Sonographers and Work-Related Musculoskeletal Disorders (WRMSDs): A Systematic Review of the Prevalence, Risk Factors, and Consequences.

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Department of Health Sciences, Faculty of Life Sciences, Hamburg University of Applied Sciences, Germany

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Submitted by: Adekunle Tomilayo Ayoola

Matriculation number: [redacted]

Primary supervisor: Prof. Dr.–Ing. habil. Klussmann André

Secondary supervisor: Mr. Duguru Dauda John (B.Pharm., MPH)

DECLARATION

I hereby declare that I am the author of this thesis and wrote the piece of academic work with the help of the referenced sources. All the articles used are fully cited in the section of the bibliography. This academic work is submitted only to the Hamburg University of Applied Sciences and has not been submitted to other examination authorities. I confirm that the content of the digital version corresponds completely with the printed version.

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Signature:

Adekunle Tomilayo Ayoola

DEDICATION

This piece of work is dedicated to God Almighty and to all sonographers who have ended their careers as a result of WRMSDs.

ACKNOWLEDGMENT

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Abstract

Introduction: Work related Musculoskeletal Disorders (WRMSDs) remains a significant issue among sonographers. Despite advancements in the ultrasound machine's technology and increased awareness in ergonomic workplace technique, sonographers continue to perform their work in pain associated with WRMSDs. Throughout their careers, sonographers are exposed to different adverse factors at their workplace. The injuries resulted in decreased productivity, increased medical expenses, financial loss in form of sick leave and staff replacement. It is necessary to evaluate the burden of WRMSDs and the risk factors related to sonographers; in order to understand the mechanism of its occurrence. This will be useful in making informed decision that will prevent and/or reduce the occurrence of WRMSDs among this population.

Methodology: A systematic review of the literature to include all relevant articles on WRMSDs among sonographers was carried out. The Elsevier, Medline, and Cochrane databases were systematically searched using the review's developed search terms. The included studies were selected based on the inclusion and exclusion criteria. The qualities of the included studies were critically appraised to ensure that only surveys which met the criteria were included.

Results: 25 articles were included in the review**.** The prevalence rate of WRMSDs among sonographers ranged globally from 53% to 99.3%. The shoulder, neck, wrist, and back regions are the most affected body areas. The predisposing factors include; awkward working posture, poor ergonomics, suboptimal psychosocial factors, adverse scanning-related activities, and individual factors such as female gender, lack of physical activities, and high BMI. The injured sonographers suffer significantly ranging from more than 50% seeking medical treatment to the extent of about 4% ending their careers prematurely.

Conclusion: The results of this review reported a continuous rise in the prevalence of WRMSDs among sonographers. The importance of a safe work environment cannot be over-emphasized as the cost of creating an ergonomically optimal workstation is lower than the cost associated with managing an injured sonographer. The identified risk factors would help in making informed choices in developing appropriate individualized ergonomic solutions by the sonographers and the employers.

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List of Abbreviations:

Abbreviations……………………………Meaning

1-YP:	1-Year-Prevalence.
BMI:	Body Mass Index.
CD:	Cannot be Determined.
CDC:	Centre for Disease Control.
CP:	Career-Prevalence.
CTD:	Cumulative Trauma Disorder.
CTS:	Carpal Tunnel Syndrome.
CT-Symptoms:	Carpal Tunnel Symptoms.
DASH:	Disability of the Arm, Shoulder, and Hand.
DALYs:	Disability Adjusted Life Years.
ESWC:	European Survey on Working Condition.
ETB:	Ethiopian Birr.
ETF:	Equivalent Full-Time.
E.U.:	European Union.
F:	Female Participants.
GDP:	Gross Domestic Product.
HBM:	Health Belief Model.
HBT:	Health Belief Trust.
HPD:	High Pain Discomfort.
HWD:	Hand Wrist Disorder.
Kg:	Kilogram.
LBP:	Low Back Pain.

Abbreviations……………………………Meaning

LPD:	Low Pain Discomfort.
M:	Male Participants.
MEI:	Mechanical Exposure Index.
MSDs:	Musculoskeletal Disorders/ Diseases.
MSI:	Musculoskeletal Injuries.
MSP:	Musculoskeletal Pain.
MSS:	Musculoskeletal System.
N.m.:	Newton meter.
N:	Newton.
N:	Number of Participants.
NA:	Not Applicable/ Not Available.
NBP:	Neck Back Pain.
NIH-Tool:	National Institute of Health-Tool
NR:	Not Reported.
OR:	Odds-Ratio.
ORSCD:	Observational Retrospective Cross-Sectional Study Design.
PACS:	Picture Archiving Computer System.
PEOS:	Population Exposure Outcome and Study-design.
PhYI:	Physical Exposure Index.
PICOS:	Population Intervention Comparison Outcome and Study-design.
P.P.:	Point-Prevalence.
PPE:	Personal Protective Equipment.
PR:	Prevalence Ratio.

Abbreviations………………………………Meaning	
PRISMA:	Preferred Reporting Items for Systematic Review and Meta-analysis.
Pt.:	Patient
RCS:	Rotator Cuff Syndrome.
RMD:	Repetitive Motion Disorders.
RMI:	Repetitive Motion Injuries
RR:	Response Rate /Participation Rate
R.R.:	Risk-Ratio.
RSI:	Repetitive Strain Injury.
U.K.:	United Kingdom.
USA:	United States of America.
WCB:	Workers' Compensation Board.
WHO:	World Health Organisation.
WMSD:	Work Musculoskeletal Disorders.
WRMSDs:	Work-related Musculoskeletal Disorders.
WRMSI:	Work-Related Musculoskeletal Injuries.
WRULMSDs:	Work-Related Upper-Limb Musculoskeletal disorder.

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Chapter 1: INTRODUCTION

1.1 Historical perspective

The musculoskeletal system is composed of soft tissue {muscles, tendons, synovial membranes, joint capsule, and also ligaments} and hard tissue {bones and cartilages} (Lowe and Anderson, 2015). One or more of the tissues mentioned above can be injured, thereby associating many injuries with the MSS. WRMSDs were first reported as a problem in the late 17th century by Bernardo Ramazzini; he described it as an illness caused by "violent , irregular motion, and unnatural posture of the body" (CDC, 1995). Ramazzini recognized work-related hand injuries among clerks and scribes in the early 18th century, which he believed were caused by repetitive movement, constrained postures, and general mental distress (Kroemer, 1989). In the early 19th century, muscular strains in the right hands and arms were also discovered in other occupational groups such as shoemakers, notaries, milkmaids, and sewists (CDC, 1995). In 1960, RSI was recognized as an occupational disease by the International Labour Office (Kroemer, 1989). The incidence of CTDs and other WRMSDs started to escalate rapidly in the USA and other developed countries from the 20th century (CDC, 1995). Due to the increasing incidence of MSDs among workers, some MSDs were identified based on the occupation where they frequently occur, e.g., "carpenters' elbow," "seamstress' wrist," "bricklayers' shoulder," "gamekeepers' thumb," "drummers' palsy," "pipefitters' thumb," "reed makers' elbow," "pizza cutter's palsy," and "flute player's hand" (Nunes and Bush, 2012). Furthermore, some were also specific to health workers, for example: "Pipettes pusher's paresthesia" among the laboratory workers (Vergouwen and Vermeulen, 2007), the "Transducer user syndrome" among the radiologist or sonographers (Schoenfeld et al., 1999), and the "Toe thumb syndrome" among the echocardiographers or the Vascular interventionalists (Tewari et al., 2014).

There are variations in the terminologies used in describing WRMSDs based on the countries of use, as highlighted in **Table 1**. From the definitions below, all terminologies are associated with pain, discomfort, or abnormal sensation in the MSS. The different terms are used to translate the relationship between the disorder and the suspected causal factor or describe the injury's mechanism or the injured area (Nunes and Bush, 2012). The various terms would be used interchangeably in this review.

Table 1: Terminologies and the countries of use

Terminology	Country of use
Cervicobranchial Syndrome	Japan, Sweden.
Cumulative Trauma Disorder	USA.
Occupational Cervicobranchial Disorder	Japan, Sweden.
Occupational Overuse Syndrome	Australia.
Repetitive Strain Injury	Australia, Canada, Netherlands.
Work-related Neck and Upper limb Disorder	United kingdom.
Work-related Musculoskeletal Disorder	Worldwide.
Repetitive Stress Injury/ Repetitive Motion Injury	Worldwide

Table adapted from Nunes and Bush, 2012.

1.2 Definition of terminologies

Musculoskeletal disorders: These are the MSS's health problems, ranging from simple transitory conditions to long-lasting disabling injuries. They include a series of inflammatory and degenerative diseases that affect the muscles, tendons, ligaments, joints, peripheral nerves and supporting blood vessels. These conditions are characterized by pain, discomfort, ache, limitation in mobility, reduced skill proficiency, and inadequate functional capacity in the system (Tinubu et al., 2010; WHO, 2018, 1999).

Work-Related MSDs: They are a subset of musculoskeletal disorders that arise from occupational exposures. They are also musculoskeletal injuries aggravated, worsened, or caused by work activities. They include various painful conditions affecting the MSS, and can occur from a single traumatic event or accumulation of injuries (CDC, 2018; Cheng et al., 2016).

Cumulative Trauma Disorders {CTD}: They are injuries that are caused by cumulative tissue damage as a result of performance of monotonous tasks, and it describes mainly injuries in the upper extremities (Cortese, 1995; CDC, 1995).

Repetitive Strain Injury {RSI}: It is also referred to as "Work-related Upper limb Disorder," or "Repetitive Motion Injuries," or "Repetitive Motion Disorder," or "Regional Musculoskeletal Disorder." They are pains, aches, or tenderness perceived in the muscles, tendons, or nerves caused by repetitive movements, vibrations, mechanical compressions, and long- sustained awkward posture (Newman and Minnis, 2018; Shuttleworth, 2014).

Occupational overuse syndrome: It is a collective name for various disorders which cause pain or discomfort in the MSS from excessive usage of some muscle groups. There are three categories: "localized Inflammation," "compression syndromes," and "pain syndrome"(Clinfton-Smith, 2015).

Cervicobranchial syndrome/Occupational Cervicobranchial syndrome: It is also called "the lower cervical syndrome." They are pains, stiffness, discomfort, abnormal sensations in the shoulder-girdle, upper extremities, and upper back with or without radiated pain to the head region (Gangavelli et al., 2016).

Rotator Cuff Syndrome {RCS}: It is a group of diseases associated with injury or degenerative conditions of the muscles around the shoulder joint (Varacallo and Mair, 2019).

Carpal tunnel syndrome {CTS}: They are disorders around the wrist joint, ranging from discomfort/paresthesia to outright pain in this region. It arises from compression of the median nerve around the wrist joint (Ruess et al., 2003).

1.3 Burden of the Disease

CTDs, RSIs, or RMIs were the most common occupational hazards among workers in the 1990s (Juge et al., 1994). MSDs are a significant cause of public-health problems globally and cause a high economic burden on employers, employees, and the health insurance company. They account annually for over 70 million physician visits, 45 billion dollars medical costs, and a median absenteeism period of 8 days globally (MacDonald and King, 2014; Sultan-Taïeb et al., 2017). MSDs cause more absenteeism and disability at the work-place than any other group of diseases in the USA, Finland, Canada, and Sweden. They represent about 33% of all registered occupational illnesses in the USA, Nordic countries, and Japan. They are also the 2nd most commonly reported work-related illness after mental ill-health in Great Britain, with more than 50% of all occupation-related diseases in the U.K. caused by MSDs (Chen et al., 2005; Punnett and H Wegman, 2004). About 60 million workers reported suffering from WRMSDs in 31 countries in Europe {EU-27 with Norway, Croatia, Turkey, and Switzerland}. Spine disorders, CTS, and other muscular disorders accounted for more than 50% of occupational diseases reported in Italy in 2010 (Campo et al., 2015; Nunes and Bush, 2012; Parot-Schinkel et al., 2012). The prevalence of MSDs is about 100% higher among the working population compared to the general population. A rise in the incidence of WRMSDs was reported in the '80s; the number of work-related CTDs cases had increased by 400% between 1984 and 1990. Between 1995 and 2005, the prevalence of non-traumatic MSDs among workers had risen by about 18% in France, and a rising trend of WRMSDs was also noted between 2000 and 2010 in Italy (Campo et al., 2015; Juge et al., 1994; Parot-Schinkel et al., 2012; Sultan-Taïeb et al., 2017). The notable increase can be possibly explained by the rise in computer-use, increase in work stress, ageing of the working population, automation in the production process and unfavourable economic condition which encourages faster pace of production, and hence a significant increase in repetitive movement (Park et al., 2010; Simoneau et al., 1996; Page 2).

There are variations in the prevalence of WRMSDs according to the body region: Upper limb > Neck/back > lower limb >ankle foot (Chen et al., 2005; Slovak et al., 2009). CTS is the most frequent upper limb MSDs among the working population, while LBP is the commonest lower limb WRMSDs (Ha et al., 2009; Parot-Schinkel et al., 2012; Piedrahita, 2006). Globally, the prevalence of work-related upper extremities injuries was about 20-30%. The reported prevalence might be the tip of the iceberg due to the low reporting level of MSDs among workers (Piedrahita, 2006; Punnett and H Wegman, 2004). LBP is the leading cause of disability globally; with an overall burden from work-related conditions being 21.8 million DALYs in 2010 (Buchbinder et al., 2013; Fatoye et al., 2019). The work-related LBP contributes significantly to the burden of disease globally. According to ESWC,WRMSDs are the most reported work-related problems in Europe accounted for 38% of all occupational illnesses in 2005; with about 24% and 22% of the workers in the EU-25 complaining of back pain and muscular pain, respectively and accounted together for 45 million cases in Europe (European

Agency for Safety and Health at Work, 2010; Pages 15-16). According to a survey carried out in Europe in 2005, the prevalence of WRMSDs varies significantly among the E.U. member countries. The highest prevalence was in Greece {with 47% of workers having back pain and 46% having muscular pain} and lowest in the U.K. {with 11% of workers having back pain and 9% having muscular pain} (Kim and Nakata, 2014; Nunes and Bush, 2012). The variation in the prevalence is caused by the difference in the reporting system of occupational illnesses in the two countries. France reported and compensated about 275,000 WRMSDs between 1996 and 2006. There were 4087 cases of WRMSDs in Finland in 2002 and approximately 25,391 cases in Sweden in 2003. About one in every five workers between 2002 and 2005 in Canada experienced non-traumatic WRMSDs in at least one body region, and about 500,000 people suffered from WRMSDs in the USA in 2002 (European Agency for Safety and Health at Work, page 17, 2010; Piedrahita, 2006; Sultan-Taïeb et al., 2017).

WRMSDs are becoming an important cause of concern globally because of the health effects on the individual, the economic impact, and social cost to the countries (European Agency for Safety and Health at Work, 2010, page 18). WRMSDs remain the leading cause of morbidity and work disability in Europe and the primary reason for disability before 45 years (Ha et al., 2009). WRMSDs are also the leading cause of compensated disease in most industrialized countries of the world; with CTDs being the fastest rising group of workers' compensation claims and accounting for approximately 61% of all claims due to work-place illnesses (Cortese, 1995; Ha et al., 2009; Punnett and H Wegman, 2004). Non-traumatic MSDs were the highest compensated diseases among France's working population and accounted for 76% of all occupationally related claims in 2015 (Sultan-Taïeb et al., 2017). WRMSDs and occupational CTDs remain the most expensive form of work disability with an annual global cost of $3,325 billion and an estimated cost of $591 billion in the E.U., which is equivalent to 3.9% of Europe's GDP. They also accounted for 50% of all estimated cost due to work-related illnesses in Europe; with a loss of about €38 billion in Germany in 2012. WRMSDs led to a loss of €710 million of enterprises' contribution in France in 2006 (Cortese, 1995; European Agency for Safety and Health at Work, 2010, page 18; Hazlegreaves, 2018; Piedrahita, 2006; Yasobant and Rajkumar, 2014). In the USA, the total cost {direct and indirect cost} linked to the reported WRMSDs is about US$45-

54 billion, which is equivalent to 0.8% of the USA’s GDP, and about 26 billion Canadian dollars was spent in Canada on WRMSDs in 1998. The non-availability of the restriction in the employers' working hours and the lack of compulsory health insurance among workers in the USA might explain the higher cost associated with WRMSDs in the USA (Piedrahita, 2006; Yasobant and Rajkumar, 2014).

MSDs among workers are associated with terrific economic burden and affect the productivity at the workplace and the workers' quality of life. They represent the second most common cause of short-term disability among workers after the common cold globally (Punnett and H Wegman, 2004; Yasobant and Rajkumar, 2014). France lost 6.3 million working days to WRMSDs in 2004; and Great Britain lost 6.6 million working days to WRMSDs in 2017/2018, which is equivalent to an average of 14 working days per case (Ha et al., 2009; Health and Safety executive, 2009). WRMSDs accounted for about 24% of all sick-leave in Germany and Great Britain in 2004 and 2017/18 respectively (Grahl et al., 2010; Health and Safety executive, 2009). Work-related LBPs accounted globally for about 21,8 million DALYs In 2010, with a ratio of 1.6:1 for men to women respectively; while in 2017, it accounted globally for 120 million DALYs (Fatoye et al., 2019; Hazlegreaves, 2018). An increase in the ageing population, intensification of the work process, increased awareness about the Disease over the years, and a modification in the reporting system enabling easier reporting of WRMSDs might explain the significant rise in the DALYs associated with WRMSDs (Ha et al., 2009).

1.4 Factors associated with the development of WRMSDs.

The physical workload was thought to be the only significant risk factor associated with WRMSDs. A high prevalence of MSDs among workers performing mental work with low physical workload implies other predisposing factors are related to WRMSDs apart from the physical workloads (Bugajska et al., 2013; Lee et al., 2011; Yue et al., 2014). The elements can be classified into three main categories, as presented in **Figure 1**: “Individual factors”{employee-related, “physical/workload factors” {job-related}, and “psychosocial factors” {Job-environment related} (Kerr, 2019).

Figure 1: Diagrammatic representation of factors associated with WRMSDs

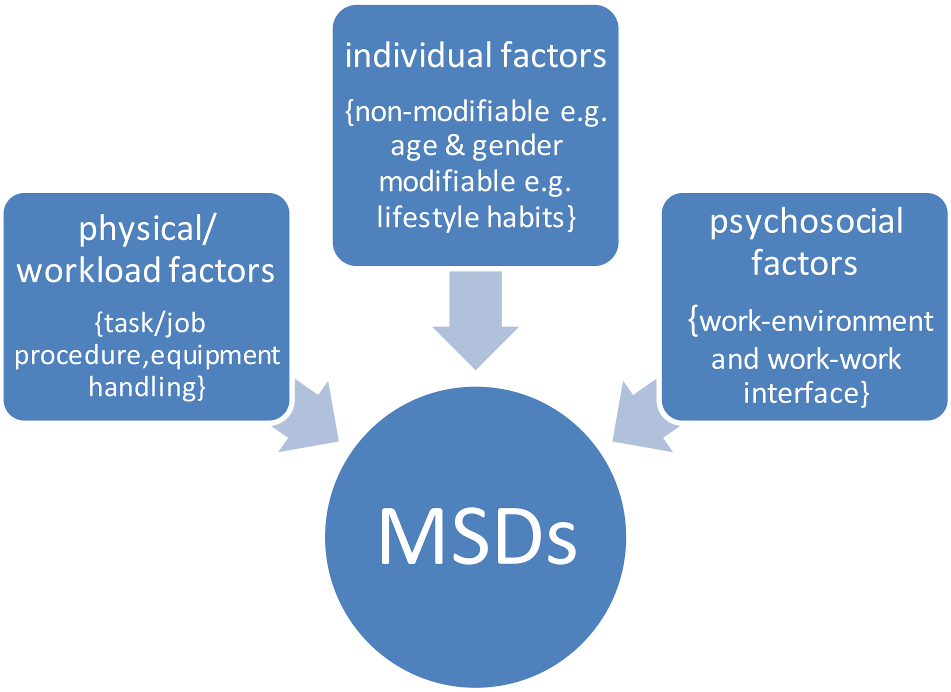


Figure adapted from Kerr, 2019 and Nunes and Bush, 2012.

1.4.1 Physical factors

Physical factors are the mechanical and environmental factors associated with the performance of work activities. The work activities include prolonged awkward work posture, repetitive movements, massive forces on the MSS, vibration, bending, twisting, working overhead, and suboptimal weather conditions (Bugajska et al., 2013; Nunes and Bush, 2012). There is a strong dose-response relationship between the physical workload and the development of MSDs; as the prevalence of WRMSDS was twice as higher among nurses with high physical workload compared to those with low physical workload (Cantley et al., 2016; Kerr, 2019; Koohpayehzadeh et al., 2016). High physical workload leads to increased work intensity, which is associated with excessive working hours, fast production pace, and flouting of safety rules, thereby increasing the risk of damages to the MSS (Leka and Jain, 2010, pages 34-38; Nunes and Bush, 2012). The high physical workloads majorly predispose to MSDs related to the upper extremities and the low-back; repetitive movement predisposes to arm pain, heavy lifting predisposes to low back-pain and pulling of heavyweights predisposes to lower limb pain

(Kodom-Wiredu, 2018). The duration of exposure to the physical workload plays a significant role in developing MSDs, as continuous exposure to the workplace's biological factors increases the risk of WRMSDs by about 200-300% (Nunes and Bush, 2012; Telaprolu and Anne, 2014). From **Figure 2**, for workers to remain in the “safe area,” an increase in the exposure duration must be accompanied by a reduction in the level of force and repetitive movement or vice versa.

Figure 2: Dose-response relationship between duration of exposure to physical factors and development of WRMSDs

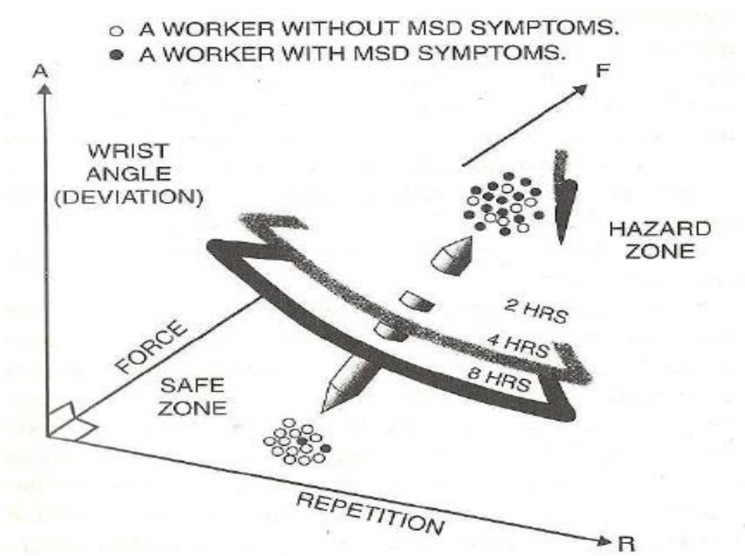


Figure adapted from Nunes and Bush, 2012.

1.4.2 Psychosocial factors

These are the predisposing factors that are non-biomechanical; they are the workers' subjective feelings towards the workplace's organizational factors (Nunes and Bush, 2012). The four main psychosocial factors identified according to Karasek's model are decision latitude, social support, psychological job demand, and the level of job security (Bugajska et al., 2013; Karasek, 1979; Kerr, 2019; Lee et al., 2011; Yue et al., 2014). Psychological factors are associated significantly with all WRMSDs with more than 40 million workers being affected by stress at the workplace in Europe. About 12% of the various WRMSDs in the U.K. are caused by suboptimal psychosocial factors at the workplace in 2010 (Faucett, 2005; Leka and Jain, 2010, Page 5). The causative mechanism is associated with the “stress,” “coping,” and “illness” pathway: a mismatch in the psychosocial factor leads to increased stress level experienced by the workers, leading to increased production of stress hormones. The increased stress hormone levels cause increased muscle spasm, increased workload perception, increased pain sensitivity, and increased susceptibility to muscle injuries (Faucett, 2005; Silva et al., 2017; Vignoli et al., 2015). High psychological job demands are associated with an increased level of pain in the upper limbs, ankle, and feet; with the OR of developing WRMSDs being 1.84 in any body-region and 3.05 in the upper limb region (Bugajska et al., 2013; Lee et al., 2011; Yue et al., 2014). Low decision latitude is associated with increased risk of pain in the upper extremities, increased risk of CTS, and the odds of developing low back pain among this group is 84% higher than those with high decision latitude (Bugajska et al., 2013; Leka and Jain, 2010, page 5; Yue et al., 2014). High psychosocial demands could alter worker's vigilance to safety precaution and worker's risk recognition, thereby increasing the risk of MSI (Cantley et al., 2016). The working population with low social support from coworkers and supervisors has a high chance of suffering from lower limb pain with an OR of 1.79 (Bugajska et al., 2013; Yue et al., 2014). High Psychological demand, reduced decision attitude, and low social support are associated with an increased average hazard rate of 1.28 and 1.35 for neck and low back injuries. As represented in **Figure 3**, a one-point scale increase in the above–mentioned factors leads to a 12% rise in neck injuries' hazard rates (Fjell et al., 2007).

Figure 3: Relationship between psychosocial factors and WRMSDs

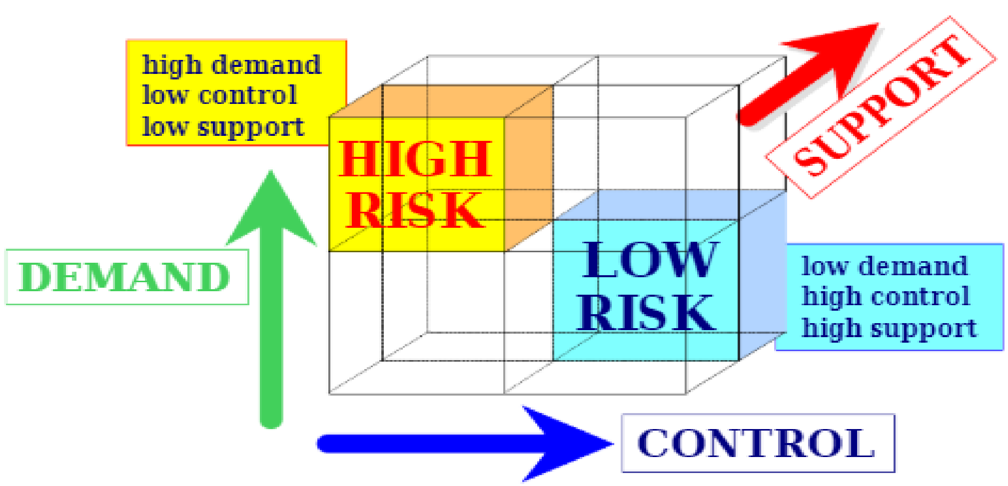


Figure adapted from Karasek, 1979.

1.4.3 Individual factors

The individual factors are the predisposing factors that are inherent in the workers themselves. These are the non-modifiable factors {age, gender, and previous WMSDs} and the modifiable factors, which are related to the lifestyle's choices of an individual {BMI, smoking, alcohol consumption, and physical activity} (Kerr, 2019). The elimination of the non-modifiable factors is impossible, so its recognition is essential in the incorporation of appropriate administrative tools in the prevention of WRMSDs (Nunes and Bush, 2012).

