the improvement strategies suggested were perceived useful and applicable.

**Keywords:** Content analysis, Ergonomics, Female, Sonography, Work environment

## Background

Sonographers constitute a professional group with a high reported prevalence of work-related musculoskeletal pain and discomfort [1], especially in the neck, upper limbs and back [2–6]. Twisted postures, sustained shoulder abduction, a tight hand grip, more than 10 years of working experience and long scanning times each day have been shown to be associated with symptoms and a higher occurrence of work-related musculoskeletal disorders among sonographers (WMSD) [3, 7–11].

Village and Trask reported that sonographers had their scanning arm abducted 30° 66 % of their scanning time [12]. Results by Arvidsson et al. showed

that sonographers perceive a high prevalence of hand pain [5]. They also perceive high sensory demands concerning eyesight, precision, attention, focus and control of body movements [5].

A relation has also been found between ultrasonography and WMSD in radiologic technologists [13], and an association has also been reported between twisted postures and physical symptoms in sonographers in obstetrics and gynaecology [14].

Sonography is an important diagnostic tool in daily medical practice [10] with little risk of adverse effects on the patient [4]. Scanning usually takes place in a darkened room, with the patient lying on a table. The sonographer usually sits during the examination, holding a transducer attached to the equipment with a cable, in one hand, while managing the control panel with the other, and observing the images on a screen. Handling

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the transducer involves static positions of the shoulder, and repetitive, force demanding and precise movements of the wrist and hand [9, 15, 16].

The level of artificial light has to be low to facilitate interpretation of the images on the screen, which may cause visual strain [15]. Examinations are sometimes carried out on the ward with the patient in bed (bedside examination). This is additionally strenuous, as the sonographer must adjust his or her working posture to the bedside situation [17].

Working posture varies depending on the type of sonographic examination being performed. In vascular examinations, for example vein mapping, the handling of the transducer involves diverse movements and postures. In echocardiography the postures and movements are less varied, and the transducer is held in a relatively fixed position. Echocardiography also requires higher grip strength than vein mapping [8]. Greater pressure must be applied to the transducer in corpulent and obese patients undergoing echocardiography [18]. A robot-assisted system in which an arm holds the transducer has been tested, but has not yet been introduced in routine in sonography [19, 20].

The ergonomic challenges of sonography have been known for many years. The Society of Diagnostic Medical Sonography developed industry standards, in 2003, to prevent sonographers from WMSDs [21]. The standards include guidelines for the ultrasound equipment, workload and best ergonomic practices. Horkey and King noted that the sonographers were aware of most ergonomic recommendations but the implementation of these was not satisfactory enough, which depended on among other things lack in organisation and planning, but also on unavailability of adjustable ultrasound equipment [6]. To identify and solve ergonomic problems is a matter which concerns all levels in an organisation.

So far, sonographers' perceptions of ergonomic problems at work has mostly been researched in quantitative studies [1, 6, 22]. There is a need of experience based research to deepen the knowledge about how sonographers perceive ergonomic problems at work. A qualitative study design is recommended when experience based knowledge is sought [23]. So far to our knowledge only a few qualitative studies have been performed in this area [16, 24].

The aim of this study was, therefore, to assess sonographers' perceptions of these issues. The specific research questions addressed were: 1) What are the perceived ergonomic problems in echocardiography and vascular sonography? and 2) How can the working situation be improved ergonomically?

## Methods

### Study design and procedure

A qualitative study was performed to ascertain sonographers' perceptions and characteristics of their work [23].

The first author contacted the heads of seven clinical physiology and cardiology departments in hospitals in the south of Sweden to present the study. The sonographers interested in participating and fulfilling the inclusion criteria were listed, and a time was booked for a 1-h qualitative interview. The interviews took place at the sonographer's workplace in a separate room. The interviews were recorded and transcribed. Pre-interviews and two pilot interviews, included in the study, were performed, and a number of minor corrections were made to the interview guide.

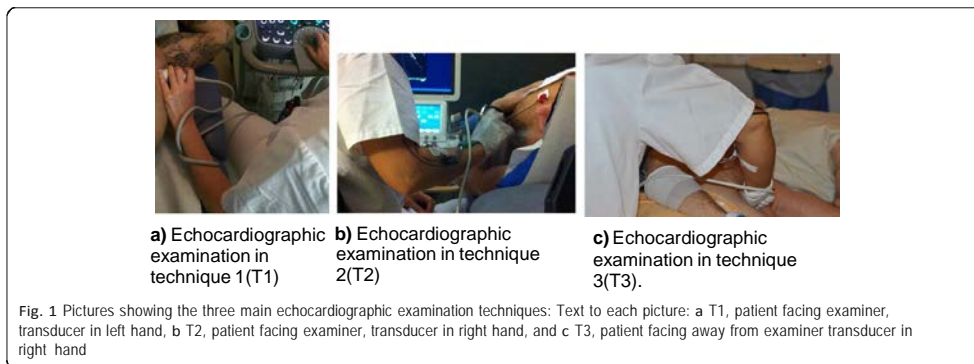
### Study participants

The sonographers were recruited from clinical physiology and cardiology departments in the south of Sweden. The participants were selected according to the following inclusion criteria: woman, interest in participating, and variation in age, seniority in sonography, workplace, examinations performed and musculoskeletal disorders. We thus attempted to enrol as varied a study group as possible, with a wide range of perceptions. A total of 22 female sonographers expressed interest in participating, and these formed the study group. The mean age was 45 years (24–59 years) and mean seniority in sonography was 13.5 years (0.5–36 years). All except one performed echocardiography, and twelve performed both vascular and echocardiographic examinations. Thirteen worked full-time and all worked at least 20 h per week.

Three main working techniques are employed and taught in echocardiography, depending on local hospital practice. In technique 1 (denoted T1) the patient is facing the examiner, who holds the transducer in the left hand (Fig. 1a). In technique 2 (T2), the patient is also facing examiner, but the transducer is held in the right hand (Fig. 1b). In the third technique (T3), the patient faces away from the examiner, and the transducer is held in the right hand (Fig. 1c). T1 was most common (N = 9) followed by T3 (N = 8). In vascular scanning the technique varies depending on the type of examination.

### Data collection

A semi-structured interview guide was developed to address the research questions. The opening question was: "How do you perceive your sonographic work?" The interview guide contained open questions concerning ergonomic, psychosocial and organisational problems at work, as well as possible solutions to these problems and improvement strategies. Both positive and negative factors were elicited. The interview was performed as an open conversation, and the interviewer used follow-up questions to ensure that the research questions were answered in depth. The data were collected over a period of 9 months.



**Analysis**

This paper focuses on ergonomic problems and improvement strategies. Content analysis was used to analyse the transcribed interviews [25, 26]. First, the interviews were read through several times by the first author to obtain a sense of the whole and to identify meaning units, i.e. relevant quotes related to the aim and research questions [27]. The first and second author then read and discussed the meaning units, condensed and coded them, and finally grouped them into categories according to each research question [25]. The categories and subcategories are described in the result together with quotations from the participants (indicated by a participant number).

**Results**

The result showed that most of the sonographers perceived their work as stimulating, including contact with the patients, but found it physically exhausting. Four categories emerged from the first research question: I) working postures and type of examination, II) equipment including physical factors (light, noise and ventilation), III) the patient's physique and health, and IV) the sonographer's working experience and knowledge (Table 1). The analysis of the second research question revealed several ergonomic improvement strategies, which were grouped into three categories: I) working tasks and postures, II)

equipment and physical factors, and III) professional working strategies (Table 2).

**Ergonomic problems**

**I. Working postures and type of examination**

The sonographers perceived that the type of examination influenced their working posture to a high degree, with less variation in posture in echocardiography compared to vascular examinations. Echocardiography was perceived to be extremely physically demanding as several measurements were required.

"I'm tired because I've done a lot of echocardiographs this week, and then I feel more tired." (9)

Regardless of the technique used for echocardiography (T1–T3), the handling of the transducer was perceived as static and strenuous.

"It's really only in heart examinations that the hand is still for so long." (20)

If the patient lay on the table facing away (Fig. 1c, T3), the examiner had to stretch her arm to obtain good images, particularly if the patient was corpulent, or was lying far away on the table.

