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Ergonomic analysis of postural and muscular loads to diagnostic sonographers

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Abstract

Musculoskeletal disorders are prevalent in diagnostic sonographers. This study quantifies the postural and muscular loads during ultrasound scanning. Video-based stop-motion postural analysis at 4 samples/minute for 24 full scans (527.5 minutes) by 11 sonographers showed sonographers spend 68% of scanning time with $>30^{o}$ shoulder abduction, 63% with $>30^{o}$ shoulder outward rotation, and 37% with the neck bent forward, laterally or twisted $>20^{o}$. The shoulder was observed to be unsupported, or static, for 73% of scanning time and this was significantly higher for carotid scans compared with abdominal, obstetrical or leg scans ($p<0.05$). Electromyography (EMG) was collected for seven scans performed by three sonographers on three shoulder muscles: Supraspinatus, infraspinatus, and trapezius; as well as for flexor carpi ulnaris. Static (0.10) amplitude probability distribution functions (APDFs) for all three shoulder muscles exceeded 3% MVC corresponding to a "medium" risk rating for shoulder–neck disorders. Mean forearm flexor EMG was 3.96 kg (SD 2.94), with occasional peak forces as high as 27.6 kg.

Relevance to industry

Diagnostic sonographers experience long durations in static shoulder abduction and outward rotation, with high peak and sustained grip forces. These risk factors are consistent with the high prevalence of neck and upper limb musculoskeletal disorders and symptoms reported by many sonographers.
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Keywords: Sonographers; Electromyography; Postural assessment; Risk assessment; Ergonomic analysis

1. Review of literature and objectives

1.1. Musculoskeletal pain and injuries among sonographers

Numerous studies have been conducted in the past decade documenting musculoskeletal injuries and symptoms among sonographers in the US (Smith et al., 1997; Pike et al., 1997), and Canada (Muir et al., 2004; Wihlidal and Kumar, 1997; Russo et al., 2002). Although the point prevalence for neck and upper limb pain for the general population is 13–22%, for sonographers it is between 63% and 91% (Brown and Baker, 2004). Wihlidal and Kumar (1997) reported three clusters of pain syndromes: Neck and interscapular pain; shoulder and upper arm, elbow and hand/wrist pain; and frontal headaches and visual discomforts. There is a considerable level of disability associated with these injuries: 80% of sonographers seek treatment for MSIs (Muir et al., 2004); 46% use physiotherapy or medication to control the pain (Smith et al., 1997); 16.7% missed work due to symptoms while a further 9.4% reduce their hours, 14.6% reduce their regular duties, 21.2% use sick leave, and 11.75% use vacation days (Wihlidal and Kumar, 1997). Although an estimated 20% of sonographers leave the profession due to persistent pain (Brown and Baker, 2004), only 12.9% of Canadian (Wihlidal and Kumar, 1997) and 4% of US (Vanderpool et al., 1993) sonographers reported the injuries to Workers' Compensation.

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1.2. Risk factors for neck/shoulder and upper limb injuries

Musculoskeletal symptoms or discomfort have been found to be correlated with a number of workplace factors: Long scan duration (Muir et al., 2004; Vanderpool et al., 1993), high scan frequency (Muir et al., 2004); a higher number of obstetrical scans (Muir et al., 2004); and the use of manually propelled devices (Smith et al., 1997). Studies of sonography work suggest shoulder risk factors include habitual arm abduction and isometric static loading, forceful gripping and applying pressure through the transducer, and habitual rotation of the upper spine (Brown and Baker, 2004). Constrained work involving repetitive movements with the hands and static muscle loading of the neck and shoulder have been shown to be risk factors for the neck/shoulder (Winkel and Westgaard, 1992a, b), and neck and intrascapular pain has been shown to be significantly related to sustained shoulder abduction, twisting of the neck and trunk, repetitive twisting of the neck and trunk and clerical activities in sonographers (Wihlidal and Kumar, 1997). Risk factors for hand/wrist and elbow disorders include forceful or sustained gripping, high repetitions and awkward bending/twisting postures (Silverstein, 1985). Although these hand/wrist risk factors have been studied extensively in short-cycle tasks of assembly lines and meat processing work, to our knowledge they have not been studied in sonographers.