1.4.3.1 Non-Modifiable Factors related to WRMSDs

1. Increasing Age

The E.U. has recognized age as a predisposing factor to WRMSDs, and there exists a direct relationship between increasing age and the development of MSDs (Aweto et al., 2015; Kaka et al., 2016; Patil et al., 2018; Okunribido and Wynn, 2010). The risk of developing MSDs is almost 300% higher among people > 30 years than the younger age-group, with most people having their first episode of work-related back pain by 35 years (Aweto et al., 2015; Mekonnen et al., 2019). The probability of developing RSI increases by 8% per year, and the prevalence of MSDs increased by about 5-fold between the age-groups 16-24 and 45-64 (Bugajska et al., 2013; Ha et al., 2009; Health and Safety executive, 2009; Slovak et al., 2009). Ageing is associated with deterioration in the functions and strength of the human body. There is also an accumulative effect of workloads and injuries on the MSS with increasing age; these factors lead to decreased capacity of the MSS for subsequent workloads (Kaka et al., 2016; Mekonnen et al., 2019; Patil et al., 2018). A 65-year old worker's work-capacity is about 50% of that of an average 25-year old worker. With an increase in the aging working population {due to increasing life expectancy and reducing birthrate}, there is an imbalance between the work demands and the populations' working capacity (Kaka et al., 2016; Okunribido and Wynn, 2010).

2. Gender

Gender is considered a confounding or modifying factor for WRMSDs, but women are three times more likely to have CTS than men (Coury et al., 2002; Nunes and Bush, 2012). The rate of developing MSDs is 2.23 higher among female sonographers than their male counterparts, with a 200% increase in the prevalence of WRMSDs among females. The increased occurrence of WRMSDs among female workers might be due to reduced capacity to cope with musculoskeletal stress (Abdullah et al., 2018; MacDonald and King, 2014), reduced muscular strength with smaller stature (MacDonald and King, 2014; Nunes and Bush, 2012) and involvement in home chores (Patil et al., 2018). The higher sensitivity to psychosocial factors among female workers is also associated with an increased risk of WRMSDs(as the probability of being affected by psychosocial factors is about 40% and 70% among males and females, respectively) (Silva et al., 2017; Telaprolu and Anne, 2014). The higher rates of reporting injuries among females is also a plausible explanation for the increased prevalence of WRMSDs among female workers(Kerr, 2019).

3. Previous MSDs

Previous experiences of MSDs remain the most resilient and the most consistent individual factor associated with developing WRMSDs (Kamada et al., 2014; Kerr, 2019). Previous damages decrease the threshold limit for further injuries and also lead to a secondary response in the surrounding tissue, thereby increasing the risk of secondary WRMSDs (Armstrong et al., 1993; Kerr, 2019; Nunes and Bush, 2012). The mechanism of developing another WRMSDS by a previous sufferer is also associated with some underlying psychological traits such as "compensational neurosis" or "Hysteria." These traits are developed spontaneously by injured workers to retain their pain in other to receive compensations even after they have been cured (Kerr, 2019).

1.4.3.2 Modifiable factors

1. Lack of Physical Activities

The association between the level of physical activity and MSDs, especially for chronic LBP, is a "U-shaped-curve." Deficient levels of or very high levels of physical activities are associated with the MSS's hazardous effect (Kamada et al., 2014). The odds of developing WRMSDs are 45% higher among workers with no physical activities than those who exercise 1-2 times per week. Vigorous exercise does not reduce the risk of developing MSDs as it might even predispose to further injuries (Holth et al., 2008; Yao et al., 2019). Moderate Physical activities improve the muscle strength, joints' range of movement, relieve psychological stress, elevate pain tolerance, and delay age-related decline in muscle strength. Thus, increasing the MSS capacity and reducing the risk of coming down with MSI (Kamada et al., 2014; Yao et al., 2019).

2. Increasing BMI

BMI {a ratio of weight to height square} < 18.5kg/m2 and >25kg/m2 doubles the risk of developing MSDs (Telaprolu and Anne, 2014). High BMI is associated with some forms of WRMSDs, especially CTS and LBP (Abdullah et al., 2018; Nunes and Bush, 2012; Viester et al., 2013). The OR of developing MSDs among overweight and obese workers is 1.13 and 1.28 compared to workers with normal BMI. Being obese or overweight doubles the odds for upper extremity pain and also increases CTS's risk by 200% (Moreira-Silva et al., 2013; Nunes and Bush, 2012; Viester et al., 2013). The increased risk are caused by increased weight loads on the tissue, increased fatty tissues and increased hydrostatic pressure in the body joints (Nunes and Bush, 2012; Sethi et al., 2011). The prevalence of MSDs was also higher among underweight farmers than the average weighted farmers because of the associated malnutrition leading to low bone mineralization (Patil et al., 2018).

3. Smoking

Cigarette smoking leads to loss of the bone's mineral content, leading to decreased resilience of the bone architecture (Abate et al., 2013). The prevalence of LBP increases with increasing pack-years of smoking, there exists a direct relationship between smoking intensity and the degree of MSS symptoms (Leino-Arjas, 1999; Nunes and Bush, 2012). Smoking about ten sticks of cigarettes daily throughout adulthood is associated with a 5-10% deficit in bone density. Smoking 100g of tobacco weekly is associated with about 2.9% and 5.0% reduction in the strength of the quadriceps muscle among women and men, respectively. Furthermore, smoking increases the risk of MSDs with an adjusted R.R. for developing neck and back pain among "ever smokers" being 1.8 (Abate et al., 2013). The mechanism for increased risk of MSDs among smokers can be explained by alteration in the vitamin D metabolism (Abate et al., 2013), Vasoconstriction of vessels leading to hypoxia, early muscle fatigue, and fibrinolysis of muscular fibers (Leino-Arjas, 1999; Palmer et al., 2003). The pharmacological effect on pain perception with increased sensitivity of the receptors (Palmer et al., 2003) and increased strain on the spine through increased intra-spinal pressure from coughing (Nunes and Bush, 2012) are also associated with increased chances of WRMSDs.

4. Alcohol Consumption

There exist a conflicting association between MSDs and alcohol intake. People who consume alcohol every day are 3.6 times more likely to develop MSDs than those who drink alcohol once per week (Mekonnen et al., 2019). On the contrary, the risk of developing WRMSDs among regular alcohol consumers {not heavy drinkers} is 60% lower than the "never drinkers"(Skillgate et al., 2009). Heavy alcohol consumption has adverse effects on bone microarchitecture, thereby increasing the risk of osteoporosis and bone fracture (Kaila-Kangas et al., 2018). On the other hand, moderate alcohol consumption is associated with a decreased level of pain perception (Skillgate et al., 2009), thus leading to reduced reporting of pain among moderate alcohol consumers and indirectly lowering the prevalence of MSDs among this group.

5. Low Socioeconomic Status

The socioeconomic status of a worker is indirectly related to the development of WRMSDs. As an individual in a low socioeconomic position is more likely to be poorly fed, to exercise inadequately, to smoke tobacco, and have reduced or no access to primary care and medical screening (Punnett et al., 2009); therefore predisposing workers to MSDs. The adjusted OR of developing WRMSDs is 3.13 higher among barbers whose monthly salary was <1100ETB compared to those whose salary was > 1700ETB (Mekonnen et al., 2019).

1.5 Biomechanical pathway for the development of WRMSDs

Figure 4: Schematic diagram of the biomechanical pathways for the development of WRMSDs

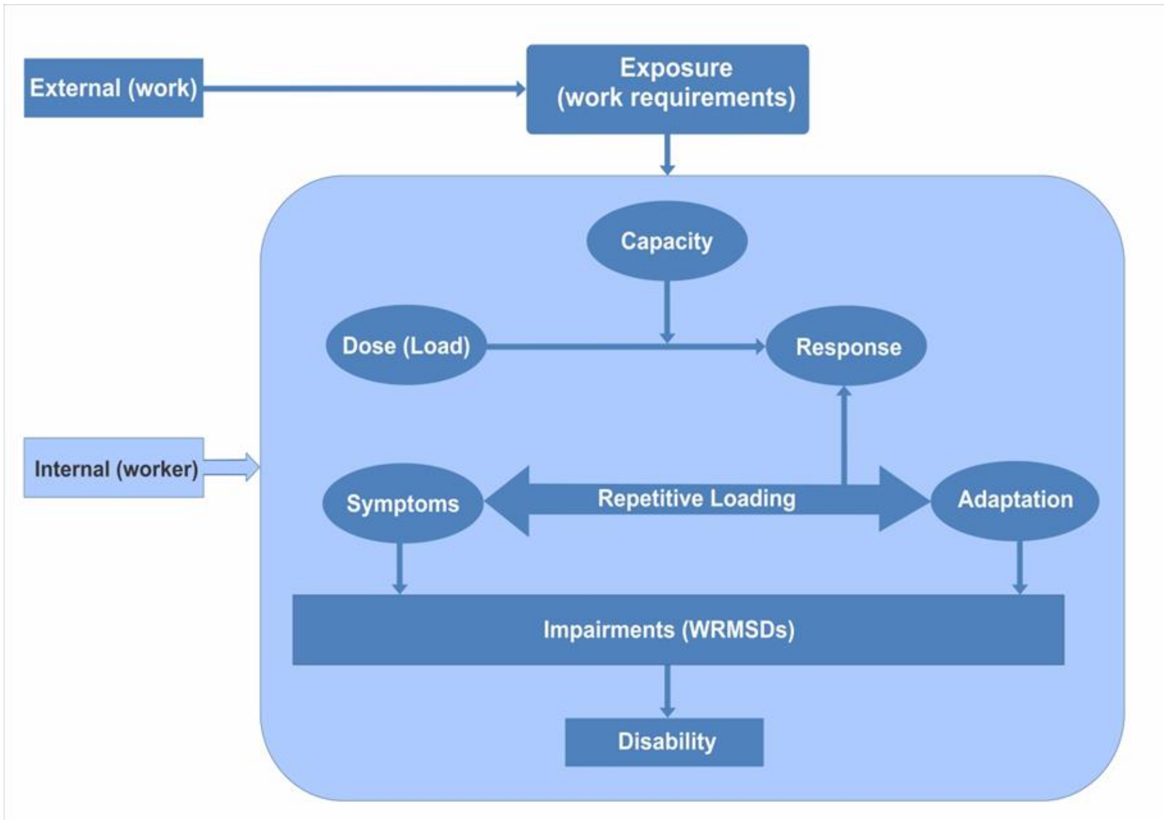


Figure adapted from Armstrong, 1993, and National Research Council (US), 1999.

As presented in **Figure 4**, the **exposure** is the external work factor that internally leads to dose or load. **Dose** refers to those mechanical, physiological, or psychological factors that disturb an individual's internal state. The **capacity** is the ability of an individual to withstand destabilization from various doses; while **responses** are changes that occur in the internal state of an individual from various loads; and **adaptation** refers to the desirable responses that occur as a result of increased tolerance due to prolonged exertion from repeated loads (Armstrong et al., 1993). When different magnitude of loads or doses are exerted on a tissue, muscle, or bones; their impact on these organs leads to several responses or symptoms (National Research Council (U.S.), 1999). On repetitive loading, the mechanical workload exceeds the mechanical tolerance, i.e., the tissue's capacity. This leads either to symptomatic response {pain, discomfort, or tingling sensation} or asymptomatic response {adaptation} in the affected tissue, which in turn affects the tissue's loading capacity and the response of an individual to subsequent loading (National research council (U.S.), 1999; WHO, 1999). The response in one tissue can also act as a loading dose for the surrounding tissue, leading to a secondary reaction. For example, the connective tissue might thicken {primary response} as a result of adaptation to the previous loads, the thickened tissue acts as a new load on the adjacent nerve leading to impaired nerve sensations or pains {secondary response} (Armstrong et al., 1993). The symptoms and adaptations interact interchangeably with one another. For example, the joint pain might lead to a rise in the production of lubricants in the joint, which is an adaptation technique to buffer the pain. The symptoms, responses, and adaptations might cause functional impairment of the MSS, giving rise to disabilities such as work absenteeism or reduced working hours (National Research Council (U.S.), 1999).

1.6 WRMSDS and health care professionals

The health care sector workers are one of the most vulnerable occupational groups with the highest risk of developing WRMSDs from their daily work routine (MacDonald and King, 2014; Yasobant and Rajkumar, 2014). The health professionals' daily work activities are associated with monotonous movements, unbalanced work postures, and high force levels {lifting and moving of patients and equipment}, which are the primary predisposing factors related to WRMSDs (Tinubu et al., 2010). In a 3years-survey between 2015 and 2018 in the U.K., the human health and social work sectors were classified among the five industries with the highest rate of WRMSDs (Health and Safety executive, 2009). Similar findings were described in a survey between 2002-2005, in which the health and social care sectors accounted for 46% of all reported WRMSDs in the U.K. (Slovak et al., 2009). About 25% of all computer-users develops computer-related MSDs. Due to the increasing computer-use among health professionals for documentation in the hospital, there is a possibility of rising MSDs among this working population (Balasuburamaniam and Vinod, 2015). Due to their long working hours, static postures, physically demanding jobs, and challenges with instrumental design; Procedural physicians such as surgeons and sonographers are at higher risk of developing MSDs than their counterparts (Epstein et al., 2018; Ruitenburg et al., 2013). The average period between the start of a carrier as a sonographer and the onset of MSDs is about 5years, and about 25% of them develop their first WRMSDs within their first year of practice (MacDonald and King, 2014; Rousseau et al., 2013). The risk of developing MSDs is about 500% higher among sonographers than in other health professionals. About 80% of the sonographers are scanning continuously annually in pain (Monnington et al., 2012; Rousseau et al., 2013).

Ergonomically, a surgeon's workplace and working conditions are comparable to, if not worse, than those of industrial workers. The poor work ergonomics has led to a higher prevalence of WRMSDs among surgeons than other labour-intensive occupations such as coal miners, manufacturing labourers, and physical therapists (Epstein et al., 2018). 82% of all surgeons experienced pain while operating, with the highest rate found among plastic surgeons, which might be associated with microscope-use among this subgroup (Memon et al., 2016).

WRMSDs are the number one cause of work-absenteeism among healthcare workers and accounting for about 50% of the total cost of occupational diseases in the health care sector (Epstein et al., 2018; Piedrahita, 2006). The rising prevalence of MSDs among physicians is an imminent epidemic coupled with insufficient knowledge and lack of application of appropriate ergonomic-practices among them (Ephraim-Emmanuel et al., 2019; Epstein et al., 2018). 80% of sonographers in the U.K. reported that WRMSDs affected their daily lives, household chores, sleeping pattern, and psychosocial well-being. About 20% had to retire abruptly due to persistent discomfort (Monnington et al., 2012; Rousseau et al., 2013). Apart from the personal impact, there is a high cost to the employer, spending close to $500,000 annually per injured sonographer (MacDonald and King, 2014).

1.7 WRMSDs and sonographers

Generally, the main work factors associated with the development of MSDs are excessive vibrations, over-use of some muscle-groups, excessive force, awkward body posture, repetitive motions, and prolonged pressure duration. All the factors named earlier except excessive vibration apply to the sonographers, thus they belong to the high-risk group for WRMSDs (Baker and Coffin, 2013; Scholl and Salisbury, 2017). The ultrasound examination is one of the most readily and commonly used imaging modalities, and it is also the “visual stethoscope” of the 21st century (Wareluk and Jakubowski, 2017). The recent advancement in ultrasound technology is associated with an increase in the demand for services and an increase in scanning time. This shift in the work environment resulted in increased workload-intensity and reduced work-control; leading to the workers missing work-breaks, scanning in pain, and not considering appropriate posture while examining (Bolton and Cox, 2015; Schoenfeld et al., 1999; Vanderpool et al., 1993).

The rising obese population globally, with its prevalence reported as 1 in 50 children and 1 in 400 adults, is also involved in WRMSDs among sonographers. Scanning obese clients require the sonographers to forcefully push the transducer to obtain appropriate images of the internal organs, leading to increased muscular strain (Baker and Coffin, 2013; Roll et al., 2012). Additionally, the introduction of PACS in sonography as an instrument used for documenting, interpreting and transmission of ultrasound images from a remote location to the hospital. The use of PACS has led to the sonographers adopting awkward postures while working with the system, as presented in **Figure 7**, thus associated with increased risk for WRULMSDs (Roll et al., 2012). Sonography is one of the fastest-growing professions globally, with a growth rate of 14% between 2008 and 2014. The increase in the number of sonographic examinations might be due to the ageing global population, with increase in the number of diseases among the older age-group. The use of non-ionizing radiation makes it a better tool in non-invasive diagnostics, vascular medicine, body joints imaging, and abdominal imaging (Bolton and Cox, 2015; U.S. Bureau of Labor Statistics, 2019; Vanderpool et al., 1993; Zhang and Huang, 2017).

In operating a sonography machine, one hand manoeuvres the transducer while the other hand adjusts the monitor and the control panel. To maintain the transducer in the appropriate position and support the arm; the neck, spine, shoulder, and upper extremity must be permanently contracted (Magnavita et al., 1999; Vanderpool et al., 1993). The prevalence of WRMSDs are higher among sonographers, with its prevalence reaching up to 90% in a survey carried out in Canada and USA (Wareluk and Jakubowski, 2017) and ranging from 63-98% in Europe (Feng et al., 2016). Although the sonographers suffer injuries in both upper limbs, the hand used in scanning has a higher risk of being injured than the non-scanning side (Schoenfeld et al., 1999; Simonsen et al., 2018; Zhang and Huang, 2017).

Craig first identified health hazards such as CTS, joint and muscular damage, and eye-strain associated with a sonographer's long-term activities in 1985 (Craig, 1985; Vanderpool et al., 1993; Zhang and Huang, 2017). He recognized repeated exertions with a hyper-flexed or extended wrist and extreme awkward posture among this population. The exertions lead to an overload of the wrist's and shoulder's muscle group, so increasing the risk of developing WRULMSDs (Schoenfeld et al., 1999; Vanderpool et al., 1993). Improvement of the equipment design and making the sonographers scan in a seated position eliminated some lower extremity complaints but failed to eradicate the eye-strain, neck, back, shoulder, and upper extremity pain among working sonographers (Vanderpool et al., 1993). A permanent sitting posture is also associated with increased risk of shoulder, back, and neck pain; hence the high level of shoulder and neck pain among sonographers since they spend almost all their working time seated (Feng et al., 2016). Low reporting of WRMSDs was also recorded among sonographers because of the fear of losing their jobs, colleagues' resentment due to increasing workload on them, negative response from the management, and some were not even provided with reporting sheet by their employer (AL-Rammah et al., 2017; Bolton and Cox, 2015). Due to the low reporting rates of WRMSDs; its high prevalence among this working population might not be an accurate representation of the actual burden of the Disease. There is insufficient knowledge of the causes and impacts of WRMSDs. There exist also a low level of awareness in the preventive measures against injuries among sonographers, with less than 35% of the sonographers being aware of any preventive measures against WRMSDs (AL-Rammah et al., 2017). The combination of the low level of knowledge and awareness among them would lead definitely to an overwhelming increase in the incidence of WRMSDs.

1.8 Workstation and scanning posture of a sonographer

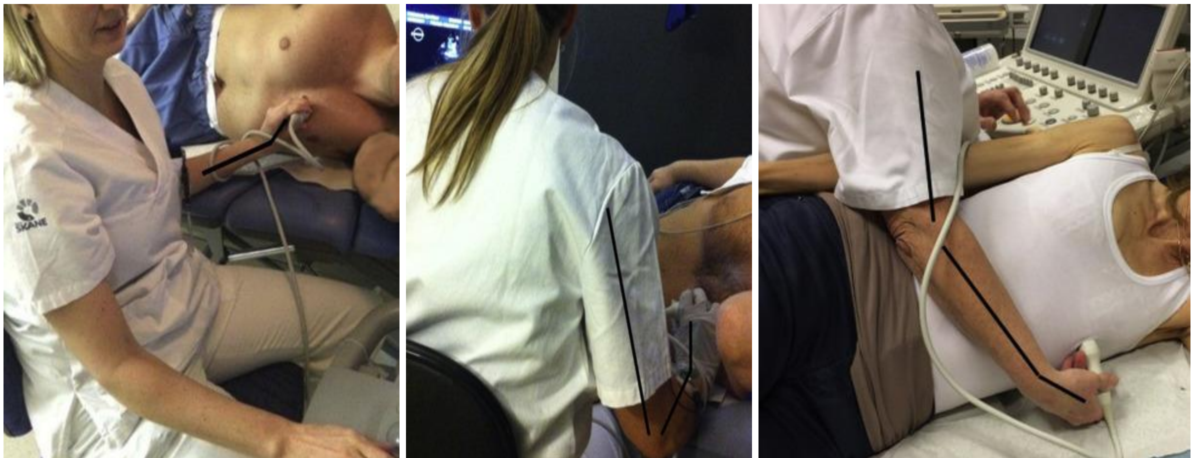
A sonographer's workstation is a tripod: the scanning machine, the operator, and the patient. The ultrasonic equipment consists of a screen, a keyboard, and a control panel, with the transducer attached to the cable. Typically, the sonographer sits on a chair, holds the transducer in one hand, with the system's control panel operated by the other hand. The sonographers focus on the screen in a darkened room at the same time scanning with the hand (Arvidsson et al., 2016; Gremark Simonsen et al., 2017). In addition to scanning, sonographers must also type, analyse results, and review images at the computer workstation (Bolton and Cox, 2015; Hill, III et al., 2009). Sonographers work averagely for about 30-45 hours per week, excluding the call-duty hours, with an average scan of 10-12 scans per shift (MacDonald and King, 2014; Orenstein, 2009). The quickest scan lasts for about 5 minutes. Some scans with abnormalities, abdominal, echo, and vascular scans can last up to 25-50 minutes per patient, with the average scanning time being 20-25 minutes per patient (Monnington et al., 2012; Orenstein, 2009). The scanning arm is contracted during the examinations. The shoulder is elevated and abducted at $20^0$and till 90^0 when scanning an organ on the patient's opposite side. The neck and torso are also twisted when trying to reach the control panel as shown in **Figures 5** (Jakes, 2001; MacDonald and King, 2014; Orenstein, 2009; Rousseau et al., 2013). The twisting postures and other awkward position lasts about 67% of the scanning time (Magnavita et al., 1999). The applied force to the hand and wrist during 90% of the scanning period is equivalent to a minimum of 1Kg, with the mean gripping pressure of the transducer over an entire scanning period being up to 3.96 kg and is as high as 27.6kg when scanning an obese patient (Rousseau et al., 2013). There is an increased risk of WRULMSD when the workers use a pinch-grip of >0.9 kg and a power-grip of > 5.5kg (Rousseau et al., 2013). Performing the task named above by a sonographer for > 4 hours per day without breaks is associated with an increased risk of WRMSDs (Bolton and Cox, 2015).

Figure 5: The working posture of a sonographer

The wrist is hyper-flexed and twisted; with the transducer held with a pinch-grip.	The trunk is twisted, and the neck is hyperextended and twisted.	The torso is bent forward and the neck is hyper-flexed. The monitor is placed below the eye-level.

Figure adapted from Coffin, 2012.

Figure 6: Awkward joint position assumed when scanning



Wrist is permanently extended. The monitor is placed too far.	Elbow flexion and extended wrist joint. Twisting of the neck.	Upper-arm is elevated, elbow hyper-extended, the wrist is twisted, and transducer held with a finger-grip.

Figure adapted from Simonsen et al., 2018.

Figure 7: Awkward posture assumed by sonographers while scanning and viewing on the PACS

Flexion and twisting of the trunk while scanning from Wareluk and Jakubowski,	Typical PACS workstation with no adjustment features for the monitor; a sonographer seen hyper-extending the arm and straining the neck from Roll et al., 2012.

1.9 Rationale of the study

There are systematic reviews assessing the prevalence and incidence of WRMSDs among health-professionals (Epstein et al., 2018; Long et al., 2012; Oude Hengel et al., 2011; Yung et al., 2017), but the above named systematic reviews failed to assess the predisposing factors and the negative consequences of WRMSDs on their lives and careers. Anderson and Oakmann (2016) carried out a systematic review assessing the prevalence, the risk factors, and the consequences of WRMSDs on allied health professionals. The allied health professionals included physiotherapists, occupational therapists, podiatrists, X-ray technologists, and sonographers; the author retrieved only one article on sonographers (Anderson and Oakman, 2016). Wooten(2019) carried out a systematic review on the risk factors for WRMSDs among sonographers and the preventive ergonomic techniques but failed to assess the actual prevalence of the disease nor the negative consequences on their daily home activities, work activities, and their careers (Wooten, 2019). A review of the literature was also carried out on sonographers assessing the prevalence and the associated predisposing factors of WRMSDs among them but failed to evaluate the bodily distribution of the injuries, the effects of the sustained injury on the sonographers, and the methodology used in retrieving articles was not clearly stated in the review (Morton and Delf, 2008). There is no systematic literature review to the author's knowledge assessing the prevalence of WRMSDs, the pattern of the bodily distribution of the injury, the significant risk factor, and the consequence of the injury among sonographers; hence the need for this systematic review.

1.10 Scope of the study

The definitions of “sonographers” in this review are “sonologists,” “radiologists or doctors who majorly perform sonography,” and “echocardiographers.” The author selected these groups due to specific and similar work activities performed. Their occupation requires using the same muscle-groups, same skills and practices for the sonographic examinations, although the scanning techniques may differ slightly across the countries (Morton and Delf, 2008). Therefore, a fair comparison can be carried out among studies from different countries, as the articles' selection was not limited to any particular country.

1.11 Benefits of the study

This research will help determine the actual burden (prevalence, distribution-pattern, and consequences) of WRMSDs among sonographers serving as a basis for structuring appropriate ergonomic interventions in conjunction with the identified risk factors.

Chapter 2: Research Objectives and Theoretical Framework for the development of WRMSDs

2.1 Research objectives: Hypothesis, Questions, and Aims

2.1.1 Research hypothesis

The work activities of a sonographer are associated with an increased risk of developing WRMSDs, and these injuries are severe enough to affect their lives and careers.

2.1.2 Research questions

What is the prevalence of WRMSDs among sonographers?

Which body areas are frequently affected by these injuries?

What are the predisposing factors identified among these working groups?

Which negative consequences or effects of WRMSDs are identified among the sonographers?

2.1.3 Aim

To evaluate the actual burden, the risk factors, and the negative consequences of WRMSDs among sonographers.

2.1.3 Objectives

To assess the prevalence of WRMSDs among sonographers.

To outline the bodily distribution of injuries among sonographers.

To evaluate the predisposing factors among these occupational groups.

To determine the negative consequences of WRMSDs on their lives and careers.

2.2 Theoretical framework for the development of WRMSDs

2.2.1 Theoretical conceptualization for the development of WRMSDs

Bongers (1993) explained that the occurrence of WRMSDs was dependent on psychosocial factors such as job-demands, job-control, and social support. These factors indirectly affect the individual's mechanical load through changes in postures, movement, and increased levels of exerted forces. The psychosocial factors interact with the worker's resilience and increases work-related stress, leading to increased muscle tone and increased pain perception. He concluded that the psychological factors are associated with escalation, prolongation, and worsening of the WMSD-symptoms (Bongers et al., 1993).