**Table 1** The table shows: Ergonomic problems divided into categories and subcategories

| Ergonomic problems |   |  |                                      |                               |
|--------------------|---|--|--------------------------------------|-------------------------------|
| Categories         | Working posture and type of examination                             | Equipment and physical factors   | The patient's physique and health    | Work experience and knowledge |
| Subcategories      | -Echocardiography<br>-Vascular examinations<br>-Bedside examination | -Ultrasonic device<br>-Examination room including table and equipment to assist patients<br>-Physical factors including light, noise and ventilation | -Patient constitution<br>-Inpatients | -Lack of skills               |

**Table 2** The table shows: Ergonomic improvement strategies divided into categories and subcategories

| Ergonomic improvement strategies |                                       |  |   |
|----------------------------------|---------------------------------------|--|---|
| Categories                       | Working tasks and postures            | Equipment and physical factors   | Professional working strategies                       |
| Subcategories                    | -Strategies for good working postures | -Ultrasound unit<br>-Robot-assisted transducer<br>-Physical factors: temperature, noise and lighting | -Practice and skill<br>-Analysis<br>-Patient handling |

“If the patient is too far away on the table, I have to stretch further.” (8)

When mapping veins the examiner occasionally sat on the floor or on a chair with no possibility to rest the hand holding the transducer.

“You map out the veins in the patient’s arms, sometimes both, so you don’t have any support for your own arm, that’s the problem.” (7)

The hand managing the control panel was stretched out several times to reach the touch screen, especially in echocardiography.

In bedside examinations the ultrasound equipment is taken to the ward, implying poor ergonomic postures and insufficient room for the examination.

“We take the equipment to the ward and do the ultrasound exam on patients that can’t be moved. You have to position the equipment to accommodate the patient in bed. We sometimes stand up as there isn’t much room.” (16)

Obtaining high-quality images was perceived as a higher priority than adjusting the equipment to achieve a comfortable working posture.

**II. Equipment and physical factors**

Some sonographers reported ergonomic problems associated with the control panel, keyboard and screen, for example, the buttons were not within comfortable reach and the screen was not sufficiently physically adjustable. The leg space in front of the ultrasound unit was too narrow, the transducer uncomfortable to handle, and the cable was heavy. The transducer was sometimes difficult to grip, especially if it became slippery.

“The transducers are hopeless... you use this gel and it makes things slippery. They’re quite heavy, and the cable makes them heavier at the end, they aren’t very easy to grip, they’re made of hard smooth plastic.” (7)

A few of the echocardiographers had experience of a robot-assisted transducer attached to an arm, but perceived it difficult to handle.

“Instead of holding the transducer with your hand, you’re supposed to manoeuvre it with a little joystick. I’ve tried it, and it’s definitely not easy.” (9)

The examination room was perceived to be too small, especially when examining an inpatient in bed. Sometimes, the ultrasound unit had to be moved to make room, which meant extra problems.

“Patients who are brought in their beds—they’re so big these days—so for there to be enough room for the patient, my chair and my equipment, as well as the desk, I think the rooms are far too small.” (9)

Lack of a patient lift also made it difficult to move the patient onto the examination table. Some of the sonographers also perceived that the tables were not sufficiently adjustable for different examinations and patients. The ultrasound unit gave off heat, even when additional cooling units had been fitted.

“When the equipment has been on all day, it feels like a sauna in here.” (2)

Exposure to noise was also perceived as a problem. The sonographers were used to the fans and were not aware of the noise until they turned the equipment off or left the room.

“The fans make a noise all the time, but you get used to it... You only think about it when you turn the machine off. Then it’s quiet.” (9)

Some of the sonographers reported eyestrain and headaches due to poor lighting in the examination room. To avoid glare on the screen the ceiling light was only switched on when the patient entered the room. Daylight sometimes came in through a slit in the curtain, which caused irritation. The same problem occurred when examining a patient on the ward, as there was no means of darkening the room.

“You get mentally tired, and your eyes get tired... I don’t want all the ceiling lights on as then I have to squint... the lights mustn’t be visible on the screen... I mean, there mustn’t be reflections.” (8)

**III. The patient’s physique and health**

The participants reported that the patient's physique and health often had negative effects on their work load, their posture and the ability to obtain good images. Corpulent patients and patients with lung disease often meant longer examinations (transducer time) due to the poor quality of the images, and the need to press the transducer harder to obtain good images.

"So fat that you have to almost lie over the patient to get around... to get close to the heart. There's a lot of fat in the way." (18)

Slim patients were also a problem as their ribs were an obstacle to the examination of the heart. When inpatients were brought to the examination room the sonographers sometimes perceived a high workload and apprehensive.

"Yes, because the patients are often very ill, and some of them aren't very mobile either, and that means heavy work." (7)

Patients in intensive care were sometimes in a respirator, which hampered communication. The priority was high to make the patient comfortable and safe. If the patient was in pain the examination was completed as quickly as possible to reduce discomfort. If the inpatient arrived in a wheelchair and was too heavy to move, the examination was performed with the patient sitting in the wheelchair, which was perceived as demanding by the sonographer, who had to adjust her working posture, i.e. bend forward.

"Sometimes we do it (the examination) in a wheelchair. Not so many heart exams, but there are lots of vascular patients who come in a wheelchair, and they're so heavy you can't lift them." (10)

#### IV. Work experience and knowledge

Lack of experience led to extended transducer time and too hard pressure in a static position.

"That's probably right... a common beginner's problem is that you press really hard." (9)

"If you're not an experienced sonographer, you tend to keep the transducer still for a long time until you get a good picture." (2)

Lack of knowledge and experience also implied stress, such as tense shoulders and forgetting the physical risks. On the other hand, a high degree of skill and experience often meant examining more patients per day.

"You need a lot of knowledge to do an ultrasound exam. Then the pictures have to be good enough to interpret, to resolve the question on the referral." (20)

Obtaining images of high quality was given higher priority than good ergonomics.

#### Ergonomic improvement strategies

##### I. Working tasks and postures

The strategy employed to vary posture was to swap hands. Some of the sonographers changed the hand holding the transducer during some vascular examinations, but not in echocardiography.

"I use my left hand as much (as my right) to hold the transducer in all examinations except the heart." (13)

Another measure employed was to adjust the position of the equipment and the patient before each examination.

"I make sure the patient moves until I get a good working position." (4)

Standing up during scanning also made it possible to change posture and was also perceived as a relaxed position when managing the control panel and handling the transducer. Resting the transducer hand on the table, on the armrest or on the patient, and the other hand on the control panel were other strategies.

"Sometimes you can stand up to do the exam, then it's easier to get to, or around the patient, and relieve the strain in another way." (2)

A physiotherapist had instructed them on how to adjust the screen in order to reduce the amount they had to turn their head during scanning. Another way of avoiding strenuous postures was to work in a team of two sonographers, i.e. one managed the control panel and screen, while the other handled the transducer.

"Two sonographers. I think that's really good—we work in similar ways and it works really well." (8)

Vascular examinations were perceived as less physically tiring than echocardiography, as they were more varied and involved less static positions. To ensure variation in workload, the working day was divided into four sessions, so that echocardiography

was performed in one session, after which other tasks were carried out.

"We feel much better when we divide the day into four sessions." (8)

When seated and using techniques (T1 and T2)) for echocardiography, the sonographer tried to sit turned towards the patient to avoid having a bent wrist when handling the transducer.

"I sit turned more towards the patient if he or she is lying down, so that I don't have to bend my wrist, so I can keep it straight." (16)

Scanning facing the patient was perceived as preferable as it was possible to rest the arm on the armrest. When the patient was lying down facing away from the sonographer (T3), it was necessary for the examiner to stretch their arm more.

"We have a chair with armrests that you can rest your arm on. What's better with the first technique... is that I don't have to stretch as much to get where I need to go." (5)

Standing and using the weight of their body during echocardiographic examination was a strategy used to facilitate the transducer projection, especially in corpulent or overweight patients, regardless of the working technique.

## II. Equipment and physical factors

An easily and highly adjustable control panel with touch buttons that could be positioned to minimize arm extension and finger pressure was considered a desirable improvement to ultrasound equipment. Likewise, a more adjustable screen would facilitate a comfortable neck position. Sufficient space for the legs when seated was another suggested improvement.

"It must be possible to move the screen on the ultrasound equipment, a better arm, so I can raise and lower it and turn it how I want to. Buttons that are very close to me so I don't need to reach out my arm, with touch buttons or buttons that are easy to press. A keyboard that can be moved up and down and sideways, that I can pull. Lots of space so you can get your legs in under the equipment. An ultrasound unit that's easy to move." (7)

A light, wireless transducer with a comfortable grip and a cover to avoid gel smears were also suggested. A cable hook attached under the

equipment was perceived to facilitate handling of the transducer.

The use of a robot-assisted transducer in echocardiography was perceived to reduce awkward postures, manual pressure and pain due to strained positions. Continued training was recommended to improve handling.