1.3. Mechanism of injury at the shoulder

Three mechanisms have been suggested for shoulder injury. The first is mechanical compression of the supraspinatus tendon between the humeral head and the acromion process (Garg et al., 2006). The second is a reduction in the blood supply to the supraspinatus and infraspinatus muscles and tendons due to an increase in intra-muscular pressure when the arm is elevated (Garg et al., 2006); fatigue and reduced blood flow occur at moderate levels of abduction (30°), even without a load in the hands. The third mechanism occurs when prolonged static contractions (as little as 3–5% MVC) of the trapezius muscle result in an overload of type I muscle fibers (Jonsson, 1988), which may lead to selective motor unit fatigue and damage (Hagberg et al., 1995).

1.4. Objectives

This study will investigate the postural and muscular loads involved in performing ultrasound sonography scans, specifically the extent of abduction and outward rotation of the shoulder, neck bending/twisting and unsupported shoulder postures, and electromyography (EMG) of three neck/shoulder muscles (trapezezius, supraspinatus and infraspinatus) as well as the gripping force of the flexi carpi ulnaris holding the transducer. These will be compared with guidelines and studies of other workers from the scientific literature.

2. Methods

2.1. Postural assessment

Numerous authors have developed postural recording systems to facilitate observational data collection (Armstrong et al., 1982; Keyserling, 1986) and several of these have been tested for validity and reliability using video-based systems (Keyserling, 1986), inclinometers (Paquet et al., 2001; Village et al., 2007, submitted April 2007), or postural analysis systems (Leskinen et al., 1997). Fransson-Hall et al., (1995) found good agreement between observers for shoulder posture using their real-time (PEO) observational technique. Paquet et al., (2001) also found good inter-observer reliability for the shoulder and they reported no significant differences in the frequency of exposure of three shoulder postures when their observational assessment technique (PATH) was compared with inclinometer data (kappa of 0.8). Since most of these observational systems collect data in real time, the authors suggest that validity can be improved with video recording and playback capabilities (Fransson-Hall et al., 1995; Burt and Punnett, 1999). To optimize the validity and reliability of the postural assessment for this study, video recordings were used with stop-motion playback. A limited number of postures were chosen for the shoulder and neck and all observations were performed by a single-trained observer. Measures of shoulder abduction could be verified with on-screen measurement using a goniometer.

Postural assessments were carried out at six hospital facilities involving a total of 11 different ultrasound sonographers. Sonographers agreeing to participate were provided an explanation of the study purpose and procedures for observation and videotaping. They in turn explained the study and procedures to patients assigned to them that day. Consent forms from the Health Region were completed by both sonographers and patients willing to participate. A total of 24 complete scans were observed and videotaped. Sonographers were instructed to perform their scans as they normally would. Videotape was recorded directly behind the sonographer to optimize capture of shoulder abduction and outward rotation, as well as neck twisting and lateral bending. The videotapes were played back and stop-motioned four times per minute (every 15 s). At each stop motion, shoulder abduction and outward rotation was categorized by a single-trained observer in one of six categories: 0–15°, 16–30°, 31–45°, 46–60°, 61–75°, and 76–90°. Neck posture was categorized as either 'neutral' or 'bent/twisted'. 'Bent/twisted' was defined as more than 20° flexed, laterally flexed or rotated. Because neck posture often involves a combination of postures and the image was from the rear; for example, if there was uncertainty as to the angle of flexion, no data was recorded. Shoulder loading was also recorded as either static (i.e. supporting the weight of the arm and transducer), or relaxed (leaning on the patient, stretcher or keypad). The percentage of scan time in each postural

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zone was derived for each scan, and later combined to generate means, standard deviations, and 90% confidence intervals. An analysis of variance (between-subjects effects) was used to test for significant differences in posture and loading between different types of scans (abdominal, carotid, obstetrical and leg).