In addition to considering the psychosocial factor, the National Research Council (1999) assessed biomechanical factors, organizational factors, and individual factors involved in the development of WRMSDs. It argued that MSDs occur when the load exceeds the physical tolerance of the tissue. The mechanical load's systematic response can either lead to developing symptoms or to developing adaptive behaviours to reduce the worker's pain, and the worker might remain asymptomatic. This response is also dependent on individual factors such as age, gender, previous injuries, or bone diseases, which affect the resilience of the muscles and the development of MSDs, as highlighted in **Figure 8** below. Other factors identified are the organizational factors, e.g., time pressure and social context. Lack of support from administration or co-workers in dealing with work-related stress influences the workers' reporting behaviour (National Research Council (U.S.), 1999).

Macdonald (2012) modified the model developed by the National Research Council and identified two hazards, which were the physical hazard {mechanical loads} and the psychosocial hazard {social context and organizational factors}. These two hazards interact together and affect an individual's internal response. The individual's perceived internal response to the hazards is "stress," leading to adverse effects on the individual's health and development of MSDs. The model showed that increasing "the job or task demands" {physical hazards} and the psychosocial risks above the available coping resources of the worker lead to the development of WRMSDs. The coping resources of an employee are affected by work-place factors such as support systems, available resources, work environment, and the workers' capacity (Macdonald, 2012).

Figure 8: Conceptual framework of the physiological pathways and factors relating to WRMSDs

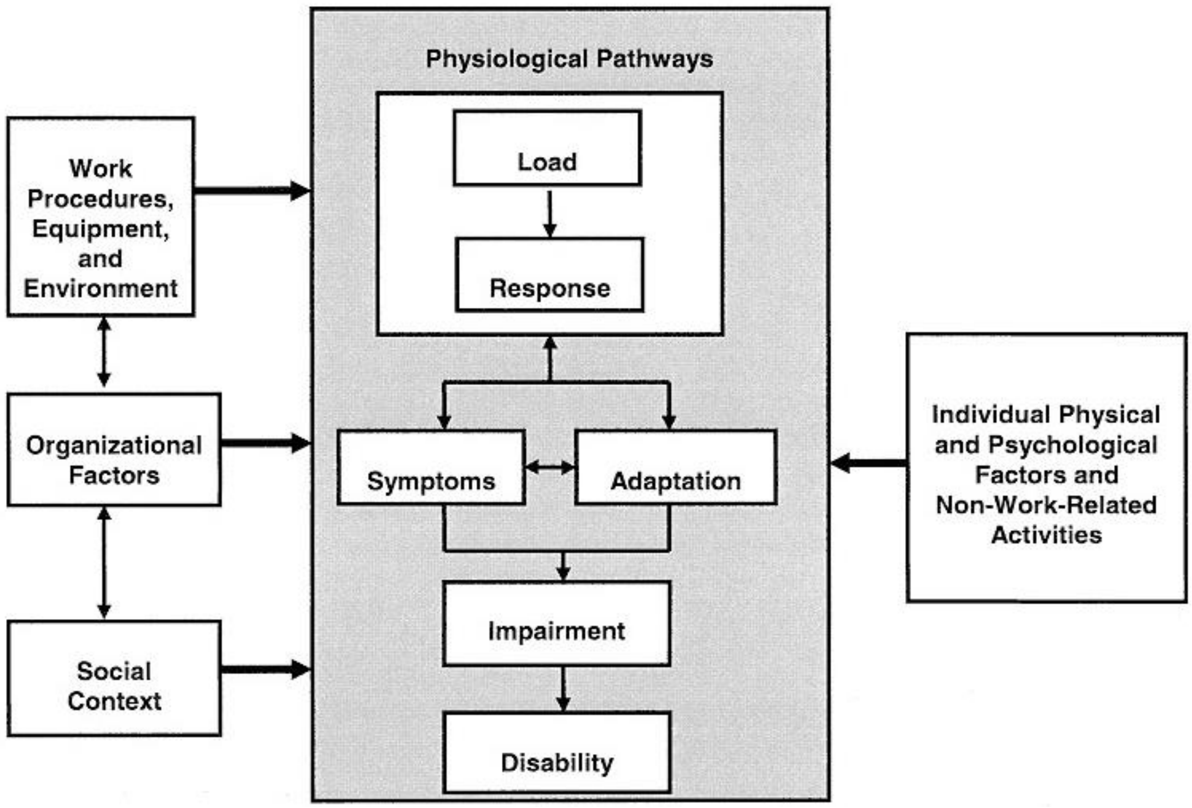


Figure adapted from National Research Council (US), 1999.

The model from Nunes and Bush (2012) focused on the workplace's factors in the development of WRMSDs. The factors identified are "work organization," "the sociocultural context of the company," and the "work-place environment." These above-listed factors interact with one another and lead to a direct or indirect effect on the physical and psychosocial work demands, causing the development of WRMSDs. The physical and psychological work demands interact with one another and lead to increased psychological strain and muscle tension. The nature of the individual also affects the physical and mental tolerance to fatigue and resistance to stress, showing that not a single factor leads to the development of WRMSDs but a combination of different factors (Nunes and Bush, 2012).

The model from Guzman (2008) focused on the development of neck pain and the process between the onset of pain and its transition from the non-interfering neck pain to interfering neck pain, i.e., neck pain that prompts an individual to take actions. The model as outlined in Figure 9 is composed of 5 major components: "factors affecting the onset and course of neck pain," "the care complex," "the participation complex," "the claim complex," and "the impact and outcomes of the neck pain." These complexes are affected by the physical work environment, social work environment, workplace culture, and individual attitudes. The risk factors increase the probability of developing neck pain, while the prognostic factors affect the ability to recover from the neck pain. "The care complex" is influenced by the individual characteristics and the local health policy affecting the care options of an individual {"no care," "self-care" or "professional health care"}. A person experiencing pain might need to adjust the participation level at work or at home. The modification in the "participation complex" depends on job-control, the availability of incentives at the workplace, the level of support from co-workers and supervisor, and the job type. The "claim complex" is affected by the workers' insurance coverage, the deductibles' amount, and the size of the payable benefits. A worker will only fill a claim form if he is insured. The presence of neck pain affects the functions of the body structures and reduces the individual's ability to accomplish defined tasks. The impact of the perceived pain is indirectly affected by environmental factors and individual factors, as presented in **Figure 9**. The individual with injury might regain a sense of cure and recovery through "Resolution" or "Readjustment" or "Redefinition." The individual can also suffer persistence of the symptoms and leads to deficits in the level of activities and the participation level (Beaton et al., 2001; Guzman et al., 2008).

Figure 9: The linking onset, course and care model for neck pain among workers

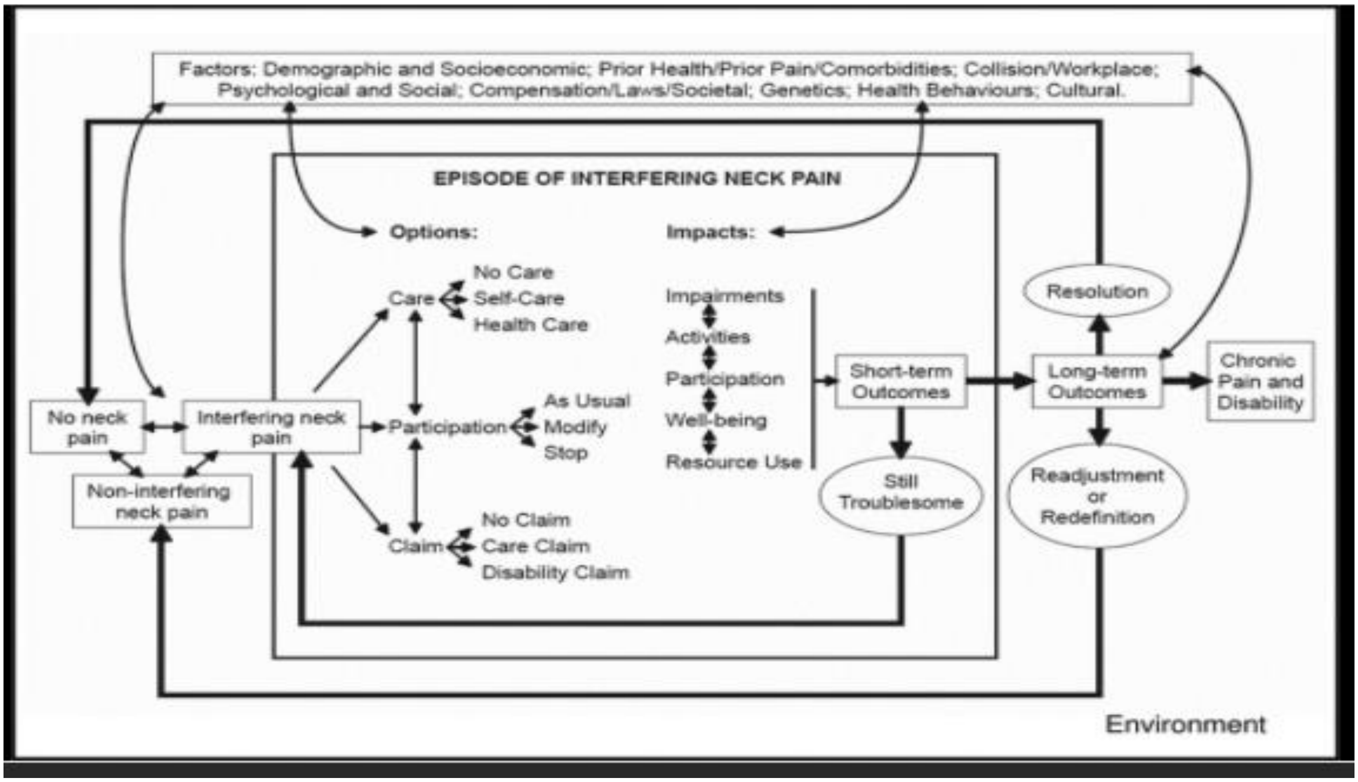


Figure adapted from Guzman et al., 2008.

Table 2: The theoretical conceptualization of WRMSDs as outlined by the authors

Authors	The identified mechanisms for the development of WRMSDs
Bongers et al., 1993	Psychosocial factors (job demands, job control, and social support).
National Research Council (U.S.), 1999	Individual factors (physical and psychosocial factors). Mechanical factors (work procedures, equipment). Organizational factors (e.g., time pressure). Social context (e.g., lack of spousal support at home).
Macdonald, 2012	Physical hazards (mechanical loads). Psychosocial risks (social context, organizational factors). Work-place factors (support systems, available resources). Individual factors.

Authors	The identified mechanisms for the development of WRMSDs
Nunes and Bush, 2012	Work-organization. Sociocultural context. Work-place environment. Physical and psychosocial work demands. Individual factors.
Guzman et al., 2008	Physical work environment. Social work environment (e.g., compensations' laws, Societies' culture). Individual factors (e.g., prior health comorbidities or pains, demographic and socioeconomic factors). Workplace culture (availability of report forms).

Table adapted from Bogners et al., 1993, National Research Council (US), 1999, Guzman et al., 2008, Nunes and Bush, 2012, Macdonald, 2012.

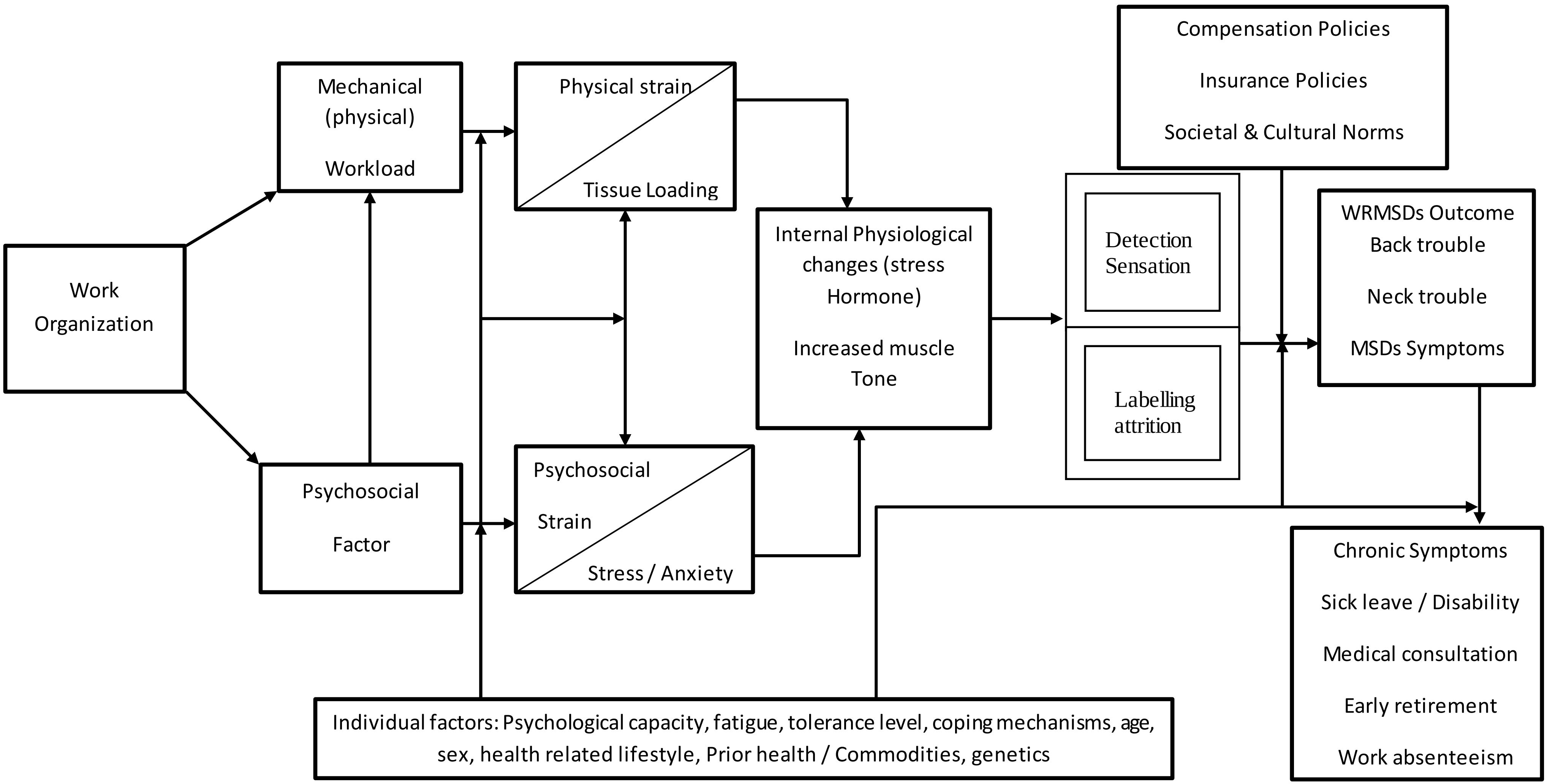
2.2.2 Conceptual framework for this systematic review

The causes of WRMSDs are multifactorial with interaction between the different components (Bongers et al., 1993). The current study's conceptual framework is created and modified for this review using the conceptual frameworks already explained above (Bongers et al., 1993; Guzman et al., 2008; Macdonald, 2012; National Research Council (U.S.), 1999; Nunes and Bush, 2012). The **work-organization** are sets of fundamental determining factors associated with both the **physical job demands** and the **psychological work environment** (Punnett et al., 2009) as outlined in **Figure 10**. The **physical job demands** has a direct internal impact on the physical strain through over-loading, accumulated charge, work style change, and fatigue (Nunes and Bush, 2012); while the **psychological factors** are recognized internally as stress and anxiety (Bongers et al., 1993; MacDonald and King, 2014). The internal responses cause physiological feedbacks such as hormonal changes and increased muscle tone, leading to the symptomatic response affecting the MSS in the form of back troubles, neck troubles, and other MSDs as highlighted in **Figure 10**. These responses interfere with the daily activities of workers; causes immediate quitting of jobs, increased work absenteeism, decreased work productivity, or disability as long-term consequences (Bongers et al., 1993; MacDonald, 2012; National Research Council (U.S.), 1999).

The individuals' factors and the workers' general well-being affect the body's mechanical response to tissue loading and the development of stress from unbalanced psychosocial factors (Bongers et al., 1993; National Research Council (U.S.), 1999). The physical workload is also influenced directly by the psychosocial factors. For example, time pressure may cause the workers to move faster and maintain poor posture during work activities (Bongers et al., 1993). The physical strain and the psychological strain interact with each other; in that stress causes an increase in muscle tone and the physical pressure from work-activities cause fatigue. This interaction is influenced by the individuals' tolerance to fatigue and resistance to stress, leading eventually to internal physiological changes and pains (Bongers et al., 1993; Nunes and Bush, 2012). The progression from ordinary pain sensation to WRMSD depends on the workplace's reporting system; which is affected by the compensation policy, insurance policy, laws, cultural norms in the country and the individual characteristics (Guzman et al., 2008). The progression from MSS symptoms to chronic symptoms or disabilities is also dependent on the individual factors and compensation policies. A diagrammatic representation of the framework is outlined in **Figure 10** below.

Figure 10: Diagrammatic representation of the conceptual framework for the study

Figure adapted from Bongers et al., 1993, Guzman et al., 2008, MacDonald, 2012, Nunes and Bush, 2012 and National Research Council, 1999.



Chapter 3: METHODOLOGY

3.1 Study design

This study's design is a systematic review of the literature, a secondary analysis of the available articles on WRMSDs among sonographers. This study design is appropriate due to the nature of the topic and the availability of various studies on the subject matter. The author reviewed and synthesized the results from the available literatures in determining the actual burden and the predisposing factors of WRMSDs among sonographers. Before reviewing the literature, the author created research questions, objectives, inclusion criteria, and search strategies. The steps involved in carrying out this review included searching in the different databases, assessment, and qualitative analysis of the included studies. The search terms' development was from the search in the literature and the systematic search was implemented in 3 databases. The assessment of the degree of bias and the included studies' validity was carried out using the NIH-tool for cross-sectional studies (National Institute of Health, 2018). This review presented the various surveys separately and synthesized the results qualitatively based on the study's structured framework. However, this study does not include a meta-analysis.

The author used the PRISMA guidelines (Moher et al., 2009) to formulate the structure of this review. The outline of the PRISMA requirement and the corresponding pages in this review are presented in **Table 14** in the appendix. **Figure 11** is a PRISMA flowchart that represents the study selection process for an easy understanding of the selection process and transparency. The inclusion criteria were defined using the "PICOS" component: Population, Intervention, Comparator, Outcome, and Study design (Methley et al., 2014). In this study, "intervention" is the "Exposure," and no comparative group is available in this present study; therefore, the author adopted "PEOS" model: Population, Exposure, Outcome, and Study design in this study. The prevalence of WRMSDs among sonographers was neither affected by the study's location nor the scanning type; therefore the author included studies from different countries and all types of sonographic examinations in the review (Morton and Delf, 2008).

3.2 Eligibility criteria

The author used the components of **PEOS-Model** to determine the inclusion and exclusion criteria with consideration of the study-year and the study's language, as shown in the table of inclusion and exclusion criteria below.

Table 3: The Inclusion Criteria.

	Inclusion criteria	**Details**
1	Population	The study populations are sonographers or other health professionals, who mainly perform sonography.
2	Exposure	Usage of ultrasound machines, unacceptable working conditions and stress at the work-place associated with scanning activities.
3	Outcome	The studies focusing on the prevalence of WRMSDs among sonographers, the affected body regions, the predisposing factors, or the consequences of WRMSDs on the injured sonographers.
4	Study design	Qualitative and quantitative randomized and non-randomized studies (peer-reviewed articles).
5	Year of Study	1990- 01.06.2020.
6	Language of study	Studies documented in the English language.
7	Place of study	All countries around the world.

Table 4: The Exclusion Criteria.

	Exclusion criteria	**Details**
1	Population	Studies carried out among other health care workers, excluding sonographers.
2	Exposure	Studies focusing on other work-related exposure; excluding ultrasound machines, stress at the work-place, and unacceptable working conditions.
3	Outcome	Work-related psychological disorder and other MSDs which are not related to the work conditions.
4	Study-design	Other systematic reviews or literature reviews, letters to the editor

		guidelines, case reports, and editorials.
5	Year of study	Before 1990 and after 01.06.2020
6	Language of study	Other than the English language.

3.3: Information sources

The search was carried out in 3 computerized databases: PubMed, Scopus, and the Cochrane library. The access to the three databases is from the library of Hamburg University of applied sciences. The last date of the search was 01.06.2020. **Table 5** shows the databases and the systems providing its access.

Table 5: The Computerized Databases for the Search.

Database	System providing access
Medline	PubMed
Elsevier	Scopus
Central	Cochrane

3.4: Search strategy

The author developed the search table based on the formulated research questions. The search terms were created using the Medical Subject Headings {MeSH terms} available in the databases (Baumann, 2016) and the synonyms for those terms found in the dictionary. The developed search terms are presented in **Table 6**. The search strategy included 3-subsets: the first set is related to sonographers, the second set focused on different forms of WRMSDs, and the third subset is a combination of #1 and #2. The terms in the first two subsets were combined using the operator "OR" to ensure all the terminologies are retrieved in the results. The operator "AND" used in the final search guarantees that only articles with both terms are in the last search. Quotation marks were used in all search terms to limit the search only to the exact expressions inside the quotation marks. A direct search in "PubMed" using the "advanced search" setting with the "search-terms" in **Table 6** resulted in 304 articles, with the application of the timeframe "1990-2020," the author retrieved 284 studies in the last search. In Scopus, a direct search with the "search terms" using the "advanced search" setting resulted in 4,551 documents. The search was refined with the subject area limited to the "health profession," the time frame "1990-2020," the "document-type" restricted to "articles" and "reviews," and the language limited to "English" resulted in 557 documents in the end search. Inputting the "search terms" in "the Cochrane Library" resulted in 107 articles, with the application of the time frame between 1990 and 2020, 104 studies were retrieved in the final research. The reference lists from identified papers were hand-searched to ensure that all relevant articles are included. The author extracted two studies additionally from the manual searching of the references of the included studies.

Table 6: The Search Terms for the Articles.

#1	"diagnostic medical sonographers" OR "radiologist" OR "sonographers" OR "breast imagers" OR "echocardiographers" OR "radiographers" OR "imaging radiologist" OR "imaging radiologists" OR "cardiac sonographers" OR "Echocardiographers" OR "Sonologists"
#2	"work-related musculoskeletal disorders" OR "repeated strain injuries" OR "repetitive Strain Injuries" OR "cumulative trauma disorder" OR "occupational overuse syndrome" OR "occupational overuse injuries" OR "work-related musculoskeletal injuries" OR "repetitive motion Injuries" OR "occupational cervicobrachial disorders" OR "carpal tunnel syndrome" OR "work-related upper-extremity musculoskeletal disorder" OR "cubital tunnel syndrome" OR "ulnar nerve entrapment" OR "low back-pain" OR "rotatorcuff-syndrome" OR "tenosynovitis" OR "neck pain" OR "shoulder pain" OR "elbow pain" OR "Job-related soft tissue disorder" OR "Occupational injuries" OR "Work-related neck and upper limb disorder" OR "Repetitive stress injuries"
#3	#1 AND #2.

3.5: Study selection

The search in the three databases resulted in 945 articles. The author screened the items using the preformed PEOS inclusion and exclusion criteria. The studies that satisfied the inclusion criteria were included in the systematic review. In contrast, those that didn't meet the inclusion criteria were excluded, as presented in **Table 12** in the appendix. The screening-process began with the titles of the articles. If they were not precise, the abstracts were reviewed. The author sometimes studied the whole articles before including or excluding the items—a diagrammatic representation of the screening-process is highlighted in **Figure 11**. **Table 12** is a tabular presentation of the all reviewed articles, with 20 articles excluded. The reason for the exclusion was stated to reduce bias and improve transparency in this review. The reasons are classified into four domains: "not work-related musculoskeletal injuries," "not an epidemiological study," "target group not working-sonographers," or "full-articles were not available." The author comprehensively reviewed the included articles and removed the duplicates manually. A full-text table as shown in **Table 12** in the appendix was developed, which the author's supervisors also controlled.

3.6 Data extraction process

A sheet for data extraction was created to assess all the articles' needed information to answer the preformed research questions. The author adopted the data extraction table from a systematic review conducted among allied health professionals (Anderson and Oakman, 2016). The pilot form of the data extraction was randomly conducted with three studies, as shown in **Table 7**.

The author extracted data on the following items from each of the included studies:

1. Information about the study: author's surname, year of publication, country, and study design.
2. Characteristics of participants in the survey: sample size, gender distribution, and the survey population's response rate.
3. Prevalence of WRMSDs: Point-Prevalence or Period-Prevalence or Career-Prevalence.
4. The common areas of the body affected by the WRMSDs.
5. The predisposing factors to WRMSDs among sonographers identified in the study, e.g., individual factors; factors related to work organization, biomechanical factors.
6. The consequences of WRMSDs on the careers, daily activities, and work activities of the sonographers.
7. The possible ergonomic intervention were also extracted and explored in details in the chapter of discussion.
8. The author also extracted other essential findings relevant to better understanding of the

subject matter.

Table 7: The Pilot Design for the Data Extraction Tables.

Study	Prevalence	Areas of injuries	Risk factors identified	Consequences of WMSDs	Other relevant findings
Al-Rammah et al., 2017 Saudi-Arabia Cross-sectional study	1-YP: 43% CP: 84%	Shoulder: 68% Low back: 54%	Scanning > 7 hours/day. Scanning > 5days/week. Moving of ultrasound machine and patients. Negative job perceptions. Increasing years of practice.	93% reported significant impacts on their daily activities. 80% stated that their ability to enjoy life is limited. 75% reported limited work activities. 46% took sick leave.	65%- had no previous knowledge of ergonomics. 71% of those with WRMSDs were not provided with an incidence form.
Gremark-Simsonsen et al., 2017 Sweden Cross-sectional study	1-YP for neck and upper Extremity pain: 65%	Neck /Shoulder pain- 58% Elbow / hand pain: 30%	Increasing years of practice. Dissatisfaction with work station. High MEI. Nonadjustable keyboards and chairs.		Sonographers had more pain in the transducer's shoulder and hand
Barros-Gommes et al. 2019 USA Comparative cross-sectional study	1-YP: 85%	Neck: 58% Shoulder: 51% Low back: 44% Wrist and Hand: 42% Neck: 58% Upper back: 37% Elbow: 17%		Interference with their performance of daily activities, Sleeping, Recreational and work activities. Considering changing their employments. Missed days at work.	