"Then I can steer it so that it moves towards the patient's chest, and I can make most of the small movements that a hand can do with the remotely controlled control panel. I wouldn't have to sit and press (the transducer) on the patient myself—it would do the heavy work. I can steer it now without thinking, it comes automatically, just like when I'm using my hand." (18)

An adjustable examination table, electrically controlled with a foot pedal, would facilitate positioning the patient and adjusting the height during the examination. A more adaptable table would facilitate performing different examinations using the same table. Also, a table resembling a dentist's chair was suggested. Technical developments and improvements of the ultrasound unit have led to more distinct images suitable for computerized image analysis. A computer workstation was also perceived to be a better ergonomic alternative for reviewing the images, where the keyboard, screen and artificial light were adjustable and daylight could sometimes be used.

"It's better for me—I know some people stay at the ultrasound unit, but then you have to click on every image, and on the computer I can scroll." (6)

Larger examination rooms with automatic door openers would facilitate bringing a bed into the room, and examining the patient without having to move the table or the equipment. Two screens were perceived to facilitate the examination when two sonographers worked together. Ergonomic aids such as a sliding sheet, a turntable and patient lift were perceived useful if located close at hand. The noise level was perceived to have improved, as the newer ultrasound units were quieter and silencers had been fitted.

"The machines have become quieter... so that's better." (7)

"We have textiles, curtains... so it doesn't echo so much." (8)

The air-conditioning system was perceived to be sufficiently adjustable in some workplaces. In others, additional cooling units had been installed to improve the ventilation, especially in smaller rooms.

"Then there's the temperature, yes, we have air conditioning in the room, so we can raise and lower the temperature, that's good." (18)

The participants perceived that the possibility of adjusting the artificial light with a dimmer, and low-glare screens had improved the lighting conditions. These made it possible to increase the level of artificial lighting in the room.

"The lights in the room have dimmers, so that can be adjusted." (13)

"The computer screens are better these days, there isn't so much reflection in them, so I decided to turn the lights on, I can still see just as well." (7)

Spectacles for computer work were reported to facilitate scanning and computer work.

### III. Professional working strategies

Most of the sonographers perceived that achieving good images depended on practice to improve skills and increase experience.

Cooperation with the doctor when reviewing the images provided an opportunity to improve knowledge and understanding. The broader the skills of the sonographer, the greater the possibility to alternate between different tasks and kinds of examinations.

"The more (sonographers) who know how to do everything, the better it is. It's also better for that person ergonomically." (21)

In some workplaces a resource person was available to assist if a colleague was delayed or a patient was difficult to examine.

"I try to help out if I see that someone from sonography is late." (12)

Being well-accustomed with the equipment was perceived as improving the likelihood of a comfortable scanning posture, especially handling the transducer with less pressure.

"No, when I've got the image I need, I try to relax my hand and find it again. I've been doing this so long it's no problem." (7)

Some employed a strategy that involved shortening the scanning period, i.e. the transducer time, while others believed that taking more images would facilitate the analysis.

"The work afterwards takes longer. I try to do as short examinations as possible to spare my body." (1)

Depending on local practices, some sonographers analysed the images directly on the unit after scanning, while others did it afterwards at a separate workstation. The latter method was perceived as shortening the time spent at the ultrasound unit, and providing the possibility to change posture.

Consultation with a more experienced colleague was recommended if the recommended scanning time was exceeded. During prolonged examinations, e.g. mapping of veins, a team of two examiners was stated to be good practice, which also shortened the total examination time.

It was also stated that preparing for the examination by checking the images from previous examinations was a good strategy. Seriously ill or unstable patients were examined in bed and, if necessary, a colleague or a member of staff from the ward was asked to assist. Scanning facing the patient facilitated observation of the patient's face.

"I always ask the patient if he or she can stand, and if they can move, and if they can't, I fetch someone who can help me with the patient, so I don't try to move them by myself." (2)

## Discussion

### Methodological considerations

The selection of the sonographers included in this study was based on several inclusion criteria to ensure a variety of perceptions [25]. One of the inclusion criteria was interest in the study, which may have led to a selection bias, in that those with a high workload and/or musculoskeletal pain may have participated to a higher extent than others [28]. The interviews were planned by the head of department. One hour was allowed for each interview, and the interviews were performed during normal working hours at the sonographer's place of work. The interview guide was followed, but was flexible regarding the order in which the questions were asked. Twenty-two sonographers participated and saturation was achieved concerning the inclusion criteria [29].

The interview questions were developed by the authors together with two researchers well-versed in the research questions and the aim of the study. The credibility of the results may have been increased by the fact that the first



author had performed pre- and pilot interviews, and had a prior understanding of the sonographers' working situation, which facilitated the development of the interview guide [23]. The second author, who was experienced in content analysis, also checked all the meaning units identified, and the authors discussed the development of the results continuously, which may also have increased the credibility. During analysis, the authors took into consideration the recommendations in the consolidated criteria for reporting qualitative research (COREQ) [29].

The results were based on the participants' unique perceptions, which allowed the researchers to gain a deeper understanding of the sonographers' working situation. This was a suitable method of obtaining information, i.e. giving the participants a voice [23]. The results should, therefore, be valid for all medical staff who use ultrasound as a diagnostic tool [30].

#### Discussion of the results

The sonographers were aware of the ergonomic problems in their working environment, but these were usually not prioritized which is in line with previous results [6]. Thus, many suggestions were made for improvements to the working situation.

Echocardiography was considered physically demanding, regardless of the technique used, as the examination was performed with little variation in working posture and required simultaneous handling of the transducer and the control panel to obtain the required images. Carrying out the examination facing the patient (T1, T2) helped keep the transducer arm less abducted, which is in line with recommendations in previous research also put forward in the industry standards [21, 31]. Being able to use both hands on either the transducer or the control panel would be even better, which is feasible in T1 and T2. Ambidextrous scanning in echocardiography should be encouraged, and has been suggested in a previous study [8]. We recommend two examiners especially in more complicated examinations, to avoid delay and to shorten the total examination time, which may be a feasible and cost-effective strategy and also a good practice. Moreover, it may reduce the stress for the patients, especially those who are in pain. Such a routine requires the availability of qualified staffs which is sometimes a problem.

The sonographers' perceptions of how the equipment could be optimized to make it more individually adjustable should be acknowledged and supported. This is in line with the accommodation to user anthropometrics described by Park et al. [32]. Equipment adjustable to suit the anthropometrics of the 5<sup>th</sup> to the 95<sup>th</sup> percentiles of the population is recommended in the industry standards [21]. Inappropriate transducer design has been noted previously [33]. In this study, a wireless transducer

was suggested, but such a transducer is not accessible. Lightweight, neutral grip and flexible cables are recommended in the standards, but not a wireless transducer [4, 21].

An articulating support arm system for left-hand scanning was developed and tested in echocardiography to reduce the gripping of the transducer in strenuous and static postures, [16] which is in line with the development of a robotic arm [20]. Some of the participants in our study had positive experiences of the robot-assisted transducer, designed for tele sonography [19, 20], as no hand-grip nor manual pressure was required. This device needs to be further introduced and tested to facilitate the implementation in echocardiography as an ergonomic solution, especially for corpulent patients where higher grip forces are needed to achieve the images [8]. A deeper cooperation between technical experts and medical expertise, i.e. the sonographers, might facilitate such an implementation. The development of a standardized report system in echocardiographic imaging is an example of how technical representatives participated together with the expertise in cardiovascular imaging [34, 35].

Some of the sonographers in our study suggested a limitation on transducer time, and image analysis at a separate computer workstation, where individual adjustment, avoidance of noise and better visual conditions are possible. These aspects are prerequisites for good work conditions when working with computers and standard in some of the workplaces [36, 37]. The examination room, including equipment and light, is designed primarily for sonography. To facilitate positioning of the patient on the table before each examination, efforts should be devoted to developing the equipment and the examination room so as to be more adaptable to the patient's physique and health.

Several aspects of sonographers' working situation must be improved in the future. These include ergonomic aids, scheduling and optimization of workplaces used for scanning. Scheduling of varied examinations and tasks, requires both access to different work task and broad skills. It is also important to motivate sonographers to take an active part in the ergonomic aspects of their work. Further research is required on ways in which this can be achieved.

#### Conclusions

The sonographers perceived their work to be stimulating but physically exhausting. They were aware of the ergonomic problems associated with the patient's poor health. However, the patient's comfort and obtaining good images were often prioritized to the detriment of working posture. Ergonomic improvements were suggested, such as reducing the manual handling of the transducer, optimizing equipment adjustability and taking the patient's

physique and health into account. As some examinations were perceived more difficult than others, variation in examinations was suggested which, however, also requires broader skills.

#### Abbreviations

T1: Technique one; T2: Technique two; T3: Technique three

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#### Availability of data and materials

Data will not be shared as we will use the data for other research questions and publish another study.

#### Authors' contributions

JGS and GG were responsible for the concept and design. JGS carried out the collection and compilation of data. JGS and GG performed the analysis. JGS was responsible for drafting the manuscript. JGS and GG were responsible for interpretation of the results. Both authors approve the final version of the manuscript.

#### Authors' information

GG is a professor of physiotherapy at the University of Lund.

#### Competing interests

The authors declare that they have no competing interests.

#### Consent for publication

Not applicable.

#### Ethics approval and consent to participate

The Regional Ethical Board at Lund University approved the study (No. 2013/721). Written and oral information was given to all the participants. Written informed consent including consent to publish results was obtained from all participants.

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Original Article

## Assessments of Physical Workload in Sonography Tasks Using Inclinometry, Goniometry, and Electromyography

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### abstract

**Background:** Echocardiography involves strenuous postures of the upper limbs. This study explored the physical workload in the neck and upper limbs in sonographers performing echocardiography, and the extent to which the workload differs from that in other work tasks (other sonographic examinations, and nonsonographic tasks).

**Methods:** The physical load was assessed by inclinometry, goniometry, and electromyography methods in 33 female sonographers during authentic work using three different echocardiography techniques and other work tasks.

**Results:** Echocardiography was characterized by low velocities of the head, arms, and wrists, and a low proportion of muscular resting time in the forearms, in the transducer limb, and the computer limb. The transducer limb was more elevated in one of the techniques, but this technique also involved a higher proportion of muscular resting time of the trapezius muscle. We also found a high proportion of awkward wrist postures in the transducer wrist in all three techniques; in one due to prolonged flexion, and in the others due to prolonged extension. Other work tasks were less static, and were performed with higher upper arm and wrist velocities.

**Conclusion:** None of the three echocardiography techniques was optimal concerning physical workload. Thus, to achieve more variation in physical load we recommend that the equipment be arranged so that the sonographer can alternate between two different techniques during the workday. We also propose alternation between echocardiography and nonsonographic tasks, in order to introduce variation in the physical workload. Clinical expertise should be used to achieve further improvements.

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### 1. Introduction

The use of sonography has increased over recent decades, both in the number of examinations and the number of hours of scanning per day for sonographers [1e4]. Sonography involves strenuous postures and precise movements of the hand manipulating the transducer [5e7], which are two well-known risk factors for neck and upper extremity pain [8]. Echocardiography, sonography of the heart, is especially demanding as it involves considerable force, static postures, and monotonous movements [9]. In order to obtain the best images it is often necessary to apply a high sustained pressure with the transducer against the patient's chest [10], which is generally not needed in other types of sonography [11]. Echocardiography also includes intense work on the keyboard,

which is another risk factor [12]. Most echocardiographers also perform other sonographic examinations, for example, vascular examinations, and nonsonographic tasks, for example, spirometry. It has been shown that those who perform echocardiography have a higher prevalence of elbow/hand pain than those who only perform other sonographic examinations [13].

In a recent study on Swedish echocardiographers, we identified three techniques. The most commonly used technique (by 47%) was to hold the transducer in the left hand, with the patient lying to the left of the ultrasound machine [13]. Two alternative techniques were identified. In these the examiner held the transducer in the right hand with the patient lying to the right of the ultrasound machine. Which technique was used depended on local tradition. It is not known if any one of these three techniques is more favorable

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than the others in terms of the physical load, or whether alternating between different techniques in echocardiography would provide a variation in workload. Furthermore, it is unknown to what extent the physical workload in echocardiography differs from that in other kinds of sonographic examinations, or nonsonographic tasks in the ward; that is, whether a variation in tasks would be favorable with respect to workload.

Previous knowledge on sonographers' physical workload is predominantly based on observational studies and surveys. Technical measurements provide quantitative exposure data, with the obvious advantage that the results are independent of the individual and the observer [14]. Technical measurements of workload in sonography have been applied in a few studies [15e18], but none of these has explored differences between the three echocardiography techniques, using three different technical measurements.

The main aim of this study was, thus, to compare the physical workload in the neck and upper limbs associated with three different techniques in echocardiography. We also investigated the extent to which echocardiography differs from other sonographic examinations and nonsonographic tasks, with respect to workload on the neck and upper limbs, using the most common echocardiography technique as a proxy for all types of techniques.

## 2. Materials and methods

### 2.1. Participants

Thirty-three experienced female sonographers employed at clinical physiology and cardiology departments, mean age 47 years (range, 28e66 years), participated in the study. All were right-handed. We established contact with the head of the different departments during a previous study, and at that time informed the sonographers about the technical measurements [19]. Those who were interested in participating notified their head of department, and contact was established with the researchers. The measurements were planned together with the head of each clinic. None of the participants reported musculoskeletal pain or discomfort of such intensity that it influenced their working technique. Data collection involved nine hospitals in Southern Sweden during 2011e2015. At least one sonographer and at most six per hospital participated. Technique (T)1 and T3 were represented in four hospitals and T2 in five hospitals.

### 2.2. Work tasks

We investigated three different types of work tasks: echocardiography, other sonographic examinations (excluding echocardiography), and nonsonographic tasks. In echocardiography, the sonographer usually sits during the examination, maneuvering a transducer connected to the ultrasound machine by a cable in one hand, controlling the keyboard, integrated to the ultrasound machine, with the other hand, and at the same time, observing the images on a screen placed on top of the ultrasound machine. The sonographer applies pressure on the transducer with the hand to achieve optimal contact [20]. The sonographers in this study used one of three techniques, denoted T1 (10 participants), T2 (13 participants), and T3 (10 participants). In T1 the table was placed on the left side of the ultrasound machine, while in T2 and T3 the table was placed on the right side. In T1 the patient faced the examiner, who held the transducer in the left hand and handled the keyboard with the right hand (Fig. 1). In T2 the patient faced the examiner, who held the transducer in the right hand and handled the keyboard with the left hand (Fig. 2). In T3 the patient faced away from the examiner, who held the transducer in the right hand and handled the keyboard with the left hand (Fig. 3).



Fig. 1. Echocardiographic examination using Technique 1.

Among the 10 sonographers using T1, six also performed other sonographic examinations, for example, abdominal aorta scanning, mapping of veins, vascular scanning, and examination of fistulas. Their working posture varied depending on the type of examination. For example, in some examinations the sonographer could change transducer hands. In addition, these 10 sonographers also performed other nonsonographic tasks, such as computer work, booking patients, spirometry, lung scintigraphy, cleaning the equipment between examinations, and fetching the patients from the waiting room.

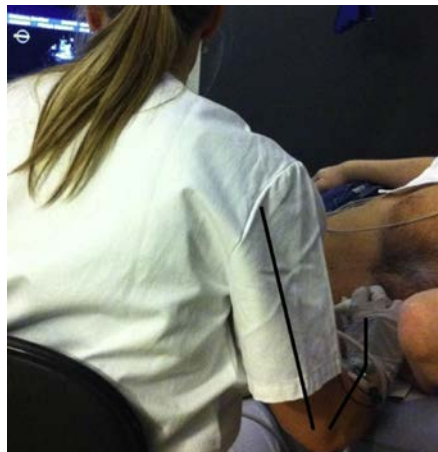


Fig. 2. Echocardiographic examination using Technique 2.



Fig. 3. Echocardiographic examination using Technique 3.

### 2.3. Recordings of physical workload

The participants carried portable data loggers that recorded and stored data. The equipment was applied in the morning, and reference postures and maximal contractions were performed. An observer followed each participant and made precise notes of the tasks that they performed. These tasks were then classified as echocardiography, other sonographic examinations, or nonsonographic tasks. We excluded data recorded during long breaks, such as lunch, from the analyses. After the recording the data were transferred to a personal computer.

To compare the different echocardiography techniques, we analyzed the data recorded while the sonographer held the transducer in her hand (transducer time). Transducer time was defined as the period from when the sonographer removed the transducer from the holder, to replacement of the transducer in the holder. The median recorded transducer time for T1 was 72 minutes (mean, 71 minutes; range, 20e169 minutes), for T2, 56 minutes (mean, 63 minutes; range, 28e94 minutes), and for T3, 87 minutes (mean, 79 minutes; range, 30e127 minutes). Data were recorded for both the transducer limb (the arm holding the transducer, i.e., the left limb in T1 and the right limb in T2 and T3), and the keyboard limb (the arm used to operate the keyboard on the ultrasound machine). For other sonographic examinations and other work tasks, only data from the right limb were analyzed, as this was the dominant limb in all participants.