3.7: Risk of bias in the included studies

Bias, referred to as the systematic error of a study, is also any process that distorts the study-results through the incorrect methodology used during the survey (Almeida et al., 2017). The assessment of the validity and reliability of the different studies included in a systematic review is critical to reducing the review's bias; since a systematic review is dependent on the data from other primary studies (Drucker et al., 2016). An article's critical appraisal assesses the potential risk of selection bias, information bias, measurement bias, and other confounders in the study (National institute of health, 2018). Several tools are available for the validity assessment of an article; the NIH-tool for cross-sectional and observational studies was used in this review and subsequently modified for the different study designs included in the systematic review (National Institute of Health, 2018). The NIH-tool developed by the National Heart, Lung, and Blood Institute {NHLBI} consists of about 14 questions with six subheadings focusing on the research question, study-population, sample size justification, exposure measurement, the study's statistical analysis, and the study's expected outcome. The questions are structured to assess the methodology of the surveys. There are three options to the level of bias: "YES" {low risk of bias} or "NO" {high risk of bias}; and the third option is either "Cannot Be Determined" {CD} or "Not Applicable" {NA} or "Not Reported" {NR}, which represents a lack of information on the potential risk of bias (National Institute of Health, 2018). An explanation of each criterion is presented below, as adopted from the National Institute of Health, 2018.

1. Research question {Criterion 1}: This appraises the aim and the research questions of a study. Stating the goal and also research questions determines the studies' quality (National Institute of Health, 2018).
2. Study population {Criteria 2 and 3}: These assess the participants in the study. A bias-free article should answer the question on participants' characteristics, the place of research and the study's time frame (National Institute of Health, 2018).
3. Uniform eligibility criteria: Criterion 4 proves the inclusion and exclusion criteria' development before selecting the participants. For transparency, it is also vital that the recruitment of the group is from the same population (National Institute of Health, 2018).

4. Sample size justification {Criterion 5}: The question aims to determine if the study had enough participants to detect an association from the study results, i.e., the statistical power of a study (National Institute of Health, 2018).
5. Exposure assessment before outcome assessment {Criterion 6}: This aspect assesses whether an exposure causes an outcome. It is possible to recruit the non-exposed participants and then the participants are exposed {prospective cohort study} or vice versa, i.e., the population with the outcome, then the evaluation of their exposure {retrospective cohort study}. For cross-sectional studies, the outcome and the exposure are measured simultaneously; therefore, the association's evidence is weaker (National Institute of Health, 2018).
6. Sufficient time frame to see an effect {Criterion 7}: This proves if the time frame was enough to see the impact/outcome of an exposure. It is essential to ensure meaningful analyses are obtained from the study results (National Institute of Health, 2018).
7. Different levels of exposure {Criterion 8}: It is vital to use multiple exposure levels to determine the dose-response relationships between exposures and outcomes. This criterion strengthens the hypothesis of causality between exposure and outcome (National Institute of Health, 2018).
8. Exposure measurements and assessments {Criterion 9}: It proves the description of the exposure measurements and the appropriateness of the tool used in measuring the exposure. The question is essential in detecting the reliability of the measured outcome (National Institute of Health, 2018).
9. Repeated exposure assessment {Criterion 10}: Multiple exposures with similar results reaffirm the association between the exposure and outcome. It also detects changes in the outcome over a period of exposure (National Institute of Health, 2018).
10. Outcome measures {Criterion 11}: The question addresses if the outcomes were measured accurately, reliably, and equally across the study-groups. A self-reported result would be rated as a high risk of bias, as there is no objective verification (National Institute of Health, 2018).

11. Blinding of outcome assessors {Criterion 12}: This assesses if the author were aware of the exposure status of the participants, as blinding is not possible in cross-sectional studies, so it is not applicable in ORSCDs (National Institute of Health, 2018).
12. Follow-up rate {Criterion 13}: After measuring the exposure at a baseline level, an acceptable overall follow-up rate is 80% or more, but this is also dependent on the length of the study. Studies with shorter duration have a high follow-up rate and vice versa (National Institute of Health, 2018).
13. Statistical analyses {Criterion 14}: It assesses if the potential cofounders were analysed and the author adjusted for them in the interpretation of the study results (National Institute of Health, 2018).

3.8 Summary measures

All the studies in this survey are cross-sectional study design except Gremark Simonsen et al., 2020, a longitudinal study design, as outlined in **Table 8** in the Results Chapter. The outcome of interest, "WRMSDs" was assessed using different survey tools. The Nordic questionnaire survey tool was employed by Gremark Simonsen et al., 2017; 2020, Hill et al., 1999 and Arvidsson et al., 2016. The modified version of the Nordic questionnaire was utilized by Zhang and Huang, 2017 and Feng et al., 2016. The revised HBT-survey instrument was employed by Roll et al., 2012 and was modified by Evans et al., 2009; 2010. Russo et al., 2002, Muir et al., 2004, and Friesen et al., 2006 used similar self-developed questionnaire as their survey tools. Different self-developed questionnaires based on the musculoskeletal symptomatology reported in the literature was utilized in Barros-Gommes et al., 2019, Wareluk and Jabokwsi, 2017; Okejie et al., 2015; Irurhe et al., 2013, Russo et al., 2002, Bagley et al., 2017, Pallotta and Roberts, 2017, Vanderpool et al., 1999, Magnavita et al., 1999, Schoenfeld et al., 1999, Smith et al.1997 and Necas et al., 1996. The variations in the survey content and the unavailability of the details of the survey tool's questions make a comparison of the results across studies difficult. The author carried out the comparison of the study results with a high level of caution.

The outcome of measure in all included studies was the prevalence of WRMSDs, which was reported with a range of different time-periods in various studies: "point-prevalence" or "1-year-prevalence" or "career-prevalence." The **Point-Prevalence** is the number of sonographers experiencing WRMSDs-symptoms related to their job at the time of the survey. While the **career-prevalence** is defined as the number of sonographers who had WRMSDs-symptoms in the past associated with their work activities, and the **1-year-prevalence** is the number of sonographers that suffered from WRMSDs as a result of their job activities in the last 12 months (Hill, III et al., 2009; Vanderpool et al., 1993). Most of the studies using the standardized Nordic questionnaires reported the prevalence of WRMSDs in the last one year, which can be considered a better tool for evaluating the outcome than the point-prevalence. As some sonographers with pain might have been treated and had no symptoms at the survey point, leading to underestimating the prevalence of symptoms. Most studies reporting point-prevalence also reported the career-prevalence, which might help to level the risk of underestimation associated with these studies' point-prevalence.

Arvidsson et al.2016, Gremark Simonsen et al., 2017, 2020 also assessed the frequency of pain {never, seldom, sometimes, often, and very often} and the intensity of the problem on a scale of 0-10. They created their definition of WRMSDs as “complaints with pain intensity of 7 and pain-frequency that is seldom” or “intensity of 3 with the symptoms that occur sometimes” or “intensity of 2 with the pain being often or very often in frequency”. These studies reported a lower prevalence of WRMSDs compared to other surveys, and the authors considered the methodology as an objective verification of the subjective reporting of pain. This approach might have also led to underestimation of the prevalence of WRMSDs in the survey population as workers with light symptoms were excluded. Vanderpool et al.1999 divided the sample population with WRMSDs into two groups based on the number of symptoms- “High symptoms group” with five or more complaints or “Low symptoms group” with 1-4 symptoms. The sample population was split by Magnavita et al., 1999 into two groups considering the number of symptomatic areas. The “NBP –Group” have four or more Neck-Back-pain-symptoms or the “Hand-Wrist-Cumulative trauma disorder” if they have three or more wrist symptoms at the point of survey. The authors chose the criteria to exclude people with either transient or relatively mild symptoms, therefore compensating for the overestimation from the subjective reporting of the WRMSDs among participants.

The risk factors identified with the development of WRMSDs are reported in some studies using different measures of associations between the exposure to the predisposing factors and the probability of developing WRMSDs among the exposed sonographers. The odds-ratio was used by Feng et al.2016, Zhang and Huang, 2017, and Magnavita et al., 1999. Gremark Simonsen et al., 2017; 2020, used the prevalence ratio in determining the probability of developing WRMSDs among those exposed to the risk factors. The percentage of variance assesses the effect of changing different work and individual domains, e.g., physical size, job-strain, and working-time on the development of WRMSDs (Hill, III et al., 2009). The correlation coefficient was used by Vanderpool et al.1993 and Schoenfeld et al., 1999, they associated a positive correlation with an increased chance of WRMSDs. The psychosocial or organizational factors are evaluated with the mean score and the score between sonographers with WRMSDs was compared to those without WRMSDs (Evans et al., 2009; Evans et al., 2010; Roll et al., 2012; Russo et al., 2002).

Chapter 4: RESULTS

4.1 Study Selection

The search in all three databases resulted in 945 articles; 891 articles were excluded based on their titles and abstracts, remaining 54 articles for further review. 11 duplicated items were manually removed, leaving 43 studies for the final review. Additional 2 surveys were retrieved by reference chase of the included articles, and a total of 45 articles were fully-reviewed. Twenty articles were excluded, as presented in **Figure 11** and in **Table 12** in the appendix. 25 articles are included in the final analysis.

Figure 11: Schematic diagram for a detailed search of review articles

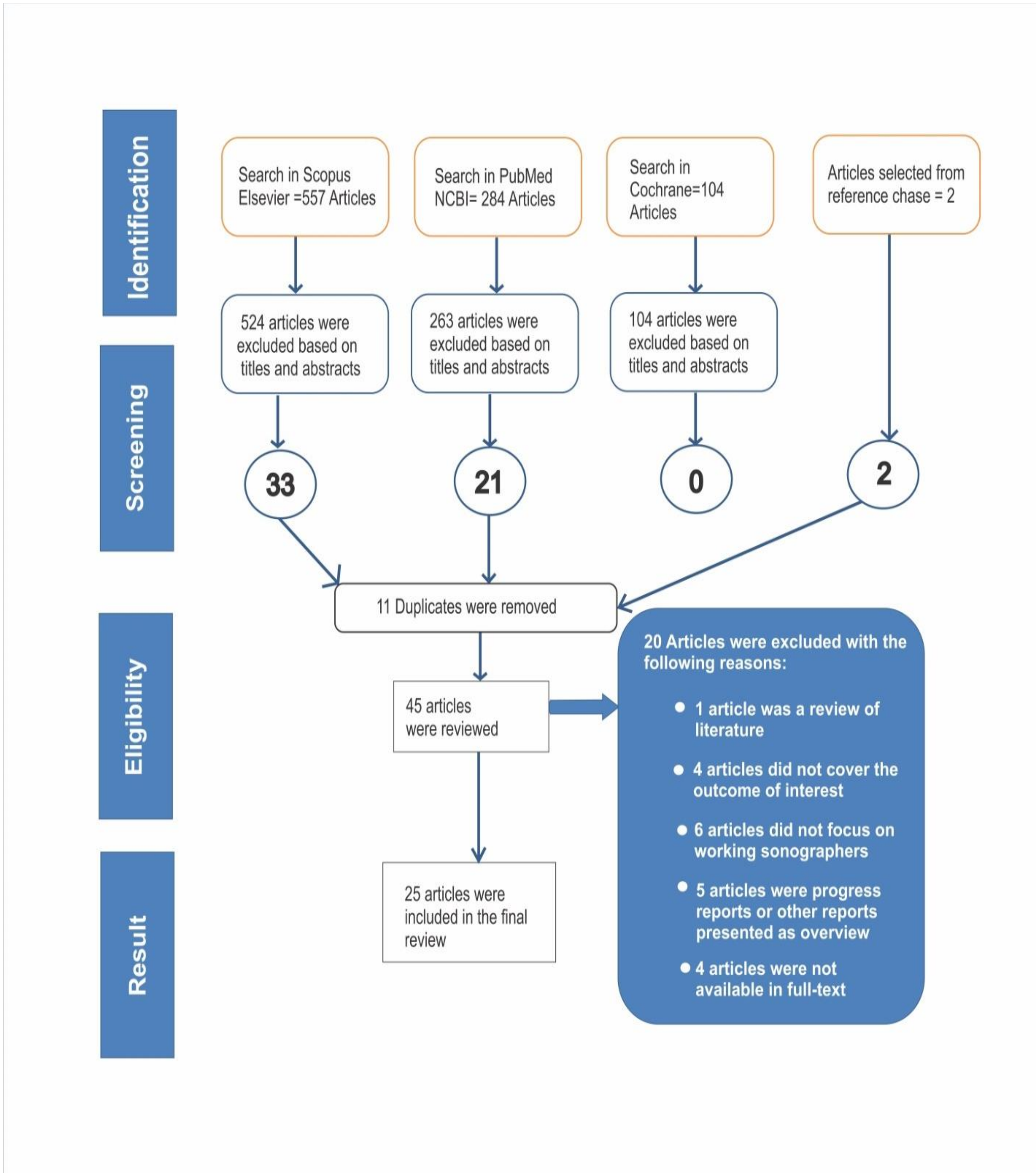


Figure adapted from Moher et al., 2009.

4.2 Study characteristics

From the 25 studies included in this review, 23 are ORCSD. The survey by Friesen et al., 2006 is a comparative study to Muir et al., 2004, as the two studies were conducted among the sonographers in rural and urban Manitoba in Canada. One of these 23 articles, Arvidsson et al., 2016, is a comparative study among female sonographers, teachers and nurses. Barros Gommes et al., 2019 is a cross-sectional cohort study between the sonographers and their peer-employees, and Gremark Simonsen et al., 2020 is a longitudinal study over a study period of 2.5 years. The author identified neither relevant randomized control trials nor meta-analysis during the search in the databases. The included studies were in English language between January 1990 and June 2020. The studies were conducted in various geographical location, including; USA {N=10}, Canada {N=4}, Sweden {N=3}, China {N=2}, Nigeria {N=2}, Italy {N=1}, Israel {N=1}, Saudi Arabia {N=1}, Poland {N=1}, and Australia {N=1}. The study population in Roll et al., 2012 included sonographers from the USA and Canada. The sample size ranged from 12 in the study population by Friesen et al., 2006 to 2963 in the study population by Evans et al., 2009; 2010; Roll et al.,2012. The gender distribution in the study population was skewed towards females except for studies conducted in Italy and Nigeria, as presented in **Table 8**.

The prevalence of the combined physical symptoms was self-reported and not based on clinical evidence. Nevertheless, the level of reported symptoms is possibly an indication of the actual burden of WRMSDs (Vanderpool et al., 1993). Due to most studies' cross-sectional nature, conclusions on the cause-effect relationship between the identified predisposing factors and WRMSDs seem impossible. The ease of use of this research method, time- and money-saving nature, and the possibility of surveying a large sample-population makes it a useful tool. The overestimation's or underestimation's problem associated with subjective reporting of pain is mitigated by either a large sample size or a high response rate. Most studies in this review reported either a high response rate or had a large sample population to make reasonable conclusions as outlined in **Table 8** (Magnavita et al., 1999; Russo et al., 2002). Since the pain from WRMSDs is intermittent, asking the respondents about suffering from pain over a long period is more reasonable than asking about pain at the survey point. For example, Arvidsson (2016) captured more than 210 women who do not currently have pain but had been badly affected by WRMSDs in the past (Arvidsson et al., 2016; Evans et al., 2009). All studies in the review reported the prevalence of WRMSD over a particular period.

Some studies like Magnavita (1999) and Russo (2002) divided the population into two groups (LPD and HPD) based on the number of symptoms to separate those with mild pain from those with severe pain (Magnavita et al., 1999; Russo et al., 2002). Arvidsson et al., 2016; Gremark Simonsen et al., 2017;2020 defined WRMSDs based on the frequency and the pain's intensity to exclude respondents without significant problems or those with mild symptoms. The population that met the set criterion was considered as having WRMSDs. The survey-methods from Magnavita (1999) and Russo (2002) are more detailed as they could not have missed out on any sonographers suffering from WRMSDs based on the methodology. In the survey population by Russo (2002), 29 respondents in the HPD submitted WCB-claim and 55% of the claims were accepted, while nine respondents of those in the LPD-Group submitted WCB-claim, and six from the nine claims were approved by the WCB (Magnavita et al., 1999; Russo et al., 2002). Using the other methodology by Arvidsson et al., 2016 and Gremark Simonsen et al., 2017, 2020 might miss out the LPD-Group in the survey population. This group also had severe WRMSDs to be considered as a claim by the WCB.

Respondents with pain might also report their work factors as more aggravating than those without pain, but some of the exposures are objective, e.g., access to ergonomic chairs or tables. The Study from Arvidsson et al., 2016 also reported a high correlation between the technical measurement and the self-reported physical work exposure; thus, the self-reported data on physical work exposure represent a reasonable assessment of the actual work exposure. The longitudinal study by Gremark Simonsen et al., 2020 also suggested that the predictor of pain among those without pain at baseline is the high MEI and high job demands, i.e., the increased workloads. The findings in the longitudinal study correlated with the cross-sectional studies' results, so the predisposing factors to WRMSDs identified by sonographers in the cross-sectional studies can be considered an actual representation.

Table 8 : Characteristics of included studies

	Authors	Study design	Place of study	Sample details	Outcome measure
1	Vanderpool et al., 1993	ORCSD	USA	N=101 RR-47% F-72% M-28%	A self-designed questionnaire. The author divided the survey population into three groups based on the number of symptoms: No symptoms, Low symptoms {1-4 symptoms}, and High symptoms {> 5 signs}.
2	Necas ,1996	ORCSD	USA	N- 143 RR-36% F-85% M-15%	A self-designed comprehensive questionnaire. The work-habit score and a 4-numeric stress scale assessed the workload and stress level. The author stratified the study population into three groups based on their symptoms: asymptomatic, symptomatic, and RSI-sufferers.
3	Pike et al., 1997	ORCSD	USA	N-983 RR-32.8% F-85% M-15%	A self-designed comprehensive questionnaire.
4	Smith et al., 1997	ORCSD	USA	N-101 RR-51% F-100%	A self-designed questionnaire.
5	Magnivita et al., 1999	ORCSD	Italy	N-2041 RR-76.4% M-73.5% F-26.5%	A self-designed questionnaire. The author divided the survey population into HWD {defined as three or more current HWD-symptoms} and NBP {defined as four or more current NBP Symptoms}.
6	Schoenfeld et al., 1999	ORCSD	Israel	N-44 RR-86% F-77% M-23%	A self-designed questionnaire.

Table 8 {continuation}: Characteristics of the included studies

	Authors	Study design	Place of study	Sample details	Outcome measure
7	Russo et al., 2002	ORCSD	Canada	N-211 RR-92% F-89% M-11%	A self-developed questionnaire. There are two groups, as defined by the author: HPD and LPD. The HPD described as current pain or discomfort with a frequency and severity ≥ three on a 4-point scale.
8	Muir et al., 2004	ORCSD	Canada	N-67 RR-88% F-84% M-16%	He adopted the questionnaire from Russo et al., 2002.
9	Friesen et al., 2006	ORCSD	Canada	N-12 RR-60% F-67% M-33%	Friesen (2006) adapted the questionnaire from Muir et al., 2004. Biomechanical assessment of the positions of the joint-angles and limb-positions during scanning were recorded with videotape and analyzed with Ergo-watch.
10	Evans et al., 2009	ORCSD	USA	N-2963 RR-65% F-88% M-12%	The Health Benefit Trust survey instrument.
11	Hill III et al., 2009	ORCSD	USA	N-26 RR-83.9% F-100%	The Nordic musculoskeletal questionnaire, anthropometric measurement, including grip-strength testing, and a review of the respondents' previous occupational health records.
12	Evans et al., 2010	ORCSD	USA	N-2963 RR-65% F-90% M-10%	The Health Benefit Trust {HBT} survey instrument.
13	Roll et al., 2012	ORCSD	USA and Canada	N-2963 RR-73% F- 100%	The revised Health Benefit Trust survey instrument.

Table 8 {continuation}: Characteristics of the included studies

	Authors	Study design	Place of study	Sample details	Outcome measure
14	Irurhe et al., 2013	ORCSD	Nigeria	N-110 RR-73.33% M-68% F-32%	A self-developed questionnaire.
15	Okeji et al., 2015	ORCSD	Nigeria	N-42 RR- 100% M-69% F-31%	A self-developed questionnaire.
16	Arvidsson et al., 2016	Comparative study	Sweden	N-291 RR-86% F-100%	The Nordic musculoskeletal questionnaire, clinical examination, and technical measurement of the physical workload. WRMSP was defined objectively by the author. The job content questionnaire {Swedish version} was used to assess the psychosocial work environment.
17	Feng et al., 2016	ORCSD	China	N-232 RR-66.4% F-75% M-25%	The modified Nordic questionnaire.
18	Gremark Simonsen et al., 2017	ORCSD	Sweden	N-263 RR-86% F-100%	The Nordic questionnaire; WRMSP was defined objectively. The workloads were assessed using MEI and PhYI. The psychological factors were evaluated using the job-content questionnaire.
19	AlRammah et al., 2017	ORCSD	Saudi Arabia	N-100 RR-83% F-76% M-23%	A self-developed questionnaire.
20	Zhang and Huang, 2017	ORCSD	China	N-567 RR- NR M-22.7% F-77.4%	The standardized Nordic questionnaire, with an assessment of the duration of the symptoms. MSDs is defined as symptoms that persisted at least one day during the last 12-month.

Table 8 {continuation}: Characteristics of the included studies					
	Authors	**Study design**	**Place of study**	**Sample details**	**Outcome measure**
21	Wareluk and Jakubowski	ORCSD	Poland	N-553 RR-not reported F-49% M- 51%	A self-developed Questionnaire
22	Bagley et al., 2017	ORCSD	USA	N-98 RR-44.3% F-87% M-13%	A self-developed questionnaire.
23	Pallotta and Roberts, 2017	ORCSD	Australia	N-85 RR- NR	A self-developed questionnaire.
24	Barros-Gommes et al., 2019	Cross-sectional cohort study	USA	N-416 Sonographers-111 RR- 86% Control-subject: 305	A self-developed questionnaire. WRMSD is defined as pain experienced in the current year resulting from work activities. The physical function and symptoms of the individual with MSDs was assessed using Quick DASH-Questionnaires The author evaluated the subjects' ability to perform work activities with the Quick –DASH-Work –Questionnaire
25	Gremark Simonsen et al., 2020	Longitudinal study (follow-up time: 29 Months).	Sweden	N-291 RR-71% F-100%	The standardized Nordic questionnaire, with MSDs defined based on the frequency and the intensity of the pain.

N: Number of Respondents. F: Female participants. M: Male participants. RR: Response Rate. DASH: Disability of the Arm, Shoulder, and Hand. ORCSD: observational retrospective cross-sectional study design. LPD: Low Pain Discomfort. HPD: High Pain Discomfort. HWD: Hand Wrist Disorder. NBP: Neck-Back-Pain. MEI: Mechanical exposure index. PhYI: physical exposure index. NR: Not reported.
Work-Habit-Score measures the awkward and potentially harmful repetitive, static, or overload motions and postures associated with scanning.
MEI assessedthe physical workloads and work-related postures and movement. PhYI focused on material handling, including the lifting of patients.

4.3: Assessing the validity of the included studies

4.3.1: Assessing the risk of Bias across studies

The research questions and objectives were stated in all the included studies. Questions {1} and {2} were answered with "yes," as highlighted in **Tables 9 and 10.** Item 3 focused on the survey population's participation rate, which was reported in all the included studies except the studies by Zhang and Huang, 2017 and Wareluk and Jakubowski, 2017 as both were online surveys. The reported response rate by Vanderpool et al., 1993, Bagley et al.,2017, Pike et al.,1997, and Necas,1996 was 43%, 44.3%,32.8%, 36%, respectively; which are less than the standard response rate of 50% in the NIH-tool used in this systematic review (National Institute of Health, 2018). However, these studies had a sufficient sample population required for the generalisation of the study-results (Pike et al., 1997; Vanderpool et al., 1993). The surveys from Necas, 1996 and Bagley et al., 2017 also stated that their response rate was higher than the previous studies. These studies have the statistical power to detect differences, and reasonable conclusions were drawn from the analyses.

All studies selected in the systematic review had a similar population, i.e., were focused on working sonographers. The surveys by Arvidsson (2016) and Barros-Gommes (2019) are exceptions, which are comparative studies between sonographers with their peer-employees and sonographers with teachers and nurses, respectively (Arvidsson et al., 2016; Barros-Gomes et al., 2019). The sample size justification is stated in most studies, but some studies didn't report the sample size justification as presented in **Table 10**. All the articles included in the systematic review were cross-sectional studies except Gremark Simonsen et al., 2020, a longitudinal study. Therefore, measuring the exposure before the outcome and calculating the reviews' time frame is not possible. The author answered these questions with 'No' based on the quality assessment tool (National Institute of Health, 2018). The exposure in all the articles cannot be varied because the sonographic examination is a dichotomous exposure. It is either one is performing it or not. Question {8} would be answered with 'NA' in all the included studies, but this doesn't affect the quality rating of the article negatively (National Institute of Health, 2018). Question {9} is answered with "yes" in all studies, since the included studies' exposure is performing sonographic examination only. Except for the survey by Wareluk and Jakubowski , 2017, the Participants performed other activities, e.g., surgeries but still performed majorly sonographic examinations. The survey population's exposure was assessed just once in all studies; except in

Arvidsson et al., 2016, in which the workload was technically measured after the participants' subjective reporting. The studies by Arvidsson et al., 2016 and Friesen et al., 2006 also estimated the positions of the joints of the sonographers during scanning examinations with an inclinometer.

As stated in the studies, the outcome of interest is assessed subjectively through the participants, i.e., self-reported work-related MSP. The self-reporting can lead to reporting bias in the form of overestimation of the pain; so Question 11 is answered with 'No' in all studies except in some studies in which an objective definition of WRMSD based on the intensity, frequency, and duration of the pain was created (Arvidsson et al., 2016; Barros-Gomes et al., 2019; Feng et al., 2016; Gremark Simonsen et al., 2020, 2017; Zhang and Huang, 2017). Blinding regarding the outcome of interest is not possible in cross-sectional studies, so Question 12 is answered "NA" in all included studies (National Institute of Health, 2018). The loss to follow-up was only applicable to Gremark Simonsen et al., 2020. This study reported loss to follow-up of more than 20%, which indicates a high bias level. Most studies adjusted the results for confounders except in 4 studies, in which the adjustment was not reported (AlRammah et al., 2017; Feng et al., 2016; Muir et al., 2004; Pallotta and Roberts, 2017). The questions for the assessment of the quality of the studies and the results of the quality assessment using the National Institute of Health tool are outlined in **Tables 9 and 10**.

Table 9: Criteria for quality assessment from the National Heart, Lung and Blood Institute (2018)

	Criteria	Yes	No	CD	NR	NA
1	The objectives or research questions; was it clearly expressed?					
2	Was the study population specifically defined?					
3	Did the eligible person partake at least at a rate of 50%?					
4	Was every subject adopted or enlisted from the same or similar populations {counting the same period}? Were inclusion and exclusion criteria for the study pre-established and put in uniformly to all participants?					
5	Were sample size justification, power description, or variance and effect estimates stated?					
6	During the analyses in this paper, was the exposure{s} of interest measured before measuring the outcome{s}?					
7	Was the timeframe enough so that one could reasonably expect to see an association between exposure and outcome if it occurred?					
8	The exposures which can vary in amount or level; did the study examine different levels of the exposure as connected to the outcome					
9	Was the exposure measures {independent variables} clearly stated, validated, and implemented consistently across study participants?					
10	Were the exposure{s} evaluated more than once?					
11	Was the outcome measures {dependent variables} clearly stated, validated, and implemented consistently across study participants?					
12	Were the outcome evaluators not aware of the exposure status of participants?					
13	The loss to follow-up after baseline; was it 20% or less?					
14	Were key potential confounding variables measured and modified statistically for their impact on the relationship between exposure{s} and outcome{s}?					