In the 10 participants who used T1, the physical workload was recorded during a complete working day, and included all the work tasks performed that day. The number of examinations and other work tasks varied depending on the appointment list for that day. The examination time was defined as the time when the patient entered the room until he/she left the room. Data were recorded from at least two echocardiographic examinations per sonographer (median recording time, 159 minutes; mean, 159 minutes; range, 46e343 minutes). Data were also recorded from other sonographic examinations in six of these participants (median, 121 minutes; mean, 133 minutes; range, 64e240 minutes). Data were recorded for nonsonographic tasks in all 10 sonographers using T1 (median, 57 minutes; mean, 69 minutes; range, 1e217 minutes). For these,

only data from the right limb were analyzed as this was the dominant limb in all participants, and was thus expected to have the highest exposure. We then compared the exposure of the transducer limb (i.e., the left limb) in echocardiography with that in the right limb in other tasks.

### 2.4. Inclination

Inclinometers based on triaxial accelerometers were used in combination with a data logger (Logger Teknologi HB, Åkarp, Sweden) to measure and record postures (inclination relative to the line of gravity) and movements of the head, upper back, and both upper arms [21]. The inclinometers were attached to the forehead, to the right of the spine at the C7 level (upper back), and on both upper arms just below the insertion of the deltoid muscles. A reference posture was recorded for the head and upper back (0° inclination) with the participant standing upright looking at a mark at eye level. To determine reference positions for the arms, the participant was seated with the side of the body leaning towards the back of a chair and the arm hanging vertically over the back of the chair, with a 2-kg dumbbell in the hand [22].

### 2.5. Goniometry

Biaxial flexible electrogoniometers (SG75; Biometrics Ltd., Cwmfelinfach, Gwent, UK) were used in combination with a data logger to measure and record postures and movements of the wrists [23]. In the first 20 recordings, a logger with a sampling rate of 20 Hz was used (Logger Teknologi HB), whereas in the remaining 13, a Mobi-8 data logger with a sampling rate of 128 Hz was used (TMS International, Oldenzaal, The Netherlands). The electrogoniometers were attached bilaterally to the wrists, one block on the third metacarpal bone and the other one at the midline between the forearm bones. The reference position (0° flexion and deviation) was defined with the forearm and hand resting on a table with the elbow flexed 90°. The hand was adjusted so that the third metacarpal bone of the middle finger and the midline between the forearm bones pointed along the same direction, with a sight line between the ulna and third metacarpal bone [24].

### 2.6. Electromyography

Bipolar surface electromyography (EMG) was performed with Ag/AgCl electrodes (Ambu Neuroline 720; Ambu A/S, Ballerup, Denmark), with an interactive diameter of 6 mm and a center-to-center distance of 20 mm, to record bilateral muscular activity of the trapezius muscles and the forearm extensor muscles (mm extensor carpi radialis longus and brevis) at a sampling rate of 1,024 Hz [25]. The electrodes were attached to the descending part of the upper trapezius muscle, 2 cm lateral to the line between the seventh cervical vertebra and the lateral edge of the acromion. The forearm electrodes were applied to the most prominent part of the muscles, approximately one-third of the distance from the lateral epicondyle to the ulnar styloid. The muscular activity during work was normalized to the maximum voluntary EMG activity recorded during maximal voluntary contractions [25].

### 2.7. Statistical analysis

#### 2.7.1. Summary measures

The 50<sup>th</sup> percentiles of the angular distributions for work postures of the head, upper back, and both upper arms were calculated. Inclination was assessed both forwards/backwards and sideways, where positive values denote forwards and right sideways [26]. The median angular velocity distributions were obtained for the head



and both upper arms, as well as the percent of the time the upper arm elevation was above 30° and 60° for both arms. The angular distributions and the median angular velocity distributions for both wrists were obtained for the 10<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentiles. Positive values denote palmar flexion and ulnar deviation, while negative values denote dorsal extension and radial deviation [27]. Awkward postures were defined as the percent of the time exceeding 40° dorsal extension or 5° palmar flexion. The peak load was defined as the 90<sup>th</sup> percentile of the EMG amplitude distributions. The proportion of time when the muscular activity was < 0.5% of the maximum voluntary EMG activity was defined as muscular rest (% of time) [25].

2.7.2. Statistical methods

As data for some of the measures were skewed, nonparametric statistical tests were used, and group medians are therefore presented. Group means and standard deviations are also used to enable comparisons with earlier studies [26,27]. In comparisons of independent observations, that is, of the different echocardiography techniques, the ManneWhitney *U* test was used. Data recorded for the transducer limb and keyboard limb were analyzed separately. In comparisons of dependent observations, that is, echocardiography versus other sonographic examinations and nonsonographic tasks, the Wilcoxon matched-pairs signed-rank test was used. We then compared the recordings from the transducer limb, that is, the left limb, with the right limb in other work tasks (as all participants were right-handed). A *p* value < 0.05 was regarded as indicating statistically significant differences. We used SPSS version 22 (IBM, Armonk, NY, USA).

2.8. Ethical considerations

The study was approved by the Regional Ethics Committee in Lund, Sweden (No. 2010/19).

3. Results

3.1. Different techniques in echocardiography

3.1.1. Transducer limb

The results obtained from measurements on the transducer limb during echocardiography using three different techniques are given in Table 1. The upper arm was elevated above 30° 93% of the time in T3 (where the arm was held around the patient), which was more than twice as long as in T1 and T2. By contrast, the proportion of time the trapezius muscle was at rest was considerable higher in T3 (18%) than in the other two techniques (w6%).

In T1 and T2, the wrist was extended during the whole examination, and in an awkward posture about 50% of the time. In T3 the wrist was flexed more than half of the examination time, and in an awkward posture 81% of the time, which was significantly more than in T1. The wrist velocities were < 2°/s and the proportion of time the forearm extensor muscles were at rest was < 1% of the time in all techniques (Table 1).

3.1.2. Keyboard limb

No major differences were found in physical workload on the keyboard limb between the three echocardiography techniques (Table 2). The upper arm was elevated above 30° approximately half

Table 1  
Physical workload in the neck and transducer limb during echocardiography transducer time in 33 female sonographers using three different techniques (T1, T2, and T3: *p* values from ManneWhitney *U* tests\*)

|  | T1     |            | T2     |            | T1 vs T2 | T3     |            | T1 vs T3 | T2 vs T3 |
|--|--------|------------|--------|------------|----------|--------|------------|----------|----------|
|  | N % 10 |            | N % 13 |            | <i>p</i> | N % 10 |            | <i>p</i> | <i>p</i> |
|  | Med    | Mean (SD)  | Med    | Mean (SD)  |          | Med    | Mean (SD)  |          |          |
| Neck/shoulder/upper back   |        |            |        |            |          |        |            |          |          |
| Head   |        |            |        |            |          |        |            |          |          |
| Inclination (°, 50 <sup>th</sup> percentile) <sup>1</sup>            | e1.3   | e0.1 (7.0) | 2.8    | 2.3 (3.7)  | 0.55     | 3.0    | 3.6 (4.1)  | 0.25     | 0.57     |
| Sideways inclination (°, 50 <sup>th</sup> percentile) <sup>2</sup>   | 0.6    | 1.1 (2.3)  | 0.7    | 0.6 (1.3)  | 0.88     | 0.3    | e1.1 (2.5) | 0.12     | 0.12     |
| Velocity (°/s, 50 <sup>th</sup> percentile)                          | 3.2    | 3.6 (1.1)  | 3.4    | 3.5 (0.7)  | 0.62     | 3.7    | 3.7 (1.1)  | 0.81     | 0.81     |
| Upper back inclination (°, 50 <sup>th</sup> percentile) <sup>2</sup> | 6.5    | 7.5 (5.3)  | 11     | 11 (3.9)   | 0.12     | 9.8    | 9.4 (4.2)  | 0.35     | 0.41     |
| Upper arm  |        |            |        |            |          |        |            |          |          |
| Elevation (°, 50 <sup>th</sup> percentile)                           | 29     | 28 (4.4)   | 19     | 22 (12)    | 0.13     | 44     | 47 (9.4)   | <0.001   | 0.001    |
| Elevation above 30° (% time)   | 47     | 41 (20)    | 26     | 36 (32)    | 0.41     | 94     | 93 (5.5)   | <0.001   | 0.001    |
| Velocity (°/s, 50 <sup>th</sup> percentile)                          | 3.6    | 4.1 (1.5)  | 4.2    | 4.1 (0.7)  | 0.50     | 4.2    | 4.3 (0.9)  | 0.29     | 0.68     |
| Trapezius muscle   |        |            |        |            |          |        |            |          |          |
| Peak load (% MVE, 90 <sup>th</sup> percentile)                       | 9.4    | 8.7 (3.5)  | 11     | 11 (5.5)   | 0.37     | 7.8    | 8.0 (2.3)  | 0.57     | 0.17     |
| Rest (<0.5% MVE % time)  | 4.3    | 6.1 (5.0)  | 1.8    | 5.6 (10)   | 0.06     | 16     | 18 (15)    | 0.09     | 0.03     |
| Forearm/wrist  |        |            |        |            |          |        |            |          |          |
| Wrist flexion/extension <sup>3</sup>                                 |        |            |        |            |          |        |            |          |          |
| 10 <sup>th</sup> percentile (°)                                      | e50    | e49 (5.9)  | e57    | e57 (10)   | 0.03     | e24    | e25 (12)   | <0.001   | <0.001   |
| 50 <sup>th</sup> percentile (°)                                      | e31    | e31 (8.2)  | e39    | e37 (12)   | 0.22     | 10     | 8.8 (8.4)  | <0.001   | <0.001   |
| 90 <sup>th</sup> percentile (°)                                      | e6.1   | e4.2 (13)  | e15    | e14 (10)   | 0.12     | 29     | 26 (10)    | 0.001    | <0.001   |
| Velocity (°/s, 50 <sup>th</sup> percentile)                          | 1.0    | 1.3 (0.7)  | 1.0    | 1.0 (0.3)  | 0.32     | 1.3    | 1.2 (0.1)  | 0.15     | 0.06     |
| Awkward postures (% of time)   | 44     | 46 (15)    | 52     | 53 (21)    | 0.39     | 65     | 81 (17)    | 0.05     | 0.19     |
| Wrist deviation <sup>4</sup>   |        |            |        |            |          |        |            |          |          |
| 10 <sup>th</sup> percentile (°)                                      | e16    | e16 (7.1)  | e14    | e12 (5.9)  | 0.12     | e18    | e21 (6.4)  | 0.29     | 0.004    |
| 50 <sup>th</sup> percentile (°)                                      | e4.3   | e3.7 (6.6) | 0.1    | 0.06 (6.5) | 0.29     | e7.5   | e6.8 (6.0) | 0.26     | 0.02     |
| 90 <sup>th</sup> percentile (°)                                      | 12     | 11 (7.5)   | 13     | 14 (5.7)   | 0.46     | 10     | 8.7 (5.8)  | 0.41     | 0.04     |
| Velocity (°/s, 50 percentile)  | 0.8    | 0.8 (0.3)  | 0.6    | 0.6 (0.2)  | 0.14     | 0.9    | 1.0 (0.1)  | 0.02     | 0.001    |
| Forearm extensor muscles   |        |            |        |            |          |        |            |          |          |
| Peak load (% MVE, 90 <sup>th</sup> percentile)                       | 19     | 18 (6.4)   | 15     | 17 (7.5)   | 0.58     | 11     | 14 (12)    | 0.02     | 0.05     |
| Rest (<0.5% MVE % time)  | <0.001 | 0.22 (0.4) | <0.001 | 0.13 (0.4) | 0.85     | 0.2    | 0.6 (1.0)  | 0.12     | 0.02     |

Med., median; MVE, maximum voluntary EMG activity; SD, standard deviation; T1, Technique 1; T2, Technique 2; T3, Technique 3.

\* Bold face denotes *p* < 0.05.

<sup>1</sup> Positive forward, negative backward.

<sup>2</sup> Positive right, negative left.

<sup>3</sup> Positive palmar flexion, negative dorsal extension.

<sup>4</sup> Positive ulnar deviation, negative radial deviation.

Table 2

Physical workload in the computer limb during echocardiography transducer time in 33 female sonographers using three different techniques (T1, T2, and T3; *p* values from Mann-Whitney *U* tests\*)

|  | T1     |            | T2     |            | T1 vs T2 |  | T3     |            | T1 vs T3 |  | T2 vs T3 |      |
|--|--------|------------|--------|------------|----------|--|--------|------------|----------|--|----------|------|
|  | N % 10 |            | N % 13 |            |          |  | N % 10 |            |          |  |          |      |
|  | Med    | Mean (SD)  | Med    | Mean (SD)  | <i>p</i> |  | Med    | Mean (SD)  | <i>p</i> |  | <i>p</i> |      |
| <b>Neck/shoulder</b>                           |        |            |        |            |          |  |        |            |          |  |          |      |
| <b>Upper arm</b>                               |        |            |        |            |          |  |        |            |          |  |          |      |
| Elevation (°; 50 <sup>th</sup> percentile)     | 32     | 31 (4.2)   | 28     | 28 (6.8)   | 0.13     |  | 30     | 32 (6.0)   | 0.92     |  |          | 0.37 |
| Elevation above 30° (% time)                   | 62     | 60 (22)    | 36     | 46 (27)    | 0.21     |  | 49     | 57 (27)    | 0.85     |  |          | 0.46 |
| Velocity (%/s, 50 <sup>th</sup> percentile)    | 5.6    | 6.6 (2.6)  | 6.8    | 7.2 (1.6)  | 0.33     |  | 6.4    | 6.9 (2.1)  | 0.56     |  |          | 0.57 |
| <b>Trapezius muscle</b>                        |        |            |        |            |          |  |        |            |          |  |          |      |
| Peak load (% MVE, 90 <sup>th</sup> percentile) | 8.3    | 8.3 (3.7)  | 7.7    | 9.2 (6.2)  | 0.92     |  | 11     | 10 (3.9)   | 0.57     |  |          | 0.35 |
| Rest (<0.5% MVE % time)                        | 6.7    | 16 (19)    | 11     | 12 (16)    | 0.66     |  | 6.3    | 10 (9.8)   | 0.81     |  |          | 0.85 |
| <b>Forearm/wrist</b>                           |        |            |        |            |          |  |        |            |          |  |          |      |
| <b>wrist flexion/extension<sup>†</sup></b>     |        |            |        |            |          |  |        |            |          |  |          |      |
| 10 <sup>th</sup> percentile (°)                | e54    | e57 (12)   | e46    | e43 (10)   | 0.02     |  | e42    | e41 (12)   | 0.009    |  |          | 0.71 |
| 50 <sup>th</sup> percentile (°)                | e36    | e38 (10)   | e35    | e30 (10)   | 0.26     |  | e27    | e25 (11)   | 0.009    |  |          | 0.30 |
| 90 <sup>th</sup> percentile (°)                | e12    | e13 (7)    | e11    | e8.5 (9.1) | 0.29     |  | e10    | e5.6 (11)  | 0.14     |  |          | 0.53 |
| Velocity (%/s, 50 <sup>th</sup> percentile)    | 4.6    | 4.5 (1.3)  | 3.2    | 3.2 (0.9)  | 0.03     |  | 3.7    | 4.0 (1.7)  | 0.46     |  |          | 0.37 |
| Awkward postures (% of time)                   | 42     | 46 (19)    | 41     | 36 (14)    | 0.29     |  | 27     | 30 (14)    | 0.05     |  |          | 0.46 |
| <b>Wrist deviation<sup>‡</sup></b>             |        |            |        |            |          |  |        |            |          |  |          |      |
| 10 <sup>th</sup> percentile (°)                | e11    | e12 (8.6)  | e11    | e10 (5.9)  | 0.76     |  | e4.9   | e6.2 (3.9) | 0.11     |  |          | 0.07 |
| 50 <sup>th</sup> percentile (°)                | 0.94   | e0.6 (7.9) | 6.1    | 4.8 (6.3)  | 0.08     |  | 7.2    | 5.4 (5.4)  | 0.07     |  |          | 0.76 |
| 90 <sup>th</sup> percentile (°)                | 10     | 9 (6.4)    | 15     | 14 (5.8)   | 0.15     |  | 16     | 15 (5.7)   | 0.04     |  |          | 0.45 |
| Velocity (%/s, 50 <sup>th</sup> percentile)    | 2.3    | 2.4 (0.5)  | 1.8    | 1.8 (0.3)  | 0.008    |  | 2.4    | 2.4 (0.9)  | 0.65     |  |          | 0.10 |
| <b>Forearm extensor muscles</b>                |        |            |        |            |          |  |        |            |          |  |          |      |
| Peak load (% MVE, 90 <sup>th</sup> percentile) | 21     | 20 (5.5)   | 15     | 15 (8.5)   | 0.13     |  | 15     | 17 (12)    | 0.33     |  |          | 0.71 |
| Rest (<0.5% MVE % time)                        | 0.4    | 1.1 (2.0)  | 0.9    | 1.7 (2.1)  | 0.21     |  | 0.5    | 0.8 (0.8)  | 0.89     |  |          | 0.18 |

Med., median; MVE, maximum voluntary EMG activity; SD, standard deviation; T1, Technique 1; T2, Technique 2; T3, Technique 3.