YES= low level of bias NO= High level of bias CD: Cannot be determined from the study NR: Not reported in the study NA: Not applicable based on the nature of the study-type CD/NR/NA= level of bias cannot be determined.

4.3.2: Assessing the risk of bias in individual studies

Table 10: Assessment of bias in the individual articles

Articles	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Grekal simsonen et al., 2017	Y	Y	Y	Y	Y	N	N	NA	Y	N	Y	NA	NA	Y
Alrammah et al., 2017	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	NR
Arvidsson et al., 2016	Y	Y	Y	N	NR	N	N	NA	Y	Y	Y	NA	NA	Y
Barros-Gommes et al., 2019	Y	Y	Y	N	Y	N	N	NA	Y	N	Y	NA	NA	Y
Zhang and Huang, 2017	Y	Y	NR	Y	Y	N	N	NA	Y	N	Y	NA	NA	Y
Hill III et al., 2009	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Feng et al., 2016	Y	Y	Y	Y	Y	N	N	NA	Y	N	Y	NA	NA	Y
Wareluk and Jakubowski, 2017	Y	Y	NR	Y	NR	N	N	NA	N	N	N	NA	NA	NR
Vanderpool et al., 1993	Y	Y	N	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Roll et al., 2012	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Schoenfeld et al., 1999	Y	Y	Y	Y	NR	N	N	NA	Y	N	N	NA	NA	Y
Russo et al., 2002	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Evans et al., 2010	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Bagley et al., 2017	Y	Y	N	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Friesen et al., 2006	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Pallotta and Roberts, 2007	Y	Y	NR	Y	NR	N	N	NA	Y	N	N	NA	NA	NR
Pike et al., 1997	Y	Y	N	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Necas,1996	Y	Y	N	Y	NR	N	N	NA	Y	N	N	NA	NA	Y
Evans et al., 2009	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Muir et al., 2004	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Okeji et al., 2015	Y	Y	Y	Y	NR	N	N	NA	Y	N	N	NA	NA	NR
Smith et al., 1997	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Irurhe et al., 2013	Y	Y	Y	Y	Y	N	N	NA	Y	N	N	NA	NA	Y
Gremark Simonsen et al., 2020	Y	Y	Y	Y	NR	N	Y	NA	Y	N	Y	NA	N	Y
Magnivita et al., 1999	Y	Y	Y	Y	Y	N	N	NA	Y	N	Y	NA	NA	Y

Y-Yes {low bias}, N- No {high bias}, NA- Not applicable, NR-Not reported {level of bias cannot be determined}.

4.4: Data extraction and results of individual studies

The author extracted results from the individual studies to answer the preformed research questions in the methodology. The main findings from the individual studies are presented in the table below. **Table 11** summarizes the individual studies' results, with the identified risk factors classified into five groups: work-related factors, individual factors, factors related to ergonomics, work-organization factors, and psychosocial factors. Expanded versions of the result findings with other essential findings extracted from the studies are presented in **Table 13** in the appendix.

Table 11: Table of results {summarized version}

Authors	Prevalence of WRMSDs	Areas of injuries {three most affected areas}	Identified risk factors	Consequences of WRMSDs
Vanderpool et al.,1993	PP of CTS: 57% CP of CTS: 63% CP of WRMSI: 81%		Awkward work posture and unfavourable work-related factors. Individual factors.	Taking sick leave. Medical treatment. Compensation claims.
Necas, 1996	CP of WRMSI: 66%	Shoulder, neck, and wrist-region.	Individual factors. Unfavourable work-related factors. Psychosocial stress.	Scanning in pain. Reduced working hours. Medical treatment. Taking sick leave. Leaving the profession.
Pike et al., 1997	CP: 81% PP: 91%	Shoulder, neck, and back region.	Awkward work posture and unfavourable work-related factors.	Scanning in pain. Reduced working hours. Medical treatment. Taking sick leave. Performing home- and work-activities in pain.
Smith et al., 1997	CP: 80%		Individual factors. Unfavourable work-related factors. Poor work ergonomics.	Medical treatment. Physical therapy.

Table 11 {continuation}: Table of results {summarized version}				
Authors	**Prevalence of WRMSDs**	**Areas of injuries {three most affected areas}**	**Identified risk factors**	**Consequences of WRMSDs**
Magnivita et al., 1999	CP: 80% PP: 61.4%	Neck and back-region.	Individual factors. Poor work ergonomics. Awkward work-posture and unfavourable work-related factors.	Medical treatment. Temporarily stopping their job.
Schoenfeld et al.,1999	PP of CT-symptoms: 57% CP of CT-symptoms: 65% CP of MSP: 80%		Awkward work posture. Individual factors.	Medical treatment. Work absenteeism.
Russo et al., 2002	CP: 91% PP: 80%	Neck, Shoulder, and wrist-region.	Awkward work-posture and unfavourable work-related factors. Poor work ergonomics. Suboptimal work organization.	Scanning in pain. Medical treatment. Performing home and work activities in pain. Reduced work hours.
Muir et al., 2004	CP: 91%	Neck, shoulder, and upper back region.	Awkward work-posture and unfavourable work-related factors. Poor work ergonomics. Suboptimal work organization.	Medical treatment. Performing home and work activities in pain. Sleeping problem. Psychological ill-health.
Friesen et al., 2006		Neck, shoulder, and upper back region.	Awkward work-posture and unfavourable work-related factors. Poor work ergonomics. Suboptimal work organization.	Medical treatment. Performing home- and work-activities in pain. Taking sick-leave.
Evans et al., 2009	CP: 90.4%	Shoulder, neck, and wrist-region.	Awkward work-posture and unfavourable work-related factors.	Received diagnosis and medical treatment. Work absenteeism. Changed their job.

Table 11 {continuation}: Table of results {summarized version}

Authors	Prevalence of WRMSDs	Areas of injuries {three most affected areas}	Identified risk factors	Consequences of WRMSDs
Hill III et al., 2009	1-YP: 96%	Shoulder, wrist, and low back region.	Individual factors. Awkward work-posture and unfavourable work-related factors. Suboptimal work organization.	
Evans et al., 2010	CP for wrist pain: 59%		Awkward work posture. Individual factors. Adverse factors related to ergonomics and work organization.	Medical treatment. Changing their job. Taking sick leave.
Roll et al., 2012	CP for Shoulder pain: 73%	Neck, wrist, and upper back region.	Individual factors. Awkward work posture and work-related factors. Unfavourable factors related to ergonomics and work organization.	
Irurhe et al., 2013	CP: 91%	Low back, neck, and shoulder region.	Awkward work posture and unfavourable work-related factors. Individual factors.	Medical treatment. Reduced performance level of work activities.
Okeji et al., 2015	CP:88.9%	Shoulder, low back, and elbow region	Individual factors. Unfavourable work factors. Poor work ergonomics.	
Arvidsson et al., 2016		Shoulder, neck, and low back region.	Unfavourable work-related factors. Psychosocial stress. Individual factors. Suboptimal work organization.	

Table 11 {continuation}: Table of results {summarized version}

Authors	Prevalence of WRMSDs	Areas of injuries {three most affected areas}	Identified risk factors	Consequences of WRMSDs
Feng et al., 2016	1-YP: 98.3%	Shoulder, neck, and low back region.	Awkward work posture. Psychosocial stress. Individual factors. Suboptimal work organization. Poor work ergonomics.	Medical treatment. Taking sick-leave. Changed their work. Work absenteeism.
Gremark Simonsen et al., 2017	1-YP in the neck/shoulder region or elbow/hand region: 65%	Neck and shoulder region.	Individual factors. Poor work ergonomics. Unfavourable work factors. Awkward work posture.	
AlRammah et al., 2017	CP: 84%	Shoulder and back region.	Poor knowledge of ergonomics. Individual factors. Unfavourable work factors and organizational factors. Adverse psychosocial factors.	Reduced performance level of work activities and daily activities. Taking sick leave.
Zhuang and Huang, 2017	1-YP: 99.3%	Neck, shoulder, Low back, and wrist region.	Individual factors. Unfavourable work-related factors and awkward work posture. Suboptimal work organization. Poor knowledge of ergonomics.	
Wareluk und Jakubowski, 2017	CP: 83%	Shoulder, wrist, and spine region.		Medical treatment. Work absenteeism.
Bagley et al., 2017	CP: 53%	Shoulder, neck, and wrist region.	Poor work ergonomics.	
Pallotta and Roberts, 2017	1-YP: 95.3%		Unfavourable work factors. Poor work ergonomics.	

Table 11 {continuation}: Table of results {summarized version}

Authors	Prevalence of WRMSDs	Areas of injuries {three most affected areas}	Identified risk factors	Consequences of WRMSDs
Barros-Gommes et al., 2019	1-YP: 86%	Shoulder, neck, and wrist region.	Unfavourable work-related factors. Individual factors.	Reduced performance level of work activities and daily activities. Work restrictions. Work absenteeism. Changed their jobs.
Gremark Simonsen et al., 2020	1-YP of neck pain at base line:61% at follow-up:68%		Poor work ergonomics. Unfavourable work-related factors. Adverse psychosocial factors. Pain at baseline.	

CT-Symptoms: Carpal-Tunnel-Symptoms. MSP: Musculoskeletal Pain. CP: Career-Prevalence. PP: Point-Prevalence. 1-YP: 1-Year-Prevalence. WRMSI: Work-Related Musculoskeletal Injuries. CTS: Carpal Tunnel Syndrome. MSP: Musculoskeletal pain

4.5 Qualitative synthesis of results and findings from the systematic review

The author carried out a qualitative synthesis and analysis of the individual studies' results. The syntheses described the prevalence of WRMSDs and the variation among the included studies, the bodily distribution of WRMSDs among sonographers. The identified risk factors are divided into: factors inherent in the sonographers, factors intrinsic in the work routine, psychosocial factors, factors related to the equipment design, and work-organization factors. The review also analysed the effects of the injuries on the sonographers.

4.5.1 Prevalence of WRMSDs among Sonographers

The prevalence of WRMSDs in the studies is reported with a range of time-periods. Most of the studies that reported career-prevalence also reported point-prevalence to reduce the recall-bias attributed to career-prevalence due to the long time frame between the injury and the point of data collection (Anderson and Oakman, 2016). The career prevalence of WRMSDs was higher in all reported studies than the point-prevalence except the review by Pike (1997), in which the point-prevalence was 10% higher than the career-prevalence of WRMSDs (Pike et al., 1997) as presented in **Table 11**. The variation in the prevalence of WRMSDs may be due to either some of the sonographers receiving treatment or therapy and are now pain-free, or the survey populations have chronic pain by continuous exposure to the predisposing factors.

The career-prevalence for WRMSDs ranged from 53% (Bagley et al., 2017) to 95.3% (Pallotta and Roberts, 2017). Some studies reported the career-prevalence in specific body regions, e.g., Evans (2010) reported a career prevalence of 59% for wrist pain while Roll (2012) stated 73% as the career prevalence for shoulder pain among sonographers (Evans et al., 2010; Roll et al., 2012). Most studies that reported career-prevalence used a self-developed Survey tool to determine the measure of outcome except the reviews by Evans et al.,2009; 2010 and Roll et al.,2012, which used the HBT-survey tool to assess the prevalence of WRMSDs as highlighted in Table 9. Only two studies reported a career-prevalence of WRMSDs ≤ 80% (Bagley et al., 2017; Necas, 1996); except for studies that focused on specific anatomical areas. Schoenfeld (1999) and Vanderpool (1993) reported career prevalence for CT-symptoms among sonographers as 63% and 65% respectively (Schoenfeld et al., 1999; Vanderpool et al., 1993). The high prevalence reported in all studies shows that sonographers continued to suffer from injuries related to scanning.

Seven studies reported the 1-year-prevalence (Arvidsson et al., 2016; Barros-Gomes et al., 2019; Feng et al., 2016; Gremark Simonsen et al., 2020, 2017; Hill, III et al., 2009; Zhang and Huang, 2017). The outcome measurement tool used in these studies is the Nordic musculoskeletal questionnaire, except for the research conducted by Barros-Gommes et al., 2019, which used a self-developed questionnaire. He defined WRMSDs in his study as pain caused by work activities experienced in the current year. The 1-year- prevalence of WRMSDs ranged from 96% (Hill, III et al., 2009) to 99.3% (Zhang and Huang, 2017). The studies focusing on upper extremities reported a lower prevalence than studies concentrating on the whole body. Arvidsson (2016) and Gremark Simonsen (2017) highlighted the 1-year-prevalence of pain in the neck with shoulder regions and the wrist region as 44% and 65%, respectively. Gremark Simonsen (2020) is the only longitudinal study included in this review and stated the 1-year-prevalence for neck pain as 61% at baseline and 68% at follow-up study (Arvidsson et al., 2016; Gremark Simonsen et al., 2020, 2017).

4.5.2 Area of injury

The included studies assessed the distribution of WRMSDs in the different body's anatomical areas. The distribution was reported either as a percentage of the whole sample population or as a percentage of those with WRMSDs. Thirteen studies reported the distribution of injury among the total sample population (AL-Rammah et al., 2017; Arvidsson et al., 2016; Bagley et al., 2017; Feng et al., 2016; Friesen et al., 2006; Gremark Simonsen et al., 2017; Muir et al., 2004; Necas, 1996; Okeji et al., 2015; Pike et al., 1997; Russo et al., 2002; Wareluk and Jakubowski, 2017; Zhang and Huang, 2017). Six studies reported the bodily distribution of the injuries among the injured sonographers (Barros-Gomes et al., 2019; Evans et al., 2009; Hill, III et al., 2009; Irurhe et al., 2013; Magnavita et al., 1999; Roll et al., 2012). The studies considering the complete survey reported higher percentages than studies focusing on the injured groups. Wareluk and Jakubowski, 2017 stated a prevalence rate of pain in the spine in the total survey population as 81%, with the highest prevalence in the lumbosacral segment. While Bagley et al., 2017 reported a prevalence of back pain among the injured sonographers with 8%. Across all studies, the five most commonly affected areas are the neck, shoulder, wrist, upper back, and lower back. The shoulder and neck regions are the most affected areas, while just two studies reported the most affected region as the low back area (Irurhe et al., 2013; Wareluk and Jakubowski, 2017). The prevalence rate for injuries in the shoulder ranged from 7% (Irurhe et al., 2013) to 95% (Zhang and Huang, 2017), for the neck region 20% (Irurhe et al., 2013) to 95% (Zhang and Huang, 2017), for the wrist-region 11% (Bagley et al., 2017) to 81% (Zhang and Huang, 2017), for the lower back 29% (Arvidsson et al., 2016) to 83% (Feng et al., 2016) and the upper back 11% (Irurhe et al., 2013) to 78% (Zhang and Huang, 2017).

4.5.3 Risk factors

Interaction of different elements is associated with the development of WRMSDs (Irurhe et al., 2013); therefore, the risk factors varied across studies in the review. All included studies except Wareluk and Jakubowski, 2017 identified some predisposing factors.

Individual factors are factors inherent in the sonographers themselves. Studies identified female gender as a significant predisposing factor to WRMSDs (Feng et al., 2016; Necas, 1996; Schoenfeld et al., 1999; Vanderpool et al., 1993). Increasing age and increasing years of practice were also recorded as significant risk factors (AL-Rammah et al., 2017; Arvidsson et al., 2016; Barros-Gomes et al., 2019; Evans et al., 2010; Gremark Simonsen et al., 2017; Irurhe et al., 2013; Magnavita et al., 1999; Okeji et al., 2015; Roll et al., 2012; Zhang and Huang, 2017). Sonographers with shorter stature (Roll et al., 2012; Smith et al., 2017) and those who are overweight (Irurhe et al., 2013) suffer more WRMSDs. Gremark Simonsen (2017) and Avirdsson (2016) also stated that high BMI is associated with increased risk of WRMSDs, but Increasing physical size and decreasing abdominal girth was associated with reduced risk of WRMSDs (Arvidsson et al., 2016; Gremark Simonsen et al., 2017; Hill, III et al., 2009). Gremark Simonsen et al., 2020 identified previous MSI among sonographers and bad visual condition as risk factors associated with suffering WRMSIs.

The Biomechanical/physical factors are the aggravating factors inherent in the job itself. Based on the focused anatomical areas, different aggravating factors were reported. For example, Vanderpool et al., 1993 and Schoenfeld et al., 1999 focused on CTS and identified pushing and twisting of the wrist, high-grip pressure, and twisted posture as aggravating factors. The other studies reported inefficient work posture such as excessive shoulder abduction, sustained twisting and bending of the neck, standing while scanning as aggravating factors. Six studies outlined moving the patient or ultrasound machine in performing bedside examination as predisposing factors to WRMSDs (AL-Rammah et al., 2017; Gremark Simonsen et al., 2020; Muir et al., 2004; Pike et al., 1997; Russo et al., 2002; Smith et al., 2017). Across all studies, some operational activities such as performing more scans, long scans, increasing working hours, and increased scanning time aggravates the development of WRMSDs.

Factors related to equipment design such as uncomfortable transducer design, non-availability of adjustable chairs, tables, PACS, swivel keyboard, sharing of workstations, poor equipment design, and use of outdated scanning equipment are factors related to the development of WRMSDs among sonographers (Bagley et al., 2017; Evans et al., 2009; Evans et al., 2010; Feng et al., 2016; Friesen et al., 2006; Gremark Simonsen et al., 2020, 2017; Magnavita et al., 1999; Muir et al., 2004; Okeji et al., 2015; Russo et al., 2002). Just five studies considered the effect of psychosocial factors on the development of WRMSDs such as dissatisfaction with the workstation, high-stress level, high job demands, and increased sensory needs (Arvidsson et al., 2016; Feng et al., 2016; Gremark Simonsen et al., 2020, 2017; Necas, 1996). Work organizational factors such as short rest breaks, variation in the sonographic studies, a long waiting list of patients were identified by Necas, 1996; Hill et al.,2009, Arvidsson et al.,2016, Feng et al.,2016, Gremark Simonsen et al.,2017;2020 as risk factors for developing WRMSDs. Scanning of obese patients (Feng et al., 2016; Friesen et al., 2006), working with multiple credentials (Roll et al., 2012), and scanning and writing of reports (Okeji et al., 2015) were all reported as work-related aggravating factors for WRMSDs.

4.5.4 Consequences of WRMSDs among the sonographers

The sonographers have developed some management strategies for WRMSD as outlined by 17 articles in this review (AL-Rammah et al., 2017; Barros-Gomes et al., 2019; Evans et al., 2009; Evans et al., 2010; Feng et al., 2016; Friesen et al., 2006; Irurhe et al., 2013; Magnavita et al., 1999; Muir et al., 2004; Necas, 1996; Pallotta and Roberts, 2017; Pike et al., 1997; Russo et al., 2002; Schoenfeld et al., 1999; Smith et al., 2017; Vanderpool et al., 1993; Wareluk and Jakubowski, 2017). All the 17 studies outlined that the sonographers with WRMSDs visited medical professionals and received some form of treatment. The treatments received included medications, massage therapy, physiotherapy, surgery, and therapy from a chiropractor. A number of the sonographers received diagnoses from health professionals. The diagnoses included CTS and carpal instability (Schoenfeld et al., 1999; Vanderpool et al., 1993), tendinitis, musculoskeletal injury, tension neck syndrome, and RSI (Necas, 1996; Pike et al., 1997). A small number of the sonographers took sick leave or missed some workdays, and a large number continued to scan in pain as outlined in **Table 13** in the appendix. Pike et al., 1997 stated that 84% of the sonographers with WRMSDs continued to scan in pain while just only 10% took sick leave after suffering WRMSDs. Eight studies out of the 17 reviews, as outlined in **Table 13**, outlined the sonographers reducing their working hour, temporarily stopping their jobs, changing to working part-time, or having some work-restrictions. A large number of sonographers stated that their daily activities, operating activities, recreational activities, and sleeping pattern were affected by WRMSDs (AL-Rammah et al., 2017; Barros-Gomes et al., 2019; Irurhe et al., 2013; Muir et al., 2004; Pike et al., 1997; Russo et al., 2002). Some sonographers had to redesign their workstation after suffering repeated injuries (Friesen et al., 2006; Russo et al., 2002). And Necas, 1996 reported 4% of the sonographers with WRMSDs prematurely ending their careers. Vanderpool et al.,1993 stated 4% receiving compensation compared to the 31% that visited the physicians and received treatment; this is due to the underreporting of the injuries to the administrators, with less than 50% of the injured sonographers reporting their injuries (Evans et al., 2009; Evans et al., 2010; Pallotta and Roberts, 2017; Roll et al., 2012).

Chapter 5: Discussion and Ergonomic Intervention

5.1 Discussion

5.1.1 Summary of evidence

The odds of having WRMSDs is eight times higher among sonographers compared to the other employees in the same department after adjusting for age, gender, weight, BMI, years in current position, workplace setting, and the performance of regular exercises. CT-symptoms such as tingling of the hand were four times higher among sonographers than the peer employees. The sonographers' pain was restricted to the scanning hand in 98% of those with wrist pain; it is inferred that scanning is more aggravating than other workplace activities. The scores on the quick-DASH and quick-DASH work questionnaires were higher among sonographers, i.e., they reported a more severe level of pain and were more affected by the problem than their peer-employees. Despite the sonographer's young age, they had more severe pain with increased risk of worsening than the other employees (Arvidsson et al., 2016; Barros-Gomes et al., 2019).

Most of the reported career-prevalence or one-year-prevalence of WRMSDs was above 60%, excluding studies considering a particular body region, except Bagley et al., 2017 stating the career prevalence of WRMSDs as 53%, which is the lowest prevalence in this review. The survey population in Bagley et al., 2017 had high level of access to ergonomics equipment. Up to 93% of the survey population had a height-adjustable sonogram or detachable monitors, 95% of the respondents had access to height-adjustable tables, and the respondents' mean-age was 37 years. Hence, the population was less likely to have suffered WRMSDs in the past (Bagley et al., 2017). The author deduced from the findings in Bagley et al., 2017 that the risk of developing WRMSDs is dependent on the individual factors inherent in the workers and also on the level of access to ergonomic equipment, which is vital in maintaining an appropriate posture during scanning. The highest prevalence rate of WRMSDs in the review is 99.3%, reported in Zhuang and Huang, 2017. This survey population had a high workload with about 90% taking < 5 minutes-break per hour and 95% of the study population working more than five days per week. Supporting the hypothesis that long continuous period of scanning activities is associated with increased risk of WRMSD. This study population's sonographers also had a low level of knowledge of ergonomic tools and inadequate access to ergonomic equipment. Just 10% had access to adjustable chairs, and 22% were aware of adjusting their workstation before scanning (Feng et al., 2016; Zhang and Huang, 2017), thus reaffirming the importance of the knowledge of, and availability of ergonomic workplace in the prevention of WRMSDs.

The reported prevalence in the included studies agrees with the reported prevalence in other studies with the same work environment involving monotonous motions with static and dynamic loading of the neck, shoulder, and upper limbs (Pike et al., 1997). The range of the prevalence-rate (53% -99.3%) reported in this review is similar to the prevalence described in a systematic review focused on dentists, in which the prevalence for WRMSDs ranged from 64-93%. The two study populations were exposed to similar aggravating factors such as static awkward position and repetitive motion (Hayes et al., 2009; Smith et al., 2017). The considerable variation in the reported prevalence may also be due to the different definitions of WRMSDs used by various authors (Anderson and Oakman, 2016). The description ranges from a general question like having had work-related pain in the profession (Necas, 1996; Wareluk and Jakubowski, 2017) to having problem associated with the MSS in the last 12-months lasting for more than one day (Feng et al., 2016; Zhang and Huang, 2017) or more explicitly considering the intensity and frequency of the pain in the definition of WRMSDs (Arvidsson et al., 2016; Gremark Simonsen et al., 2020, 2017). Despite the considerable variation in the prevalence, the number of sonographers suffering from WRMSDs remained high in all the studies. Some studies used the same survey tool to determine their outcome; therefore, it is possible to compare results from those studies.

Russo (2002), Muir (2004), Friesen (2006) used the same survey tool and had comparable population-survey; the career-prevalence for WRMSDs was similar in all the three studies. The study-population in Friesen (2006) was located in rural Manitoba compared to Muir (2004) in urban Manitoba, but the location of the survey didn’t have a significant effect on the prevalence of work-related injuries among sonographers (Friesen et al., 2006; Muir et al., 2004; Russo et al., 2002). In the USA, the study by Evans (2009) conducted 12 years after Pike (1997) reported a rise in the career-prevalence by 9%, which may be due to the aging of the sonographers and the accumulation of injuries with years of practice (Evans et al., 2009; Pike et al., 1997). The study by Vanderpool (1993) and Schoenfeld (1999) focused on the career-prevalence of CT-symptoms. They stated a prevalence rate of 63% and 65%, and about 3% and 4% respectively of the population with CT-symptoms were diagnosed with CTS (Schoenfeld et al., 1999; Vanderpool et al., 1993). The comparison of the results shows more sonographers are still being injured due to work tasks since the authors identified the same aggravating factors in the two studies. The studies by Arvidsson (2016) and Gremark Simonsen (2020) were both conducted in Sweden with a similar survey population and they both used the same methodology to assess the outcome measure. The one-year-prevalence rate of pain in the neck region increased from 44% in 2016 to 61% at baseline and 68% at follow-up in 2020 (Arvidsson et al., 2016; Gremark Simonsen et al., 2020). These studies' comparisons indicate a trend of an increasing prevalence of WRMSDs despite the improvement in the sonogram technologies and the availability of ergonomic equipment. The sonographers continue to report the same aggravating factors of the work tasks. Even after many years of ergonomic advancement, the profession continues to experience an increase in the incidence of WRMSDs (Evans et al., 2009). Therefore a comprehensive approach to preventing WRMSDs among sonographers is urgently needed to prevent further injuries and untimely ending of careers in the profession.

The most affected areas in descending order—neck and shoulder>> wrist and hand>> back. The historical description of "Transducer user syndrome" as predominantly affecting the wrist should be reviewed as most of the studies in this review reported the neck and shoulder region as the frequent areas affected by the transducer use. The anatomic distribution area of the pain correlates to sonographers' body positioning during scanning. The cervical spine is twisted, flexed, and rotated forward, leading to static and continuous contraction of the neck, shoulder, back, and upper extremity. These contractions are to support and fix the abducted arm and wrist against a particular area of scanning. The non-dominant hand is extended and used for manoeuvring the control panel (Magnavita et al., 1999; Russo et al., 2002). According to Roll (2012), most respondents reported more pain on the right side (scanning side) of the shoulder through the wrist to the fingers. The prevalence of pain on the right wrist and elbow is 2.5 times higher than on the left side. The prevalence rate of the right shoulder discomfort is about 18% higher than the left shoulder, but there was no significant difference in the prevalence of pain between the left and right sides in the lower extremities (Roll et al., 2012; Zhang and Huang, 2017). The higher prevalence of pain on the scanning side showed that the sonogram's use aggravates the sonographers' problem. The upper extremities kinematics when scanning showed that the shoulder abduction ranged from 39^0 to 113^0 with an average of > 55^0; and the wrist flexion and extension were between 9^0 and 70^0, with an average > 30^0. These ranges of motion are far greater than the optimum position recommended for scanning. The shoulder abduction should be <30^0 and wrist flexion and extension <15^0—the risk of developing WRMSDs increases when the sonographers exceed the recommended degree of joint movement. The blood flow to the tissues is also strongly compromised at a high degree of abduction, leading to tissue damage and pain in the affected areas (Harrison and Harris, 2015; Pocratsky et al., 2014).

The risk factors identified varied widely across studies; this review identified similarities in the studies' risk factors despite these variations. Being a female sonographer was recognized as one of the individual elements that predispose to WRMSDs; developing WRMSDs was five times higher among the female sonographers than their male counterparts. The odds of suffering from CTS are also three times higher in females. Females generally have lower muscle mass and muscular strength, thereby holding the transducer with more perceivable hand grip pressure with an increased incidence of pain (Feng et al., 2016; Schoenfeld et al., 1999; Vanderpool et al., 1993). Sonographers with hand-grip-strength of < 73kg force reported more hand/ wrist symptoms than those with > 76kg. Females also generally have a smaller stature, which can also be related to the height of the worker (Hill, III et al., 2009). Taller sonographers are less symptomatic compared to those of smaller stature. The mean-height for the sonographers with WRMSDs is 63.4 inches, and the mean-height for those without WRMSDs is 66 inches (Roll et al., 2012; Smith et al., 1997). Studies like Pike et al., 1997; Necas, 1996, and Irurhe et al., 2013 didn’t show any correlations between the height of the sonographers and WRMSDs, as the mean height reported in these studies is 65.6±4 inches, and this was close to the size of the “no pain” group as outlined by Smith et al., 1997. The relationship between a sonographer's height and the predisposition to WRMSDs is linked with the work posture. Sonographers with shorter stature have shorter arms and may have to assume a greater degree of abduction in the scanning arm to reach the scanning area (Irurhe et al., 2013; Necas, 1996; Pike et al., 1997; Smith et al., 1997).

BMI is the bodyweight proportion to the individual's height and used more often to estimate the health risk due to obesity (Pike et al., 1997). Gremark Simonsen et al.,2017, Arvidsson et al., 2016, and Irurhe et al., 2013 associated high BMI with an increased risk of suffering from

WRMSDs. BMI is inversely proportional to height, so the explanation for increased risk among sonographers with small stature seems also plausible for those with high BMI. Being overweight is also associated with an increased incidence of WRMSDs. The prevalence of WRMSDs is about 12% higher in those that are overweight compared to those sonographers with average weight. The mean value for those with pain is 72.42±20.67Kg, and the "no pain" group is 52.9±39.75kg. The study population's mean weight increased from asymptomatic through the symptomatic, and the RSI- sufferers had the highest value (Arvidsson et al., 2016; Gremark Simonsen et al., 2017; Irurhe et al., 2013; Necas, 1996). Therefore maintaining a normal BMI is associated with a reduced risk of developing WRMSDs. Hill (2009) stated that increasing abdominal girth and increasing BMI was associated with a 35% cumulative variance in the incidence of WRMSDs among sonographers, and they are also associated with an increased likelihood of ever having a first-aid injury event as a sonographer (Hill, III et al., 2009).

WRMSDs are chronic severe pain and not isolated pain. With higher incidence of chronic pain among the older population, ageing plays a significant role in the development of WRMSDs (Magnavita et al., 1999). Evans et al., 2009 reported that the prevalence of WRMSDs increased from 9.7% among respondents between the ages 20-29 years to about 27% among sonographers > 50 years; and the prevalence of WRMSDs doubled among those with > 21 years of work experience compared to those with < 10 years of work experience. Zhang and Huang (2017) reported similar findings as OR for neck and upper back pain among the age-group of 30-39 years was 4.26 and 2.24, respectively, compared to the age-group 20-29 years with OR of 1. The odds of WRMSDs are also 3.5 times higher among those with > 16-20 years of practice compared to those with < 5 years of practice (Evans et al., 2009; Zhang and Huang, 2017). The likelihood of developing WRMSDs increases with increasing age as only 20% of sonographers between the ages of 23-40 years reported WRMSDs, which progressed to about 72% among respondents > 50 years. RSI incidence rate rose from 0% among sonographers with < 5years of working experience to about 25% among those with > 20 years of working experience (Necas, 1996; Okeji et al., 2015). The rise in the incidence of WRMSDs with age can be due to degenerative changes in the muscular system, leading to a decreased tolerance level and reduced load-bearing capacity of the worker. Increasing work years leads to the accumulation of small repetitive stress leading with time to the development of WRMSDs (Arvidsson et al., 2016; Magnavita et al., 1999). The above-listed factors are individual factors that affect the workers' systematic responses to the workload and determine the sonographers' physical tolerance. WRMSDs occurs when the physical workload exceeds the workers' tissue tolerance as outlined in the theoretical conceptualization framework (National Research Council (US), 1999; Nunes and Bush, 2012).

Respondents stated that high handgrip pressure and abnormal wrist postures such as twisting and bending of the wrist correlated with increased physical symptoms in the wrist region with a correlation-coefficient of +0.186 (Evans et al., 2010; Schoenfeld et al., 1999; Smith et al., 1997; Vanderpool et al., 1993). Feng (2016) reported that the odds of having wrist disorders increased by 3.5 among sonographers bending their wrist during scanning. The prevalence ratio of wrist disorders among this group also increased by 1.64 (Evans et al., 2010; Feng et al., 2016). The surveys reported a direct dose-response relationship between the duration of scan and the development of pain symptoms; as the sonographers performed more scans and as the duration of scans increases, the incidence of multiple pain symptoms increases (Magnavita et al., 1999; Muir et al., 2004; Okeji et al., 2015; Russo et al., 2002; Schoenfeld et al., 1999). The Odds for wrist pain quadrupled among those scanning >50 patients compared to those < 30 patients per day. Increased scanning duration is associated with an extended period of maintaining the wrist in an awkward position, increased hand-pressure, and increased risk of MSPs (Feng et al., 2016). Performing on the average more than ten scans per day or 40 scans per week or performing more than 100 scans per month increased the risk of suffering an injury, as a prolonged period of scanning leads to muscle fatigue and inflammation of the tendons (Friesen et al., 2006; Necas, 1996; Smith et al., 1997). A high MEI was associated with pain in all body parts; as the MEI increases, the prevalence ratio for hand and shoulder symptoms doubles among sonographers. A high PhYI especially lifting of patients, was associated with increased pain symptoms in all body region (Arvidsson et al., 2016; Gremark Simonsen et al., 2017; Roll et al., 2012).

The work habit score is the abnormal body posture, harmful repetitive, and static motion assumed during work activities. The work habit score increased from 4.8±2.8 among the asymptomatic to about 7.3±2.1 among those suffering from RSI; increasing work habit score correlated positively with the number of symptoms and the symptomatic areas (Necas, 1996). Twisted work posture correlates positively with WRMSDs with a coefficient of +0.315 and increases the odds of WRMSDs by 100%. Being in an upright position is associated with the least amount of strain and stress on the discs, joints, muscles, and ligaments; moving out of this balance leads to increased pressure on these structures leading to inflammation and pain (Feng et al., 2016; Schoenfeld et al., 1999; Vanderpool et al., 1993). Sitting-posture correlated negatively with WRMSDs, while standing-posture correlated positively with OR of 2.0; standing also increases the risk of ever having a first-aid injury during scanning. In the standing position, the sonographers have to lean over the patient and towards the screen, thereby twisting their trunk, and increasing the risk of WRMSDs (Hill, III et al., 2009; Pike et al., 1997; Zhang and Huang, 2017). All sonographers found applying pressure on the transducer, shoulder abduction, sustained twisting of the neck, and trunk, as outlined in **Table 13**, very aggravating. These factors mentioned earlier raises the occurrence of WRMSDs in all anatomical locations. Bending and twisting of the trunk and neck increases the OR of having neck pain and low back pain by 6.4 and 3.9 respectively (Feng et al., 2016).

With an increase incidence of obesity worldwide, most sonographers found scanning of obese patients aggravating. Scanning obese patient involves using high grip strength and holding the transducer with increased force to get a clear image when scanning. The amount of load and momentum in the shoulder joint depends on the pressure applied to the transducer. The load moment in the shoulder is 0.6 of every applied downward force on the transducer. For example, an applied force of 10N causes 6N.m. momentum of load in the shoulder. The risk of WRULMSD increases when the pinch grip on the transducer is >9N and the force required in holding a transducer to get a clear image on an obese client can be as high as 260N. Scanning of obese patient is also associated with a higher degree of shoulder abduction and a high grip pressure in the wrist/hand region; this leads to increased strain on the muscles and increases the odds of WRMSDs among sonographers by 300% (Feng et al., 2016; Friesen et al., 2006; Rousseau et al., 2013).

Due to the increased diversity in ultrasound as a diagnostic tool and its less invasive nature, bedside examinations are performed often. According to Russo (2002), mobile scanning is at least 18 minutes longer than the standard examination because of the movement of the equipment. The prevalence ratio of WRMSDs is 1.5 times higher among sonographers performing mobile scans. The patients' rooms do not also offer the best ergonomic environment for scanning, so the body is maintained in an awkward position for a more extended period, which is associated with increased risk of WRMSDs (Gremark Simonsen et al., 2017; Muir et al., 2004; Russo et al., 2002). These above listed factors are the biomechanical or physical factors inherent in the job activities, leading internally to loads and symptoms of WRMSDs as outlined in the theoretical frame work by MacDonald, 2012 and National Research Council (U.S.), 1999.

Sonographers' perception of their work environment and work culture remained in most studies, neutral or positive. The majority reported an inability to control their day-to-day workload, plan overtime or extra work, take scheduled breaks, and working for a long duration without breaks as aggravating (Muir et al., 2004; Pike et al., 1997; Russo et al., 2002). 61% took no break or one 10-minute break, and about 79% of the sonographers reported not having scheduled breaks during their working hours. 85% of the sonographers felt rushed during the day, with about 92% of the survey population finding the job challenging due to higher frequency of ultrasound examination requests and disproportionate work/rest cycle (AL-Rammah et al., 2017; Muir et al., 2004; Smith et al., 1997). Arvidsson (2016) also reported that sonographers had the lowest job control when compared to nurses and teachers. The absence of job control is associated with an increased incidence of MSDs in that the workers are not allowed to make informal changes in the workflow in other to prevent first aid injury events, and they also have to work without mistakes despite the high workload (Arvidsson et al., 2016; Hill, III et al., 2009). The author inferred that the sonographers belong to low-control and high-demand groups, which is the highest point in Karasek's model with the highest predisposition to developing WRMSDs (Karasek, 1979). The incidence of RSI rose from 13% among sonographers having average stress to 21% among those with severe strain. The OR of neck pain and shoulder pain was 7 and 10 among sonographers with high-stress levels and psychological fatigue. The studies attributed the high level of stress with tight scheduling and mental stress associated with making accurate diagnoses (Feng et al., 2016; Necas, 1996). Just 14% found the sonogram comfortable, and 70% of the respondents had to rest on their patients while scanning. There was a high level of dissatisfaction with their workstations, and the sonographers assumed an unbalanced work postures during their work activities (AL-Rammah et al., 2017; Gremark Simonsen et al., 2017). The association between suboptimal psychosocial factors and the development of WRMSDs among sonographers is plausible as the factors mentioned earlier are adverse psychosocial factors and stress, which were identified by the conceptual framework model by Bongers (1993) as predisposing factors for the development of WRMSDs (Bongers et al., 1993).

Task rotation is a useful work-organization tool associated with an increased risk of having a first-aid injury among this survey population. Sonographers with two certifications, i.e., a license to perform two different ultrasound examinations, were more likely to have had wrist pain than those with one credential. 70% of the sonographers working with multiple certifications reported a high level of pain in the shoulder compared to 53% of the population performing just heart-sonography (Hill, III et al., 2009; Roll et al., 2012).The sonographers with one credentials perform the same movements during work activities and might find the work activities less strenuous with increasing practicing years, thus reduced risk of suffering work-related injuries.

The availability of ergonomic-designed work stations varied among different studies, with the highest accessibility found in the survey population from Bagley (2017) and the lowest found in Feng (2016); these two studies reported the lowest and 2nd highest prevalence of WRMSDs respectively in this review, as presented in **Table 13** in the appendix (Bagley et al., 2017; Feng et al., 2016). The sonographers found the use of outdated equipment with no adjustable stretchers, chairs, or keyboards aggravating (Friesen et al., 2006). Just 22.4% were aware of the need to adjust their workstation before scanning, and in 41% of cases, the sonographers placed the monitor above the eye level (Feng et al., 2016). The odds for shoulder pain and neck pain were 90% and 80% respectively lower by the use of ergonomic-chairs. Placing the devices at the appropriate height reduced the odds of upper-back-pain by 70%. The access to adjustable chairs with tables and keyboards reduced the prevalence ratio of shoulder and wrist pain by 32% and 38%, respectively (Feng et al., 2016; Gremark Simonsen et al., 2017). The survey population also worked with PACS for documentation of ultrasound studies. The PACS was not height-adjustable in about 91% of cases, 75% of the respondents reported no access to an adjustable keyboard, and no access to keyboard-tray to support their hand while working on the PACS. Most PACS users reported shoulder pain, with about 88% of those with shoulder symptoms using PACS for documentation (Evans et al., 2009; Evans et al., 2010; Roll et al., 2012). One of the major findings in this review is the lack of awareness among the sonographers about sonography's modern practices. 53% had received education on the available ergonomics, and in

Just 55% of cases, the administrator showed the sonographers the various ergonomic adjustments in the workplace (Muir et al., 2004; Roll et al., 2012; Russo et al., 2002).

The percentage of sonographers receiving treatment increases with age, as 64% of those within 20-29 years received medication compared to 75.1% of those > 50 years. Surgery was more frequent among those above 50 years as a treatment option and three times higher among this age-group than the sonographers between the age group 20 and 29 (Evans et al., 2009). The author deduced that WRMSDs arise from repetitive and persistent injury, which becomes more severe with increasing working years and age, requiring a higher level of treatment with advancing working years. In almost all studies in the systematic review, there is a disparity between the percentage of sonographers suffering from pain and those taking sick-leaves or reducing their work hours. Most of the sonographers continued to scan in pain, as outlined in **Table 13** in the appendix, which decreases productivity and increases future costs both to the individual and organization. Taking sick-leave by the injured workers was affected by the employment grade, as older workers were more likely to have taken sick-leave due to their symptoms than younger ones who tend to use their vacation days (Evans et al., 2009; Roll et al., 2012).

The attitude of underreporting among sonographers is also a significant finding in this review; only a low percentage in most cases <50% of those who suffer injuries reported to their employers. Evans (2009) outlined that 90.4% of the survey population suffered from WRMSDs, 48% had even received a diagnosis from medical professionals, but only 43% of those who received diagnoses reported the injury to their administrator. The low level of reporting was due to fear of not getting support from the administrators, fear of losing their jobs, fear of being a liability to the employer, and the fear of being stigmatized as less productive. The necessity to maintain their source of income, feeling of professional obligation, and also satisfaction with the work environment were other reasons for the low reporting levels among the sonographers (Bagley et al., 2017; Evans et al., 2009; Pallotta and Roberts, 2017; Russo et al., 2002). The factors mentioned earlier were also identified in the theoretical conceptualization framework of WRMSDs by Guzman (2008) as factors related to the workplace's culture, and these factors affect the reporting ability of a worker and also the probability of the workers submitting claim forms after sustaining an injury at work (Guzman et al., 2008).

5.2 Ergonomic measures

As seen from the systemic review results, an increasing number of sonographers are being affected by WRMSDs. The symptoms persist after medical treatment in more than 50% of cases (Friesen et al., 2006; Muir et al., 2004; Russo et al., 2002). The persistence of symptoms showed that the intervention should continue beyond treating the symptoms. Work injuries among sonographers are detrimental in terms of cost to the workers and the employer. It is associated with decreased productivity, increased medical expenses, time and money losses in form of sick leave and staff replacement. The salary of sonographers ranges from $100 to $400 hourly based on the working area; the monetary loss of an injured sonographer daily is about $800-$3200 and rises to almost $2400-$9600 per day with the replacement cost of a sonographer from an operating agency. The average duration of sick-leave among sonographers who sustained injuries is 51.9 hours (6.7 days) per ETF costing about $1218 per ETF. The average total cost from sick-leave is approximately $69,750 (50×1218), excluding the charges from training new sonographers or replacement costs (Muir et al., 2004; Pallotta and Roberts, 2017).

No single factor is associated with the development of WRMSDs but interplay of different factors and mechanisms. Magnavita (1999) stated that the primary and secondary causes of WRMSI among workers performing light jobs are poor job-design and the awkward posture adopted by workers during their operational activities. Although complete elimination of the predisposing factors seems impossible, improving working conditions and providing ergonomic equipment allows the sonographers to scan without pain. Ensuring frequent breaks from the administrator also enables the recovery of the muscles. The employer should factor the measures mentioned earlier in the facility’s operating system in order to reduce the incidence of WRMSDs among sonographers (Irurhe et al., 2013; Magnavita et al., 1999). Although there has been an upgrade in the ultrasound-machine functionality in recent years, but sonographers continue to suffer injuries during their work activities. The machine's new features might just be focused on improving its diagnostic ability and producing better images but not focused on reducing injuries among the operators (Pallotta and Roberts, 2017). The level of intervention can be prevention measures in the non-symptomatic sonographers (primary intervention) or actions to prevent long-term disability in those with WRMSDs (secondary measures) or activities to avoid relapse after successful treatment (tertiary measures) (Brown, 2003). The management of WRMSDs involves a combined effort of the equipment manufacturers, employers, and sonographers, i.e., a multidisciplinary approach is needed to implement effective ergonomic interventions (Wooten, 2019).

Ergonomics focuses on interactions of the workers with their work-environment and modifying the workplace to the workers' abilities and limitations. For the sonographers, it is defined as the sonographers' capability in adjusting the work environment so that it is possible to deliver comfortably optimal diagnostic examination with reduced risk of sustaining injuries at work (Bagley et al., 2017; Harrison and Harris, 2015). Proper ergonomic program is associated with a 3% decrease in the absenteeism level, 4.4% increase in productivity, and 80% decrease in the incidence of WRMSDs over a six-year's timespan of implementing ergonomically designed workstations. The cost of setting up an excellent ergonomic work environment is about four times less than the price involved in the treatment of an injured sonographer (Baker and Coffin, 2013; Scholl and Salisbury, 2017). Although providing an ergonomic workstation is an essential tool in reducing WRMSDs, the workers' usage of the employers' provided tools is crucial. The sonographers have identified different barriers mitigating against acceptable ergonomic practices; the barriers outlined includes high workload, portable scans, obese patients, and patients with limited mobility or critical illnesses (Scholl and Salisbury, 2017). Most of the sonographers without WRMSDs, although with high years of practicing (15-35 years), used the provided ergonomic tools and took time to adjust their workstation before scanning. The ergonomic tool's usage helps in preventing overreaching, exaggerated shoulder abduction, twisting of the neck, and the trunk (Gibbs and Edwards, 2012; Magnavita et al., 1999).

In finding the appropriate ergonomic intervention, the administrators and workers should focus on redesigning the work-related physical factors, the work environment, the work organization, and the behaviour of the workers (van der Beek et al., 2017). Workplace interventions are developed according to the "risk control hierarchy model," as presented in **Figure 12**. The first two levels are the most effective but also not realistic and almost unachievable. Irurhe (2013) stated that the complete elimination of the predisposing factors among sonographers seems impossible. Improving the working conditions and provision of ergonomic tools that fall under the third level, "Engineering-control," allows the sonographers keep an ideal posture while scanning. Good job design and allowing adequate breaks are administrative tools. The use of accessory equipment, e.g., arm-cable, voice activator, robotic arms are classified under the PPE, which is considered the least effective but the most easily achievable control measures (CDC, 2018; Irurhe et al., 2013; NIOSH 2017). The reduction in the risk of MSDs is achieved by a combination of measures which must involve the relevant parties such as departmental managers, sonographers, safety representatives, occupational health services, health, and safety department in designing a clear policy of identifying and controlling the risks associated with WRMSDs among sonographers (Society of Radiographers (Great Britain), 2007)(page 19).

Figure 12: Levels of ergonomic intervention

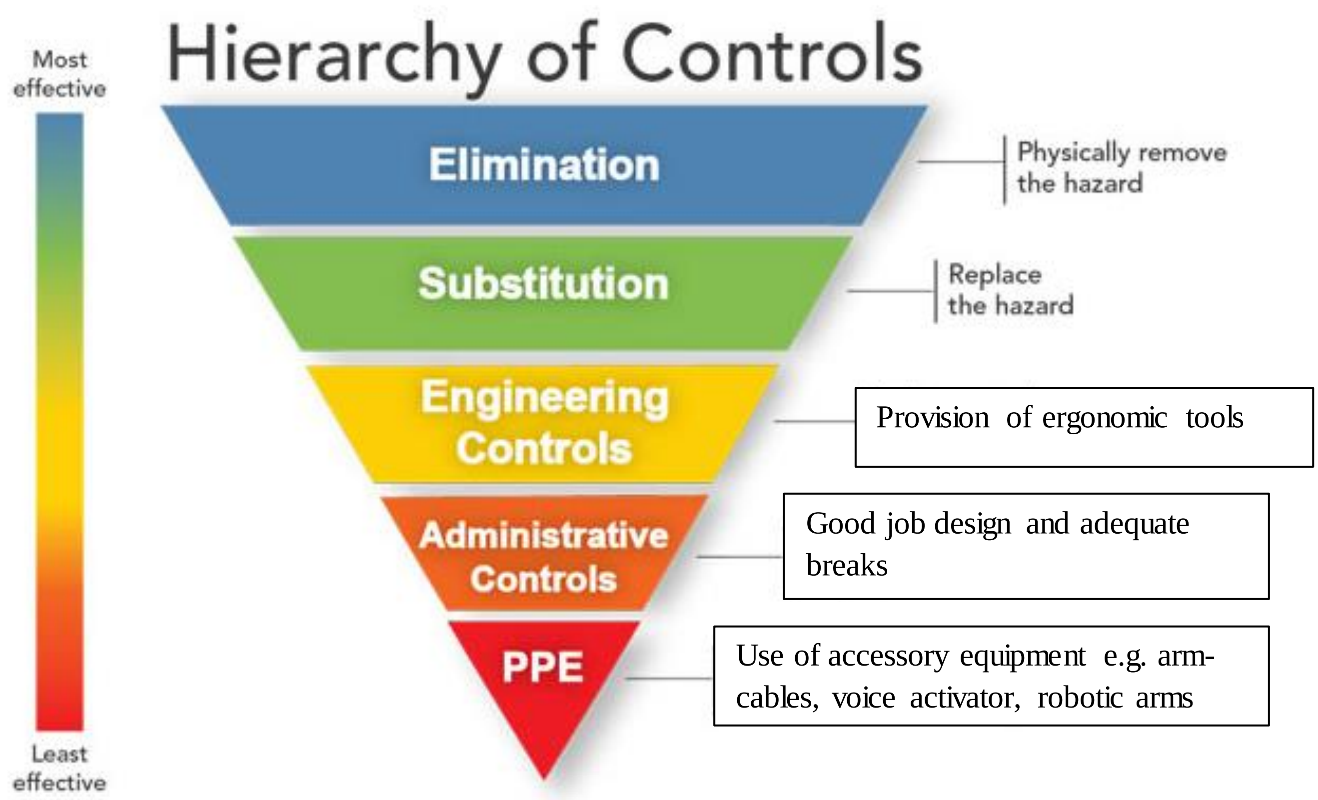


Figure 12 adapted from CDC, 2018.

Figure 13: A diagrammatic representation of the possible ergonomic interventions

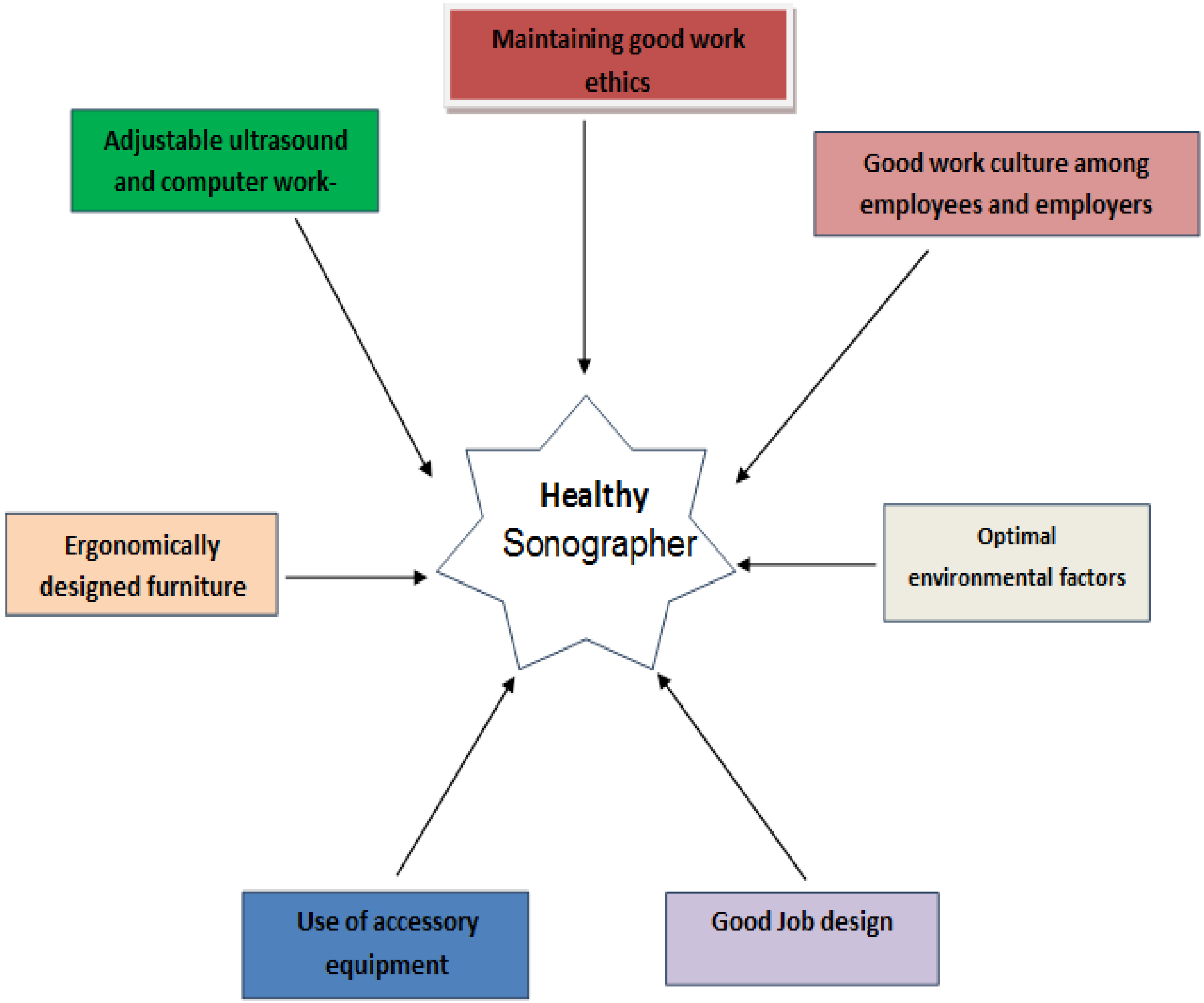


Figure 13 adapted from (Society of Radiographers (Great Britain), 2007) (page 17).