<sup>†</sup> Bold face denotes *p* < 0.05.

<sup>‡</sup> Positive palmar flexion, negative dorsal extension.

<sup>‡</sup> Positive ulnar deviation, negative radial deviation.

of the time in all three techniques. The wrist was dorsally extended in all techniques during the whole transducer time, and most extended in T1 (-57<sup>th</sup> percentile). The time spent in awkward wrist posture was highest for T1 (46%). The wrist velocities were < 5%/s in all three techniques, and the proportions of forearm extensor rest were < 2%.

### 3.1.3. Transducer limb versus keyboard limb

In T3, the transducer arm was elevated above 30° for a longer time (*p* % 0.008) and the 50<sup>th</sup> percentile (*p* % 0.008) for elevation was higher than in the keyboard arm (Tables 1 and 2). The opposite was found for T1 (*p* % 0.05) and T2, that is, the keyboard arm was elevated > 30° longer than the transducer arm. The proportion of time the trapezius muscle was at rest was higher in the transducer arm in T3 (*p* % 0.02) than in the keyboard arm. The wrist was less extended in the transducer limb than in the keyboard limb in all percentiles in T3 (10<sup>th</sup>: *p* % 0.01, 50<sup>th</sup>: *p* % 0.008, 90<sup>th</sup>: *p* % 0.008). The wrist velocity was lower in both flexion/extension in the transducer limbs than in the keyboard limbs in all techniques (T1: *p* % 0.005, T2: *p* % 0.001, T3: *p* % 0.008), and in deviation (T1: *p* % 0.005, T2: *p* % 0.005, T3: *p* % 0.005). In T3, the transducer wrist was held in an awkward posture twice as long as the keyboard wrist (*p* % 0.01). The proportion of time the extensor muscle was at rest was also overall lower in the transducer forearm than in the computer forearm, and significantly lower in T2 (*p* % 0.002).

### 3.2. Echocardiography versus other work tasks

Other work tasks were less static than echocardiography (Table 3). Head velocity was lower in echocardiography than in nonsonographic tasks. Upper arm velocity as well as wrist velocity were lower in echocardiography than in both other sonographic examinations and in nonsonographic tasks. The wrist was held in

awkward postures nearly half of the time in both echocardiography and in other work tasks.

## 4. Discussion

In general, echocardiography is a static work task, characterized by low velocities in the head, arms, and wrists, and with low proportions of time of muscular rest, particularly in the forearm extensor muscles, also shown by Village and Trask [16], compared with other occupational groups [27]. This was true for both the transducer limb and the keyboard limb. The transducer arm was more elevated in T3 than in the other techniques, but this technique was associated with a higher proportion of time of muscular rest in the trapezius muscle. The transducer wrist was held in awkward postures a considerable proportion of the time: in T3 due to prolonged flexion, and in T1 and T2 due to prolonged extension. Other sonographic examinations and nonsonographic tasks were performed with somewhat higher upper arm and wrist velocities, and were thus less static.

### 4.1. Methodological considerations

Since the examination room is arranged for the technique in question and there is limited scope for variation in posture, we consider the number of measurements and recording times enough to capture possible variations. We focused on echocardiographic examinations when planning the technical measurements, which explains why all the participants performed echocardiography, but not necessarily other sonographic examinations, which was a limitation as only six sonographers performed other sonographic examinations. Sonographers who were interested participated in the study, which may have affected the number of sonographers performing other sonographic examinations and the variety of such

Table 3

Physical workload in 10 female sonographers during different tasks. Recordings from neck and transducer limb in echocardiography (Technique 1), neck and right limb in other sonographic examinations and nonsonographic tasks (*p* values from Wilcoxon matched pairs test<sup>a</sup>)

|  | Echocardiography |            | Other sonographic examinations |            | <i>p</i> vs. echo | Nonsonographic tasks |            | <i>p</i> vs. echo |
|--|------------------|------------|--------------------------------|------------|-------------------|----------------------|------------|-------------------|
|  | <i>N</i> = 10    |            | <i>N</i> = 6                   |            |                   | <i>N</i> = 10        |            |                   |
|  | Med              | Mean (SD)  | Med                            | Mean (SD)  |                   | Med                  | Mean (SD)  |                   |
| <b>Neck/shoulder</b>   |                  |            |                                |            |                   |                      |            |                   |
| <b>Head</b>  |                  |            |                                |            |                   |                      |            |                   |
| Inclination (°, 50 <sup>th</sup> percentile) <sup>b</sup>            | 3.3              | 4.3 (6.2)  | 8.0                            | 8.1 (6.5)  | 0.25              | 8.3                  | 7.8 (5.9)  | 0.05              |
| Sideways inclination (°, 50 <sup>th</sup> percentile) <sup>c</sup>   | 0.7              | 0.9 (1.5)  | 0.3                            | 0.3 (0.8)  | 0.35              | e0.4                 | e0.3 (1.0) | 0.05              |
| Velocity (%s, 50 <sup>th</sup> percentile)                           | 5.3              | 5.7 (1.7)  | 6.4                            | 7.0 (2.8)  | 0.17              | 7.3                  | 8.9 (4.6)  | 0.04              |
| Upper back inclination (°, 50 <sup>th</sup> percentile) <sup>d</sup> | 8.0              | 9.1 (4.7)  | 8.0                            | 11 (5.6)   | 0.08              | 7.3                  | 10 (5.0)   | 0.09              |
| <b>Upper arm</b>   |                  |            |                                |            |                   |                      |            |                   |
| Elevation (°, 50 <sup>th</sup> percentile)                           | 27               | 26 (3.0)   | 28                             | 29 (4.5)   | 0.17              | 28                   | 27 (4.0)   | 0.89              |
| Elevation above 30° (% time)   | 38               | 38 (4.9)   | 43                             | 46 (16)    | 0.35              | 37                   | 37 (14)    | 0.67              |
| Velocity (%s, 50 <sup>th</sup> percentile)                           | 6.5              | 7.4 (3.1)  | 12                             | 14 (8.0)   | 0.05              | 11                   | 20 (17)    | 0.05              |
| <b>Trapezius muscle</b>  |                  |            |                                |            |                   |                      |            |                   |
| Peak load (% MVE, 90 <sup>th</sup> percentile)                       | 7.8              | 8.6 (3.3)  | 12                             | 11 (2.5)   | 0.50              | 10                   | 9.0 (3.1)  | 0.67              |
| Rest (<0.5% MVE % time)  | 9.5              | 11 (8.7)   | 13                             | 14 (5.7)   | 0.23              | 21                   | 15 (13)    | 0.48              |
| <b>Forearm/wrist</b>   |                  |            |                                |            |                   |                      |            |                   |
| <b>Wrist flexion/extension (°)<sup>e</sup></b>                       |                  |            |                                |            |                   |                      |            |                   |
| 10 <sup>th</sup> percentile (°)                                      | e46              | e47 (4.1)  | e50                            | e53 (11)   | 0.25              | e47                  | e47 (12)   | 0.87              |
| 50 <sup>th</sup> percentile (°)                                      | e21              | e22 (5.0)  | e24                            | e28 (11)   | 0.25              | e24                  | e24 (11)   | 0.58              |
| 90 <sup>th</sup> percentile (°)                                      | 11               | 11 (7.4)   | 5.0                            | 3.8 (8.9)  | 0.03              | 6.9                  | 10 (13)    | 0.51              |
| Velocity (%s, 50 percentile)   | 1.6              | 2.1 (1.4)  | 5.1                            | 6.0 (3.2)  | 0.03              | 4.2                  | 7.3 (6.7)  | 0.007             |
| Awkward postures (% of time)   | 42               | 44 (8.9)   | 38                             | 42 (14)    | 0.75              | 40                   | 41 (14)    | 0.58              |
| <b>Wrist deviation (°)<sup>f</sup></b>                               |                  |            |                                |            |                   |                      |            |                   |
| 10 <sup>th</sup> percentile (°)                                      | e20              | e20 (6.0)  | e15                            | e16 (2.8)  | 0.46              | e20                  | e20 (8.6)  | 0.79              |
| 50 <sup>th</sup> percentile (°)                                      | e3.4             | e4.0 (5.6) | e1.6                           | e2.0 (2.6) | 0.75              | e6.04                | e5.9 (5.2) | 0.51              |
| 90 <sup>th</sup> percentile (°)                                      | 11               | 10 (5.8)   | 9.8                            | 9.9 (3.3)  | 0.25              | 6.01                 | 6.8 (4.6)  | 0.07              |
| Velocity (%s, 50 percentile)   | 1.1              | 1.4 (0.6)  | 3.0                            | 3.3 (1.5)  | 0.03              | 2.98                 | 4.1 (2.8)  | 0.005             |
| <b>Forearm extensor muscles</b>                                      |                  |            |                                |            |                   |                      |            |                   |
| Peak load (% MVE, 90 <sup>th</sup> percentile)                       | 17               | 11 (4.2)   | 21                             | 12 (4.2)   | 0.14              | 21                   | 19 (4.4)   | 0.26              |
| Rest (<0.5% MVE % time)  | 9.1              | 8.1 (5.5)  | 3.2                            | 3.1 (1.4)  | 0.07              | 9.7                  | 9.0 (5.2)  | 0.78              |

Med., median; MVE, maximum voluntary EMG activity; SD, standard deviation; T1, Technique 1; T2, Technique 2; T3, Technique 3.