5.2.1 Adjustable ultrasound-system and computer workstation

The two systems should be effortlessly and fully adjustable in seating- or standing-position for the anthropometrics of the 5th to 95th percentile of the sonographers. The console system should be designed to have adequate space for legs and knees in a seated position and also designed in a way that examiners can come as close as possible to the patients, thereby avoiding overreaching and excessive abduction in the shoulder as outlined in **Figure 15** (Merton, 2017). The control panel should allow some degree of tilt for easy access to the control icons. The monitor should be adjustable and placed directly in front of the sonographers at arm-length and eye-level, with a sonographer-monitor distance between 20-40 inches approximately 45.7-76.2cm as highlighted in **Figure 14**.

The usage of the keyboard tray keeps the wrist in a neutral position, and placing the mouse close to the keyboard prevents over-reaching as presented in **Figure 16** (Alshuwaer and Gilman, 2019; Baker and Coffin, 2013; Chandler, 2019). The transducers should be light-weighted allowing for palmar-grip and neutral positioning of the wrist, as pinch-grip is associated with an increased muscle strain. It requires up to 5 times more muscle and tendon force to hold an object with pinch-grip as with palmar-grip, as shown in **Figures 6 and 29**. The transducer should also be suitable for the 5th-95th percentile of the working population's hand size (Baker and Coffin, 2013; Merton, 2017).

Providing appropriate space to support the feet during the examination and at their computer workstation is also crucial in maintaining neutral posture during scanning and documentation of results, as shown in **Figures 15,16, and 20** (Alshuwaer and Gilman, 2019). Feng et al., 2016 also suggested that the equipment- design should consider more female characteristics as they make up more of the working sonographers, as presented in **Table 8** in the chapter of results. Manufacturers should modify the transducer-designs to produce good quality images among obese-population without the sonographers holding them with high-grip hand pressure. The ultrasound equipment should be generally designed to encourage a better hand-tool-interface between the sonographers and the machines (Harrison and Harris, 2015; Hill, III et al., 2009).

Figure 14: Monitor positioned at eye level and Figure 15: A workstation with foot rest.

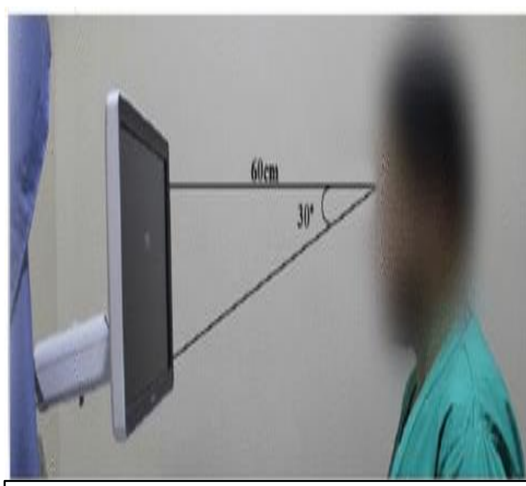


Figure 14 and 15 adapted from Alshuwaer and Gilman (2019).

Figure 16: An ideal computer workstation of a sonographer

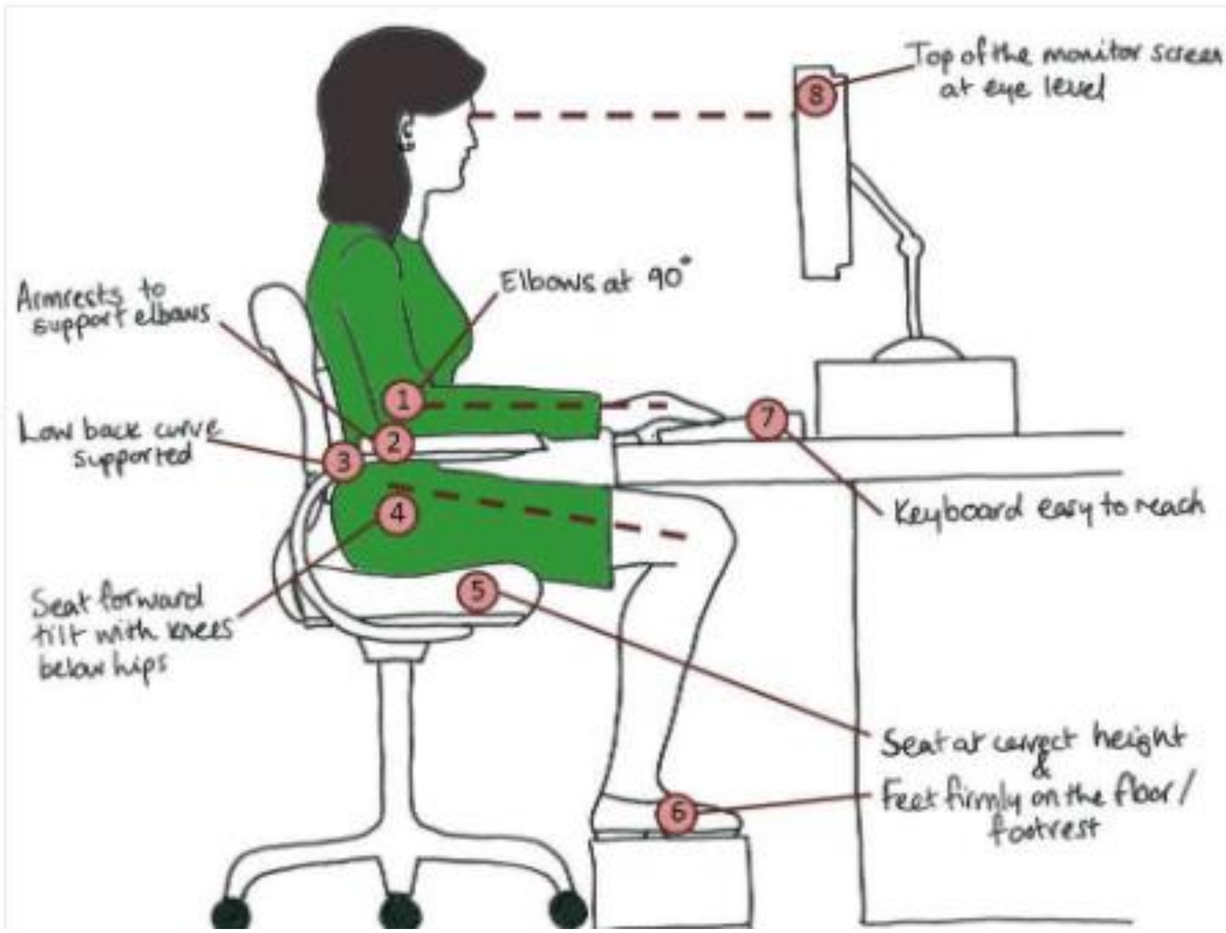


Figure from Chandler, 2009.

5.2.2 Ergonomically designed furniture

The examination tables and chairs should be completely adjustable for the sonographers' population between 5^{th}-95^{th} percentiles; the chairs' control buttons should be electronic and accessible from a seated position for easy use. The scanning chairs should have lumbar support, adjustable footrest without an armrest to reduce the distance between the sonographers and the clients, as represented in **Figure 20**. These above named features of the scanning chair support the back, legs, and feet of the sonographers, promoting an upright posture during scanning; with the shoulder abduction and the elbow joint maintained at $< 30^0$ and 90^0, respectively. With the abduction in the shoulder < 30^0, the upper-limb fatigue time is tripled compared to a shoulder abduction angle of 60^0. The back should be supported and the support should allow some degree of bending between 10^0 and 20^0, as shown in **Figures 19 and 20**. The examination table should also be compatible with other patient lifting devices for unassisted patients' transfer and suitable for different ultrasound-examinations, as presented in **Figures 17 and 18**. (Alshuwaer and Gilman, 2019; Brown, 2003; Merton, 2017; van der Beek et al., 2017).

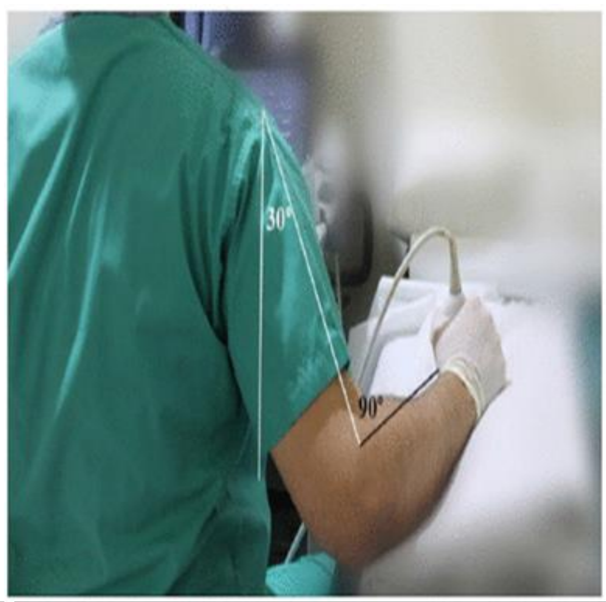
Figure 17: Fully adjustable examination table

Figure 18: Unassisted transfer of patient and Figure 19: Back support

An unassisted transfer of patient is possible because of a height-adjustable

Sonographer should sit with the back supported and allowing 20◦ of tilting.

Figure 20: Adjustable chair with backsupport and Figure 21: Optimal joint positioning



A scanning chair with a footrest and the operator sitted at an appropriate distance from the patient and the equipment

Optimal positioning during scanning: shoulder abduction $\leq 30^0$ and elbow flexion $\leq 90^0$

Figure 17, 18, 19, 20, and 21 adapted from Alshuwaer and Gilman, 2019; and Baker and Coffin, 2013.

5.2.3 Usage of accessory equipment{cable-brace, wrist brace, elbow-support, voice-activators, anti-fatigue mats}

A cable-brace will offset the transducer's weight, reducing the shoulder muscles' exertion and the torque on the hand while holding the transducer. The wrist-brace prevents the wrist's excessive flexion and extension during scanning, thereby maintaining the wrist in a neutral position as highlighted in **Figures 22 and 23** (Alshuwaer and Gilman, 2019; Bagley et al., 2017; Themes, 2016). The elbow support also reduces the level of abduction in the shoulder joint and reduces the muscles' firing activity by 78%, as shown in Figure 25 (Brown, 2003). Although the cost price for the cable-brace is less than $20, only 2% of the sample population in Bagley (2017) had access to it, despite the high level of access to ergonomic equipment and furniture in this study population. This review inferred that the sonographers and employers delibrately ignore the use of accessories tools. These tools are also crucial in maintaining the joint in a neutral position, thereby reducing the risk of WRMSDs (Bagley et al., 2017).

The use of a voice activator reduces overreaching in the non-scanning hand. Both hands are available to hold the transducer or alternating the scanning hand during prolonged examination, thereby reducing the pressure caused by holding the transducer and also reduces the risk of twisting the trunk when reaching out to the control panel (Bravo et al., 2005; Gremark Simonsen et al., 2020). Holding of a transducer with alternating hand or with the two-hands was found protective against WRMSDs. Scanning ambidextrously gives break to one side of the body; so training the sonographers on the ambidextrous scanning method is another possibility of reducing the risk of WRMSDs (Gremark Simonsen et al., 2017). The use of antifatigue mats should also be encouraged during examinations requiring prolonged standing, e.g., endovaginal scanning as seen in **Figure 28** (Bagley et al., 2017; McDonald and Salisbury, 2019; Merton, 2017).

Figure 22: Picture of a cable-brace and Figure 23: Picture of a wrist brace

Figure 24: Picture of a voice-activator and Figure 25: Picture of a elbow-supporting device

The use of voice activator eliminates the use of the control panel.

The elbow-supporting device maintaining the elbow flexion at 90^0

Figure 23 adapted from Themes, 2016; Figure 24 and 25 adapted from Bravo et al., 2005 and Baker and Coffin. 2013.

5.2.4 High level of awareness on the benefits of Ergonomics and good safety culture among employers and employees.

According to the occupational safety and health act, the employer is responsible for maintaining a hazard-free work environment through administrative and ergonomic measures. Still, the safety-culture has to be shared between the employer and the employees (Murphey, 2017), as highlighted in **Figure 26**. The employer should ensure organisation of annual education on the risk factors of WRMSDs and the techniques to protect the employees from these injuries. The sonographers should understand their involvement in the prevention of WRMSDs by becoming aware of the behaviour that led to their pain and be ready to make the necessary changes to avoid those behaviours (Baker and Coffin, 2013; Merton, 2017; Middlesworth M., 2018). The employer should provide job coaching at the workplace through sonographers' educators who are occupational health specialist in the workplace problem of sonographers. The employment of sonographers' educators at the workplace encourages excellent working habits. It also serves as a mechanism for preventing WRMSDs and also as an early intervention tool among sonographers with WRMSDs (Evans et al., 2009; Friesen et al., 2006; Muir et al., 2004).

Generally, ergonomic training and safer scanning practices should be incorporated at the initial training, especially among young sonographers with increased attention on the shoulder's position during scanning (Hill, III et al., 2009; Irurhe et al., 2013). According to Wareluk and Jakubowski (2017) about 13% of the sample population had received education on ergonomics, but only 7% applied the information in their daily work activities. There is a low level of awareness of safe work practices among sonographers; therefore, information regarding safe ultrasound practices and injury prevention measures should be made compulsory in all training courses and workplaces (AL-Rammah et al., 2017; Wareluk and Jakubowski, 2017). The sonographers should also be aware of applying correct and proper mechanism in moving patients and ultrasound machines. They should keep their forearm and wrist straight when moving equipment, as most sonographers found moving patients and machines while performing mobile scans very aggravating (AL-Rammah et al., 2017; Pike et al., 1997; Russo et al., 2002).

Lack of awareness on safe work practices among sonographers and employers would lead to WRMSDs, regardless of the level of access to ergonomically modified ultrasound or computer workstations. According to HBM, attending courses would increase their awareness about their susceptibility to WRMSDs, the severity of WRMSDs, and the benefits of using the provided ergonomic tools; thereby increasing the chances of the sonographers modifying their behaviour as outlined in the formula developed by HBM:

the Probability of behaviour modification = Susceptibility+ severity+ {Benefits-Barriers} (Peterson et al., 2017).

Figure 26: Workplace safety

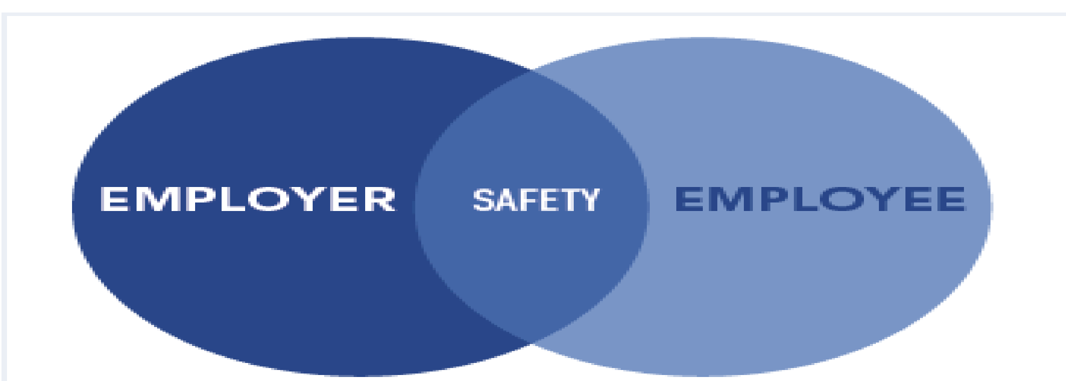


Figure adapted from Murphey, 2017.

5.2.5 Maintaining good working ethics by the sonographers (maintaining optimal scanning posture and engaging in physical activity).

Although the administrator has to make the ergonomic equipment available, the provided tools' usage lies solely with the sonographers. Bagley (2007) outlined about 75% of the sonographers had access to the ergonomic-adjusted equipment, but only 30-45% of them adjusted their stations before scanning. Changing the sonographers' mindset from seeing the use of the available ergonomic tools as an option to seeing it as an obligation is an essential factor in reducing the prevalence of WRMSDs. Since adjusting the station to fit the size of the sonographer is vital in lowering awkward working posture; it would be crucial in this regards designing health promotion programmes for the target population (Bagley et al., 2017; Hill, III et al., 2009; Magnavita et al., 1999; Scholl and Salisbury, 2017). A study on sonographers without WRMSDs despite long praticing years reported that they always took time to adjust their workstation before scanning. This study shows that adhering to the best work practices is the primary key to preventing WRMSDs (Gibbs and Edwards, 2012).

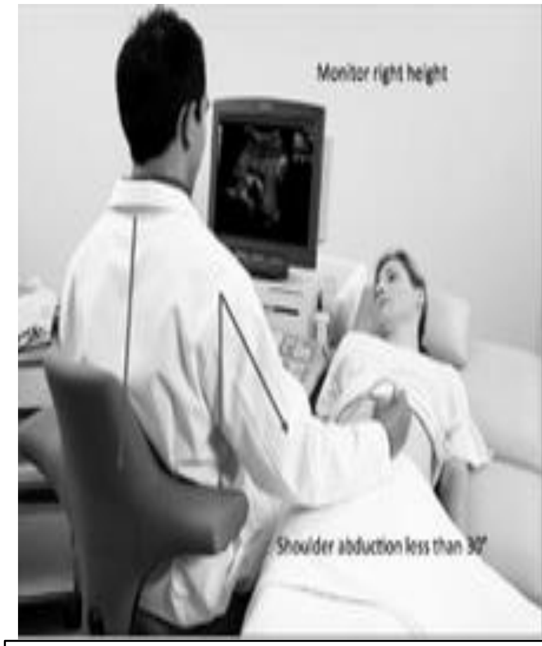
The universally recommended sitting posture among sonographers by Craig et al.,1985 should be reviewed, as the prevalence of WRMSDs continues to increase despite maintaining a sitting posture while scanning. Some examinations, e.g., transvaginal scannings as presented in **Figure 28** are easier performed standing. Therefore, attention should be shifted to maintaining a neutral and appropriate posture either in sitting or standing position. Which is defined as a seated or standing posture balanced around the user's center of gravity. The scanning arm should be supported with the sonographers positioned as close as possible to the patient and the control panel, thus reducing excessive abduction and excessive extension in the scanning and the non-scanning arm, respectively. The monitor should be adjusted to allow a neck flexion of about 20^0 and placed directly at the eye-level of the operators. The sonographers should also hold the transducers with the palm and the wrist maintained in a neutral position allowing some degree of wrist flexion and extension $< 15^0$ as shown in **Figures 27,28 and 29** (Baker and Coffin, 2013; Friesen et al., 2006; Harrison and Harris, 2015; Merton, 2017; Scholl and Salisbury, 2017). As most of the sonographers are unaware of their awkward position during scanning, employing the Alexander technique is a useful and effective method against adapting awkward posture and the usage of high-grip pressure when scanning. It is a neuromuscular re-education that enhances the relationship between thoughts and muscular activity, helping sonographers be more conscious of their body posture and reducing the muscles' physical tension (Gibbs and Young, 2008).

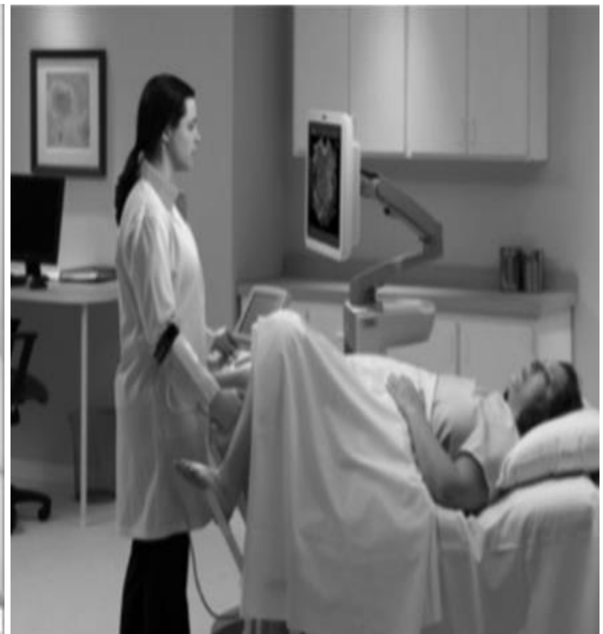
Engaging in physical exercises is one of the proactive early intervention and belongs to the essential pillars of preventing WRMSDs.Optimal level of physical activities improves muscular capacity, efficiency, and strength, thereby enhancing physical balance (McDonald and Salisbury, 2019; Middlesworth M., 2018). Sedentary lifestyles increase the risk of spine degeneration and the chances of becoming overweight. While performing physical activities, especially upper-body exercises was associated negatively with the development of WRMSDs and decreases the odds of WRMSDs by 30% (Magnavita et al., 1999; Russo et al., 2002; Smith et al., 1997; Zhang and Huang, 2017). Due to persistent abduction of the shoulder, a warm-up exercise of the shoulder muscles before scanning improves these muscle groups' flexibility. This also increases the oxygen and blood supply, preventing the muscles from becoming sored, stiffened, or injured. A randomized control trial on 11 sonographers showed that sonographers who perform stretch-exercises during their leisure time reported a lower frequency of MSDs despite performing twice as many echocardiographic examinations than those in the control group. Specific exercises are more beneficial than the others, e.g. yoga and pilates were associated with strengthening the muscles used in everyday activities and reducing MSDs occurrence (Christenssen, 2001; McDonald and Salisbury, 2019).

5.2.6 Optimal environmental factors {examination room size, lighting, the flooring of the room, the arrangement of equipment and items, temperature}

The examination room size should be at least 150 square feet to accommodate all the equipment needed for scanning and providing adequate space for easy maneuverability of the equipment around all sides of the examination table. The room should also have enough space to accommodate a wash hand-basin for hand hygiene compliance. Items such as gel bottles and recording devices should be placed at a position for easy reach of the examiners, optimally at arm's length, thereby avoiding unnecessary twisting or bending of the trunk and overreaching. The lighting should be placed indirectly and controlled using a rheostat to reduce interference with viewing on the monitor, reducing the risk of eyestrains when scanning. Eye-strain is associated with a 34% increase in the prevalence of neck and shoulder pain. Maintaining the room at optimal temperature and humidity and designing the floor to allow easy maneuverability of the equipment is crucial in the workplace design (Baker and Coffin, 2013; Gremark Simonsen et al., 2017; Merton, 2017; van der Beek et al., 2017).

Figure 27: Optimal sitting posture and Figure 28: Optimal standing posture





The monitor at the eyelevel, the trunk is not twisted and the shoulder abduction < 30^0 .	The sonographer is close to the patient and machine to avoid overreaching in the arms.

Figure 27 and 28 adapted from Baker and Coffin, 2013.

Figure 29: optimal wrist position and palmar-grip when holding a transducer

Figure adapted from Alshuwaer and Gilman, 2019.

5.2.7 Good Job design

Good job design is an administrative tool to reduce the high job demands among workers by adjusting the facility's procedures to minimize risk factors (Feng et al., 2016; Themes, 2016). Increasing workload and lack of breaks between working hours are associated with poor ergonomic practices among sonographers as they don't have time to adjust the equipment (Scholl and Salisbury, 2017).

The administrator should employ an adequate number of staffs based on the facility's workload and limit the daily shift duration of work to 8 hours per sonographer, thus reducing the work demands and preventing stress from the prolonged and unplanned examinations. The number of scans performed should be reduced so that each sonographer performs on the average 100 scans/month. The older sonographers should have lesser workloads than the younger due to the increased risk of WRMSDs with ageing (Alshuwaer and Gilman, 2019; Gremark Simonsen et al., 2020; Merton, 2017; Muir et al., 2004; Okeji et al., 2015). Employing organisational efforts in structuring the scanning list allows a fair distribution of scanning types in terms of difficulty and length of scans, with the scanning time not more than 25 minutes per examination (Alshuwaer and Gilman, 2019; Pallotta and Roberts, 2017). Provision of written protocols informing the referrals about the limitation of studies with obese patients and critically-ill-patient would ease the sonographers' pressure of making accurate diagnoses at the expense of their health. Scanning of obese patients and critically–ill patients are barriers to correctly employing ergonomic measures, leading to excessive pressure, overexertion in the upper extremity, and adaptation of an unbalanced posture by the sonographers (Harrison and Harris, 2015; Scholl and Salisbury, 2017; Society of Radiographers (Great Britain), 2007, page 21).

A study on sonographers without WRMSDs showed that they had high level job satisfaction and job control; therefore inolving the sonographers in planning their work load can improve their morale, general sense of wellbeing, level of job control and also their level of job satisfaction (Harrison and Harris, 2015; Scholl and Salisbury, 2017; Society of Radiographers (Great Britain), 2007, page 21). A good work-break-cycle with an adequate recovery phase is essential for performing sonography without injuries (Zhang and Huang, 2017). The administrator should incorporate a mandatory meal break and planned micro-breaks of 5-10 minutes per hour in the work routine to allow for muscle stretching and muscle recovery. The sonographers should also use their break wisely by engaging in walking activities to increase the blood flow to the joints (Pallotta and Roberts, 2017; Society of Radiographers (Great Britain), 2007 page 20).

The employer should provide transparent procedures for prompt reporting of WRMSDs without the employees being discriminated against and they should also provide adequate information to the sonographers about the reporting procedures. Changing the culture of self-management of WRMSDs among sonographers, early reporting and documentation of their injuries, and seeking competent medical treatment when injured should be prioritized among sonographers.As such behaviors allow early development of appropriate interventions from the administrator and analysis of the identified causative factors (Bagley et al., 2017; Evans et al., 2009; Merton, 2017; Pallotta and Roberts, 2017; Themes, 2016).

5.3 Limitation of the study

- The language restriction to English might have led to some level of bias in the choice of articles in this systematic review.
- Due to the limited number of articles related to the topic, the review used an extended time frame between 1990-2020.
- This review included only three databases PubMed, Scopus, and Cochrane-library. This was due to my school library's limited access to databases. Accessing more databases from other universities' libraries was impossible due to the COVID-19 pandemic restrictions.
- Due to the non-availability of the full text, the author excluded four articles from the 45 papers selected for this review. The authors of these items were contacted through e-mail, only Magnivita et al.1999 responded at the point of collation of the results. The excluded articles could also have contained relevant findings, which might have influenced the results of this review.
- This systematic review is only a qualitative synthesis of the included studies' results without calculating the measure of consistency between the articles as in a meta-analysis.
- The author covered the available ergonomic-interventions in the chapter of discussion, but all the available articles on the subject matter were not included, so a systematic

review on the available ergonomic interventions to reduce the prevalence of WRMSDs among sonographers would benefit from further research.

5.4 Conclusions and recommendation

5.4.1 Conclusion

This systematic review supports the hypothesis that the usage of ultrasound machines is associated with WRMSDs among sonographers. The prevalence rate of WRMSDs has remained high over the last three decades despite the advancement in the machines' technology. The possible reasons are the increasing workload, high demand in sonographic examination, non-availability or non-usage of the ergonomic-equipment, and the aging working population. The culture of self-management among sonographers and the low level of reporting of WRMSDs to the administrator might have also contributed to the rising prevalence. Since most of the employers are not aware of the disease's actual burden, limited risk-assessments and interventions are planned to curbing the risk factors in the workplace.

The sustained injuries from the suboptimal work enviroment of a sonographer is detrimental to the sonographers in terms of limitation of their work and leisure activities, undergoing medical treatments and surgeries, to the extent of them ending their careers abruptly as a result of pain from WRMSDs.The identified predisposing factors associated with WRMSDs should form the basis for the development of the ergonomic interventions, helping to curb the growing burden of WRMSDs among sonographers.

5.4.2 Recommendations

- For identifying the possible barriers to an optimal work environment; focus-group discussion including the sonographers, physical and occupational therapist, employers and manufacturers or an opened-ended questionnaire survey should be organized (Evans et al., 2009; Scholl and Salisbury, 2017).
- Researchers should carry out more randomized controlled trials on the possible ergonomic solutions with appropriate statistical power analysis and larger survey groups to allow generalization of the interventions in the profession.
- Limiting subsequent studies on WRMSDs to using a standardized questionnaire and not using different self-developed questionnaires would allow for easy comparison between

studies. HBT-Questionnaire would be recommended for further studies because it also assesses the psychosocial factors related to WRMSDs compared to the Nordic questionnaire, which addresses only the severity and the distribution of pains in the body region (Evans et al., 2009; Hill, III et al., 2009).

- The author would recommend further research on the issue of "presenteeism" among sonographers. "Presenteeism" measures the impact on the productivity of the symptomatic workers, who remained at work despite sustaining WRMSDs. The studies should analyse the time spent on scanning or the number of scans performed per day by the injured sonographers compared to the healthy ones (Russo et al., 2002).
- Job rotation is considered a useful administrative tool in reducing the incidence of WRMSD. This systemic review results proved otherwise, as performing different scanning examinations was associated with an increased risk of developing WRMSDs among sonographers. Studies should be focused on this subject area to prove the efficacy of job rotation among sonographers.
- The low reporting level of WRMSDs among sonographers is also a significant finding in this review. Conducting qualitative studies such as focused group discussion or open-ended questionnaire study, including the sonographers, insurance facilities and the employee, would help identify further factors related to this finding and provide appropriate intervention techniques.

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APPENDIX

Table of Study Selection

Table 12: Table of assessment of articles {included and excluded articles}.

	Title	Author	Included or Excluded	Reason for Exclusion
1	Neck and Upper extremity pain in sonographers- association with occupational factors.	Gremark Simonsen et al., 2017	Included	
2	The prevalence of WMSDs among Sonographers.	Al-Rammah et al., 2017	Included	
3	Cross-sectional association between occupational factors and musculoskeletal pain in women teachers, nurses, and sonographers.	Arvidsson et al., 2016	Included	
4	Work-related Stress, MSDs complaints, and stress-symptoms among radiographers in northern part of Jordan.	Alhasan et al., 2014	Excluded	The articles focused on only radiographers performing X-rays Examination.
5	Society of interventional Radiology: occupational back and neck pain and the interventional radiologist.	Dixon et al., 2017	Excluded	The article is not a survey but a report.
6	Carpal tunnel syndrome and cubital-tunnel syndrome- work-related MSDs among 4 Radiographers.	Ruess et al., 2003	Excluded	The paper is a case report.
7	Characteristics and consequences of WRMSP with peer employees among cardiac sonographers.	Barros-Gomes et al., 2019	Included	
8	The prevalence of WRMSDs among Sonographers in China: a result from a national web-based survey.	Zhang and Huang, 2017	Included	
9	Anthropometric measurements, job strain, prevalence of MSDs in female sonographers.	Hill III et al., 2009	Included	
10	The prevalence of and risk factors associated with MSD among sonographers in central china.	Feng et al., 2016	Included	

Table 12 {continuation}: Table of assessment of articles {included and excluded articles}.

	Title	Author	Included or Excluded	Reason for Exclusion
11	Evaluation of MSDs among Physicians performing ultrasound.	Wareluk and Jakubowski, 2017	Included	
12	Industrial physicians and orthopedists taking care of sonographers with WMSDs.	Nakajima, 2016	Excluded	The full-article is not available.
13	The prevalence of carpal tunnel syndrome and work-related musculoskeletal problems in cardiac sonographers.	Vanderpool et al., 1993	included	
14	An analysis of occupational factors related to shoulder discomfort in diagnostic medical sonographers and vascular technologists.	Roll et al., 2012	Included	
15	Survey of UK sonographers on the prevention of work-related MSDs.	Bolton and Cox, 2015	Excluded	The Paper focused on students as the study population.
16	Musculoskeletal symptoms among radiologists in Saudi-Arabia- A multi-center cross-sectional study.	Al-Shammari et al., 2019	Excluded	The articles focused on only radiographers performing X-rays Examination.
17	Transducer user syndrome: an occupational hazard of the ultra-sonographers.	Schoenfeld et al., 1999	Included	
18	The prevalence of musculoskeletal symptoms among the British Columbia sonographers.	Russo et al., 2002	Included	
19	The prevalence and causes of MSI among sonographers.	Morten und Delf, 2008	Excluded	The article is a literature review but lacked a well-documented search terms and methodology.
20	Factors that contribute to wrist-hand-finger discomfort in diagnostic medical sonographers and vascular technologists.	Evans et al., 2010	Included	
21	Work-related MSD in sonography and the Alexander Technique.	Gibbs and Young, 2008	Excluded	The paper focused on students in training and not on working-sonographers.

Table 12 {continuation}: Table of assessment of articles {included and excluded articles}

	Title	Author	Included or Excluded	Reason for Exclusion
22	Importance of sonographers reporting Work-related musculoskeletal injury: a qualitative view.	David, 2016	Excluded	The paper focused on sonographers already with injuries; neither the prevalence nor risk factors were assessed.
23	Work-related MSDs in Sonography.	Murphey, 2017	Excluded	The paper was a review by the society of diagnostic medical radiographers.
24	Sonographer scanning practices and musculoskeletal injury: Evaluation of an occupational health issue using the Health-Belief Model.	Peterson et al., 2017	Excluded	The paper is an interventional study; it examines the effectiveness of the model among sonographers with injuries.
25	On the job-pain and injury as related to adaptive ergonomic equipment s in the sonographers' workplace and areas.	Bagley et al., 2017	Included	
26	Work-related MSDs in ultrasound: can you reduce risk.	Harrison and Harris, 2015	Excluded	The report discussed the predisposing factors, but it was not a survey.
27	Relationship of MSDs and perceived workload among hospital workers.	Ryu et al., 2012	Excluded	The paper assessed all the hospital workers, but the author did not outline the worker's occupations.
28	Musculoskeletal injuries among ultrasound sonographers in rural Manitoba: A study of workplace ergonomics.	Friesen et al., 2006	Included	
29	Musculoskeletal pain and injury in sonographers: causes and solutions.	Pallotta and Roberts, 2017	Included	
30	Physical activity, Exercise, and Musculoskeletal Disorders in Sonographers.	McDonald and Salisbury, 2019	Excluded	The article focused only on the association between WRMSDs and the level of physical activities.

Table 12 {continuation}: Table of assessment of articles {included and excluded articles}

	Title	Author	Included or Excluded	Reason for Exclusion
31	Work-Related Musculoskeletal Complaints in Sonologists.	Magnavita et al., 1999	Included	
32	The prevalence of musculoskeletal disorders among diagnostic medical sonographers.	Pike et al., 1997	Included	
33	Musculoskeletal symptomatology and repetitive strain injury in diagnostic medical sonographers: A pilot study in Washington and Oregon.	Necas,1996	Included	
34	Work-related MSD among registered diagnostic medical sonographers and vascular technologists.	Evans et al., 2009	Included	
35	The nature, cause, and extent of occupational musculoskeletal injuries among sonographers: Recommendations for treatment and prevention.	Muir et al., 2004	Included	
36	Patterns of Work-related MSDs among practicing sonographers in Enugu-State, Nigeria.	Okeji et al., 2015	Included	
37	Musculoskeletal pain in cardiac ultrasonographers: Results of a random survey.	Smith et al., 1997	Included	
38	Work-related musculoskeletal discomforts in ultrasonologists: Prevalence and risk factors.	Irurhe et al., 2013	Included	
39	Work-related MSDs in sonographers.	Brown, 2003	Excluded	The paper was a report on the prevalence of WRMSDs and the suggested interventions to the problem.

Table 12 {continuation}: Table of assessment of articles {included and excluded articles}

	Title	Author	Included or Excluded	Reason for Exclusion
40	Neck and upper extremity pain in sonographers: A longitudinal study.	Gremark Simsonsen et al., 2020	Included	
41	Work-related musculoskeletal disorders in veterinary echocardiographers: A cross-sectional study on prevalence and risk factors.	Macdonald and King, 2014	Excluded	The study population was the veterinary doctors. Comparing this result to human sonographers would be inappropriate because of the differences in the equipment and the body size of animals and human beings.
42	A Holistic Evaluation of Risk Factors for Work-Related Musculoskeletal Distress Among Asymptomatic Sonographers Performing Neurosonology: A Pilot Study.	Evans et al., 2010	Excluded	The author did not state the outcome of interest.
43	[An investigation of work-related musculoskeletal disorders among sonographers in a province of China and related influencing factors].	Deng et al., 2018	Excluded	The Full-article is not available.
44	Evaluation of work-related musculoskeletal disorders among sonographers in general hospitals in Guangdong province, China.	Zhang et al., 2019	Excluded	The Full-article is not available.
45	[Frequency of musculoskeletal symptoms in diagnostic medical sonographers. Results of a pilot survey].	Mirk et al., 1999	Excluded	The Full-article is not available.

Table of results {expanded version}

Table 13 is an expanded version of the individual studies results; it includes presenting the specific risk factors and the percentage of the bodily distribution of the injuries among sonographers. The consequences of WRMSDs are also stated in more detail, and other significant findings are also included.

Table 13: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
Vanderpool et al., 1993	PP of CTS: 57% CP of CTS: 63% CP of other WRMSI: 86%		Pushing and twisting of the wrist. High hand-grip. Pressure. Twisted postures. Female sonographers.	31% -had received treatment. 17%-missed work. 4% received workers' compensation. 3% have been diagnosed with CTS.	CTS High symptoms-6%. Low-Symptoms-57%. WRMSI High symptoms-25%. Low symptoms-55%. Standing and long examination duration correlated to increased symptoms but did not achieve significance.
Necas, 1996	CP: 66%.	Neck: 76% Shoulder: 66% Wrist: 61% Upper back: 56% Low back: 46% Finger: 40% Elbow: 33% Foot: 27%	Female sonographers. High work habit score. Performing > 40 scans per week. Having < three; 10-minutes break. High occupational stress level.	65% continued to scan in pain. 43% still undergoing Treatments. 22% received treatment, but unsuccessful. 30% resorted to working part-time. 4% left the profession.	15% were diagnosed with RSI. Weight, number of working years, working hours per week, and the number of scans per week showed an increasing tendency for symptoms but did not achieve significance. Prevalence of wrist-ganglion among symptomatic- 13%.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	**Prevalence of WRMSDs**	**Area of injury**	**Identified Risk factors**	**Consequences of WRMSDs**	**Other relevant findings**
Pike et al., 1997	CP: 81% PP: 91%	Neck: 74% Shoulder: 74% Low back: 69% Upper back: 68% Wrist: 65% Hand & Finger: 61% Upper arm: 48% Fore arm: 40% Knee: 25%	Applying high-pressure on the transducer Shoulder abduction. Sustained twisting and bending of the neck and trunk. Transporting of patients. Standing while scanning.	84%- continued to scan in pain. 60% had pain while performing home activities. 52% saw a medical professional and received treatment. 22% reduced the ability to perform their work activities. 10% took sick leave.	Most sonographers have a positive perception of their work environment. The most common diagnoses were Tendinitis, musculoskeletal injury, Tension neck syndrome, Carpal tunnel syndrome, and other diagnose.
Smith et al., 1997	CP: 80%		Decreasing height. Increasing number of scans and scanning time. Manually propelled machine.	47% sought physical therapy or medical treatment.	7% reported the use of a self-propelled machine or motorized equipment.
Magnavita et al., 1999	CP: 80% PP:61.4%	Neck –Back: 54.3% Hand- wrist: 7.1%	Increasing age, duration of employment, and scanning hours. No physical activity. Uncomfortable transducer and non-adjustable chairs. Awkward posture.	25% received treatment. 10.3% temporarily stopped their work.	45.2% placed the viewing screen at the eye-level. 59.7% used adjustable chairs. 85.9% felt the transducer-design were uncomfortable. 45% moved the patients. 68% had cable supporting devices.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
Schoenfeld et al., 1999	PP of CT-Symptoms: 57% CP of CT-Symptoms: 65% CP of WRMSP: 86%		Twisting and pushing of the wrist joint. High-grip pressure. Twisted body posture. Standing while scanning. Female sonographers.	34% have received treatment. 12% have missed work because of their symptoms.	4.5% have been diagnosed with CTS. 2.3% diagnosed with carpal instability. All the survey population worked full-time. Severe symptoms were associated with performing more scans and increased scanning time.
Russo et al., 2002	CP: 91% PP: 80%	Shoulder: 84% Neck: 83% Upper back: 77% Upper arm: 77% Wrist: 61% Low back: 58% Hand & Finger: 56% Forearm: 40%	Increasing scanning time. Shared workstations. Control panel at an uncomfortable height. Work factors such as shoulder abduction, high pressure on the transducer, sustained twisting of the neck and trunk, lifting of patients, performing mobile scans, and prolonged sitting.	68% continued to scan in pain. 65% consulted physicians. 56% had pain during home and recreational activities. 13% had to change their work pattern 7% worked fewer hours. 16% had to redesign their work station. 5% were absent from work.	HPD: 49%; LPD: 51%. 5% had a vertically adjustable control panel. 9% had adjustable footrests. 53% support their arm or hands. The most common diagnosis is Tendinitis (53%), musculoskeletal injury (24%), and other diagnoses. About 60% used no employment benefits. The mean-score for the work environment >3.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
Muir et al., 2004	CP: 91%	Shoulder: 78% Neck: 71% Upper back: 61% Hand & Finger: 55% Wrist: 52% Fore arm: 50% Low & mid-back: 40% Upper arm: 34% Knee: 7%	Increased workload and fewer breaks. Poor equipment design. Excessive shoulder abduction. High hand-grip pressure. Sustained twisting of the neck and trunk. Performing on-line scans.	74% and 77% had difficulties performing house chores and daily activities, respectively. 67% saw physicians and received treatment. 40% had difficulties with their work responsibilities. 36% had a problem with sleeping. 36% had psychosocial ill-health.	The most common diagnoses were Fibromyalgia, myofascial pain, rotator cuff tendinitis, bursitis, and CTS. 60% had received ergonomic education in the last two years. Most workers are satisfied with their work environment.
Friesen et al., 2006		Neck: 81% Shoulder: 81% Upper back: 72% Wrist: 64% Lower back: 64% Hand & Finger: 64% Forearm: 57%	High hand-grip pressure with the wrist flexed and shoulder abducted. Use of outdated equipment. Scanning of obese patients. Performing > 10 scans per day. Long waiting lists of patients and reduced rest breaks.	75% reported the affectation of their daily activities. 55% sought treatment by health care professionals. 30% had initiated changes in their workplace. 18% took sick-leave.	Despite treatment and changes in the workplace, 64% continue to scan in pain.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
Evans et al., 2009	Career-prevalence: 90.4%	Shoulder: 78% Neck: 65.8% Wrist: 50% Upper back: 44% Hand & Finger: 44% Lower back: 33% Fore arm: 32% Upper arm: 27% Knee: 7% Middle back: 7%	Abduction of the arm. Twisting of the neck and the trunk.	48% had received diagnosis related to WRMSDs and treatments. 33% took some time off work. 24% changed their work.	57% did not report to their administrator. Sonographers tend to take more time off work and report their injuries with increasing age, years of experience, and part-time workers. 54% were shown various ergonomic adjustments. 90.4% had education on ergonomics. 80.8% had adjustable tables but had to be manually adjusted. 86% had adjustable chairs. 91% worked with PACS that cannot be adjusted.
Hill III et al., 2009	1-YP: 96%	Shoulder: 73% Lower back: 69% Wrist: 54% Neck: 50% Elbow: 27% Hip: 27% Knee: 23% Upper back: 15% Ankle/foot: 8%	Small physical size. Increasing Job strain score. Increasing the variability of studies and task rotation. Larger abdominal girth. Increasing period of standing.		Sonographers with higher grip-pressure have more symptoms but did not achieve significance.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
Evans et al., 2010	CP of wrist pain: 59%		High grip-pressure. Shoulder abduction. Sustained repetitive twisting of the neck and Performance of bedside scan. Nonadjustable PACS. Increasing years of experience.	76.4% used medicaments. 38% took sick leave. 20% used physical or occupational therapy. 16% had changed their jobs.	Shoulder pain was the most frequent comorbidity, with 75% of the population with wrist pain being affected. Only 46% reported the complaints to the administrator, with only 26% making a formal report. 62% did not take time off work.
Roll et al., 2012	CP of shoulder pain: 73%	Neck-71% Wrist: 50% Upper back: 48% Hand & Finger: 45% Elbow:33% Low back: 32% Arm: 31%	High transducer pressure. Sustained twisting of the neck. Bedside examination. Use of PACS. Working with multiple credentials.		Only 33% reported to their employer. 25% of people taking time-off from work used their vacation days instead of sick leave. 25% have adjustable workstations. Older workers tend to find work factors more aggravating than younger workers.
Irurhe et al., 2013	CP: 91%	Low back: 37% Neck: 20% Upper back: 11% Shoulder: 7%	Increasing body weight and year of service. Increasing scanning and repetitive motion.	92% received physical therapy and medical treatment. 31%- reduced the performance of work activities.	Older workers had more pain than younger ones.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
Okeji et al., 2015	CP: 88.9%	Shoulder: 81% Lower back: 63% Elbow: 44% Wrist: 33% Neck: 27% Hip: 27% Hand and finger:23% Upper back: 20% Knee: 7%	Repetitive twisting of the upper limb. Increased workload. Awkward postures. Poor workplace ergonomics. Scanning and writing reports at the same time. Draping of transducer cable around the neck while scanning. Increasing age and increasing years of experience.		
Arvidsson et al., 2016		Shoulder: 51% Neck: 44% Lower back: 29% Hands:25% Foot: 10%	High MEI. High PhYI. Low job control. High emotional demands. Dissatisfaction with the workstation. Increasing age. High BMI. Reduced rest breaks		The most common diagnoses in the neck and shoulder regions are cervicalgia and acromioclavicular disorder, respectively. The correlation between the measured and the reported workload is high. Sonographers had the lowest score for job control.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
Feng et al., 2016	1-YP : 98.3%	Neck: 94% Shoulder: 92% Lower back: 83% Wrist: 80% Upper back: 73% Elbow: 42%	Female gender. Low psychosocial score. Twisting of the wrist, the trunk, and the neck. Increasing scans. Scanning of obese clients. Insufficient breaks. Lack of adjustable chairs, tables, and work-stations.	58% visited doctors and received physiotherapies or massage therapies. 16% were absent from work. 10% changed their job-duty.	10% had adjustable chairs. 41% used non-adjustable chairs. 22% were aware of the need to adjust their workstations before scanning. 41% of the sonographers placed the monitor above the eye-level. 50% of the population stated that the equipment or transducer has to be improved.
Gremark Simonsen et al., 2017	1-YP of pain in the neck/shoulder-region and/or elbow/hand region: 65%	Neck/shoulder :58% Elbow/hand: 30%	Increasing BMI. High seniority in sonography. Dissatisfaction at the workstation. High MEI. High job demand. The non-availability of adjustable chairs and keyboards. Daily bedside examination. Increasing scanning time. Eye pain.		Considerable pain was defined as pain intensity of 7 and pain occurring seldom, or pain intensity of 3 and sometimes, or pain intensity of 2 with very often occurrence. More Sonographers reported pain in the "transducer shoulder and hand" than in the "computer shoulder and hand" (33 vs. 13) and (30 vs. 4), respectively. Holding of a transducer with alternating hand or with the two-hands was found protective.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
AlRammah et al., 2017	CP: 84%	Shoulder: 68% Back pain and other location: 54%	Increasing Years of experience. Scanning time > 7 hours/day and > 7 patients/day. Insufficient breaks. Moving the scanning machines or patients. Low level of Knowledge on ergonomics and good scanning practices.	93% reported the affectation of their daily activities. In 80% of cases is their ability to enjoy life affected. 75% stated that their work activities were affected. 46% took sick leave.	43% had the symptoms after one year. 89% felt performing ultrasound was stressful. 91% experience pain while scanning. 85% of the population felt rushed during the day. 65% did not know about ergonomics. 84% of the employers were not informed about ergonomics measures in the workplace.
Zhuang and Huang, 2017	1-YP: 99.3%	Neck: 95% Shoulder(right): 84% Lower back: 82% Wrist: 81% Upper back: 81% Elbow: 72% Shoulder(left): 66% Thigh: 40% Knee: 27% Ankle& Foot: 12%	Increasing age. Lack of regular physical activity. Lack of rest breaks. Awkward work-posture. Long scanning hours. Increasing number of patients scanned per day and increasing working years.		The prevalence of MSDs is significantly higher on the right side (scanning side) than the left side. Almost all respondents used the right hand to manipulate the transducer. <10% reported taking rest-breaks of > 5mins per hour. 80% adapted sitting posture during scanning, and 22% adopted alternating sitting and standing posture.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
Wareluk and Jakubowski, 2017	CP: 83%	Spine: 81% Shoulder: 49% Wrist: 44% Wrist: 44% Hand and Finger:22% Elbow: 17% Others: 4.2%		50% used physical therapy treatment. 49% received medication. 17% took time off work.	50% had no improvements in the symptoms after treatment. 13% had received education on ergonomics, but only 7% applied the information in their work activities. 68% never took breaks while working. About 73% described their pain as moderate and severe.
Bagley et al., 2017	CP: 53%	Shoulder: 57% Neck: 25% Wrist: 11% Back: 8%	The non-availability of swivel keyboards and separate moving monitors. The absence of large rooms to accommodate scanning equipment. Lack of ergonomic chairs.		No significance was found in the prevalence of WRMSDs among sonographers in different specialties. 21% of those with pain reported to their administrator. 93% had access to height-adjustable machines or separately detachable monitors. 95%have access to height-adjustable tables. 73% have access to a swivel keyboard. 2% have access to cable-brace.
Pallotta and Roberts, 2017	CP: 95.3%		Increasing number of working days. Poor ergonomics.		Only 61.2% reported pain to the manager.

Table 13 {continuation}: Expanded version of the results from the individual studies

Study	Prevalence of WRMSDs	Area of injury	Identified Risk factors	Consequences of WRMSDs	Other relevant findings
Barros-Gommes et al., 2019	1-YP: 86%	Neck: 58% Shoulder: 51% Low back: 44% Wrist/Hand: 42% Upperback:37% Elbow: 17%	Increasing years in current position. Low level of physical activities in leisure time.	Interference with the performance of daily activities, recreational and work-related activities. Work absenteeism. Changing of employments. Had work restriction.	The 12-month –prevalence of WRMSP among the peer employee, i.e., control-group is 46%. The occupation of a cardiac sonographer is associated with WRMSDs after adjustment for confounding factors (OR-8.2). CT-symptoms were four times frequent among the sonographers compared to the control group. The pain of the sonographers is reported more severe.
Gremark Simonsen et al.,2020	1-YP of neck pain: 61% at baseline 68% at follow-up For the elbow/hand pain: 30% at baseline 31% at follow-up		Bad visual condition. High level of dissatisfaction with the workstation. High MEI, high job demands, and high sensory demands. Lack of ergonomic adjustment for the equipment. Pain at the base-line.		

PRISMA checklist for this systematic review

Table 14: PRISMA checklist

Section/topic	Item No	Checklist item	Reported on page No
Title			
Title	1	Identify the report as a systematic review, meta-analysis, or both	Cover page
Abstract			
Structured summary	2	Provide a structured overview including, as applicable, background, objectives, data sources, study eligibility criteria, participants, interventions, study appraisal, and synthesis methods, results, limitations, conclusions, and implications of critical findings, systematic review registration number	iv
Introduction			
Rationale	3	Describe the rationale for the review in the context of what is already known	21
Objectives	4	Provide an explicit statement of questions being addressed regarding participants, interventions, comparisons, outcomes, and study design (PICOS)	23
Methods			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (such as web address), and, if available, provide registration information including registration number	NA
Eligibility criteria	6	Specify study characteristics (such as PICOS, length of follow-up) and report features (such as years considered, language, publication status) used as criteria for eligibility, giving the rationale	32
Information sources	7	Describe all information sources (such as databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched	33
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated	33
Study selection	9	State the process for selecting studies (that is, screening, eligibility, included in the systematic review, and, if applicable, included in the meta-analysis)	34
Data collection process	10	Describe the method of data extraction from reports (such as	35

Section/topic	Item No	Checklist item	Reported on page No
		piloted forms, independently, in duplicate) and any procedures for obtaining and confirming data from investigators	
Data items	11	List and define all variables for which data were sought (such as PICOS, funding sources) and any assumptions and simplifications made	31
Risk of bias in individual studies	12	Describe methods used for assessing the risk bias of individual studies (including specification of whether this was done at the study or outcome level) and how this information is to be used in any data synthesis	37
Summary measures	13	State the principal summary measures (such as risk ratio, the difference in means).	39
Synthesis of results (Qualitative)	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (such as I^2 statistic) for each meta-analysis	58
Risk of bias across studies	15	Specify any assessment of the risk of bias that may affect the cumulative evidence (such as publication bias, selective reporting within studies)	49
Additional analyses	16	Describe methods of further analyses (such as sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified	NA
Results			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram	41
Study characteristics	18	For each study, present attributes for which data were extracted (such as study size, PICOS, follow-up period) and provide the citations	43
Risk of bias within studies	19	Present data on the risk of bias of each survey and, if available, any outcome-level assessment (see item 12).	52
Results of individual studies	20	For all outcomes considered (benefits or harms), present for each study (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot	53
Synthesis of results (Qualitative)	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency	57

Section/topic	Item No	Checklist item	Reported on page No
Risk of bias across studies	22	Present results of any assessment of the risk of bias across studies (see item 15)	49
Additional analysis	23	Give results of other investigations, if done (such as sensitivity or subgroup analyses, meta-regression) (see item 16)	NA
Discussion			
Summary of evidence	24	Summarise the main findings, including the strength of evidence for each primary outcome; consider their relevance to crucial groups (such as health care providers, users, and policymakers)	62
Limitations	25	Discuss limitations at study and outcome level (such as the risk of bias), and review level (such as incomplete retrieval of identified research, reporting bias)	87
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research	88
Funding			
Funding	27	Describe sources of funding for the systematic review and other support (such as the supply of data) and the role of funders for the systematic review	89

Table adapted from Moher et al., 2009.