<sup>a</sup> Bold face denotes *p* < 0.05.

<sup>b</sup> Positive forward, negative backward.

<sup>c</sup> Positive right, negative left.

<sup>d</sup> Positive palmar flexion, negative dorsal extension.

<sup>e</sup> Positive ulnar deviation, negative radial deviation.

examinations as we had a focus on echocardiography. However, since it was the same individual performing both tasks (matched pairs test), we believe that the number of participants was sufficient for reliable interpretation of the results. The extent to which nonsonographic tasks were performed was determined by hospital policies and the patient reservations on the measurement day, which was a limitation as the variation in these tasks could have been affected by these factors. However, as nonsonographic examinations were performed by all 10 sonographers, we consider the results to be reliably interpretable.

In contrast to previous measurements by our research group [28], we used the anatomical reference position of the wrist [24] instead of the functional reference. This decision was taken as the functional reference position is associated with considerable intervariability [23]. The anatomical reference position is well established and standardized [24]. Thus, we have no reason to believe that this change in reference position has had any negative effects on the validity of this study, but rather will improve comparison with future studies. However, when comparing the results in the present study to our previously published data on other occupational groups, the differences in reference position must be taken into account.

We chose to define awkward wrist postures as postures where the wrist is either in dorsal extension > 40° or in palmar flexion > 5°, for several reasons. We have measured wrist postures during work in many different occupations [27], and the mean of the group means of the 10<sup>th</sup> percentile in those was -40°, and for the 90<sup>th</sup>

percentile 5° (after adjustment for differences in reference position). This is in line with the fact that a functional handgrip entails a somewhat extended wrist. The so-called functional arcs of motion have been found to be from 5° of flexion to 30° of extension [29]. O'Driscoll et al. [30] showed that the self-selected hand position was 35° of extension and 7° of ulnar deviation, when testing grip strength. We have also shown in a previous study that the risk of elbow/hand disorders increase with increasing palmar flexion [31]. We therefore suggest that the limits are not symmetrical around 0°.

#### 4.2. Physical work load in echocardiography

It has been reported from questionnaire and observational studies that echocardiography is static [16,32]. This was confirmed in a recent study, where we compared whole-day recordings from sonographers with those from nurses, assistant nurses, and teachers, where it was found that the sonographers had lower movement velocities than the other groups (12°/s) [19]. In the present study, a high proportion of time was spent in awkward wrist postures, and the proportion of muscular rest time in the forearm was low. Thus, low movement velocities and awkward postures are probably major reasons why echocardiographers have a high prevalence of work-related musculoskeletal disorders (WRMSDs).

Echocardiography is highly sensory demanding, requiring mental focus and control of body movements [13]. This is similar to the cases of dentists and air traffic controllers, who have also been

found to experience WRMSDs [33,34]. This supports our assumption of a causal relationship between this type of work situation and WRMSDs.

#### 4.3. Which echocardiography technique is preferable?

Upper arm elevation was higher in T3 than in T1 and T2. By contrast, the proportion of muscular rest time was three times higher in T3 than in the other techniques, which indicates that the arm may have been supported against the patient during transducer handling. This is in accordance with another study on echocardiography [18] where arm support led to a reduction in trapezius muscle activity during scanning; T1 had the lowest proportion of trapezius muscular rest in both limbs (w6% time), which is low in comparison to other types of work [26].

Extreme wrist extension characterized both limbs in T1 and T2 as the sonographer applies pressure with the transducer away from herself, which could explain why the transducer wrist was in an awkward extended posture about half the time in these techniques. In T3, pressure is applied towards the sonographer. Thus, the transducer wrist was in an awkward flexed wrist posture in T3 as much as 81% of the time. The direction of applied pressure with the transducer may explain the differences in forearm extensor peak load between T1/T2 and T3.

A low velocity forearm posture characterized both the transducer and keyboard limbs in all techniques. We know from observations that the wrist, but not the forearm, usually rests on the ultrasound keyboard. The keyboard wrist was more extended in T1 than in the other techniques, but we were unable to provide an explanation for this.

In summary, neither T1, T2, nor T3 was optimal, but they each had some advantages. T1 and T2 were most favorable concerning upper arm posture, whereas T3 had the advantage of the sonographer being able to support her arm against the patient. Concerning the workload on the forearm and wrist, T1 or T2 is preferable, at least for the transducer limb. The optimal solution would be to change between T1/T2 and T3 to ensure variation in wrist posture.

#### 4.4. Is it advantageous to alternate with other work tasks?

Echocardiography was more static than other work tasks, with lower velocities in the head, upper arm, and wrist. However, the wrists were equally extended in all three work tasks, that is, more than half of the time, and held in awkward postures 40% of the time. The proportion of forearm muscular rest time was even lower in other sonographic examinations. We know from observations that some of these examinations (especially examinations of veins in the legs) were strenuous for the upper limbs as the patients were examined standing. The sonographer maneuvered the transducer with one hand and applied pressure on the vein being examined at the same time. In echocardiography, the keyboard and transducer were usually operated with the same arm/hand either right or left, while in other work tasks, alternating or two-handed operation was more common.

Echocardiography also required multitasking. The sonographer has to maneuver the transducer with one hand and the keyboard with the other, while at the same time watching the images on the screen. Nonsonographic tasks included computer work as well as several other tasks, which probably gave opportunities for more variation in posture than in echocardiography. As the physical load differs between different tasks, alternating seems favorable, especially between transducer and nontransducer tasks, that is, non-sonographic examinations.

#### 4.5. Recommendations

We propose alternation between echocardiographic techniques, most easily accomplished between T2 and T3 (Figs. 2, 3) by placing the examination table on the right side of the ultrasound machine. Patients should be examined alternately with their heads at one end of the table or the other. As the patient lies on the left side during the examination, they will either lie facing the unit (T2) or with their back to the unit (T3). The examiner sits in front of the unit with the patient on the table on her right side, holds the transducer in her right hand, and operates the keyboard with the left hand. An adjustable table would be required, that is, one where it is easy to change head ends, with cushion drop-downs on both sides of the table, and supports for the patient. A multifunction chair will also be needed. This arrangement would provide the sonographer with two alternative ways of examining the patient.

A more flexible transducer design allowing different grips is also desirable, as forceful hand exertions have been found to be associated with carpal tunnel syndrome in a large prospective study [35]. Regarding the keyboard limb, the ultrasound keyboard should be designed so as to provide rest for a more relaxed forearm, and the keys used most often should be positioned so as to minimize arm extension. Measures taken to improve ergonomics in computer work in general have not yet been fully implemented in sonography.

As none of the three echocardiography techniques was found to be superior to the others, we recommend that as little time as possible is spent working at the ultrasound unit. This can be achieved by downloading the images to a regular computer workplace for analysis and consultation response. The computer workplace should be individually adjustable and located in an office with daylight.

As an intervention against WRMSDs, more physical variation is suggested, however, the evidence for this intervention is weak [36]. Alternation between work tasks, that is, dividing the workday into several sessions, has already been introduced in some sonography departments, and has been perceived as positive [11]. As echocardiography is static, and other sonographic and nonsonographic examinations are less so, we strongly recommend a combination of all three.

The knowledge of clinical experts is also needed. As suggested by Sommerich et al. [10], we propose that sonographers using different working techniques are brought together in focus groups for discussions, so that they can share their experiences in an effort to improve their working conditions.

#### 5. Conclusions

Echocardiography is static, with low velocities of the head, upper arm, and wrist, awkward wrist postures, and a lack of forearm muscular rest. Both the transducer and keyboard limbs are at risk of musculoskeletal disorders. To prevent such disorders we recommend that the equipment be arranged so that the sonographer can alternate between two different techniques, which will introduce variation in physical load, although the task will still be demanding. We also recommend that other work tasks be interspersed during the workday.

#### Conflicts of interest

The authors have no conflicts of interest to declare.

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