2.2. Muscle load assessment

EMG was collected during one full shift at one of the six hospital facilities. Three sonographers volunteered to perform 2–3 scans each (a total of seven scans) on whichever patients were assigned to them on that particular day. Informed consent was signed by both the sonographers and the patients. EMG was measured using a portable data collection system with on-board memory (ME3000P4/ME3000P8, Mega Electronics, Finland). Pairs of disposable 12 mm Ag–AgCl electrodes (Blue Sensor N-00-S, Ambu, Denmark) with a 20 mm inter-electrode spacing were placed over four muscle groups: The middle trapezius, supraspinatus, infraspintus, and flexor carpi ulnaris. As all participating sonographers were right-hand dominant and performed all scans with the right hand, data were collected on the right-hand side only. Skin was abraded then cleaned with alcohol to maximize conductivity and electrode adhesion. Electrodes, preamplifiers, and lead wires were secured using medical tape to guard against movement, tugging, or peeling during the scan.

EMG signals were calibrated as a percentage of a maximum voluntary contraction. Each static calibration effort was repeated three times for 5 s each, with a 1-min recovery period. Activity of the horizontal fibres of the middle trapezius were measured with electrodes placed 2 cm lateral from mid-point of a line from the spinous process of C7 to acromion process of the scapula, with a ground electrode on the spinous process of C7. The trapezius calibration employed a broad strap placed over the shoulder and secured under the feet. The participant was asked to elevate their shoulder as hard as possible against the resistance of the strap.

The supraspinatus muscle activity was accessed via the supra-scapular fossa as described in Murphy and Milkowski (2006), with the ground electrode on the acromion process. Supraspinatus calibration was achieved by placing a broad strap over the participant's wrist while the arm was laterally abducted at a 45° angle and asking the participant to abduct against the strap with full effort. For the infraspinatus, electrodes were placed on a line 2–4 cm below and parallel to the scapular spine in the infraspinatus fossa over the belly of the muscle and below the medial portion of the spine of the scapula. The ground electrode was placed on the scapular spine. Since the infraspinatus is primarily an external rotator of the shoulder, calibration was performed standing beside a wall with their arm bent to 90° at the elbow and the back of their hand touching the wall. Participants were asked to externally rotate their upper arm in a static, maximum effort similar to calibration reported by Hansson et al., (2000).

Electrodes for the forearm flexors were centered over flexor carpi ulnaris placed one-third of the distance on a line from the medial epicondyle to the ulnar styloid process with the ground electrode on the medial epicondyle. Forearm flexors were calibrated using a power grip maximum squeeze effort on a hand-grip dynamometer with the elbow at 90° and the arm vertical at the shoulder. Maximal grip force values were recorded for subsequent estimations of the grip force during the work shift.

Calibration signals were collected in 'raw online' mode at 1000 Hz. To express muscle activity as a percentage of a maximum voluntary contraction (%MVC), the central 3 s of each 5-s effort was averaged to represent the maximum muscle activity for that muscle group. All EMG signals collected throughout the work shift were then divided by this value to estimate percent MVC. Grip force values from the forearm flexor calibration maneuver were recorded and used to develop a linear calibration equation to estimate grip force during the work shift. The measured muscle activities (in uV) and grip force values (in kgs) were used to generate a linear equation that was constrained to go through the origin.

Work shift signals were collected in 'average' mode at 1000 Hz and the averaged value was stored at 100 ms intervals. All data were filtered internally using an 8–500 Hz band pass filter. Work shift data were downloaded from the EMG data collection system onto a laptop computer after 2–3 scans. After transforming to a percent MVC, EMG signals for all four channels were analyzed in parallel by windowing the time spent scanning a patient. Arithmetic means, standard deviations, and amplitude probability distribution functions (APDF) were generated. As described in Jonsson (1988) APDF values of 10, represented 'static load', APDF 50 represents the 'median' value, and APDF 90 represents the 'peak' level exposures.

Means and standard deviations for each muscle are presented and compared with existing risk guidelines. Although many studies have suggested possible exposure cut-offs for increased risk (Armstrong et al., 1982; Keyserling, 1986; Grandjean, 1988; Bjorksten and Jonsson, 1977 and Jonsson, 1988), Winkel and Westgaard (1992a, b) reviewed hundreds of studies of neck and shoulder disorders and systematically selected the 15 best studies that used EMG of the trapezius muscles. These data were plotted to indicate three levels of risk: Low, medium and high. At low risk, the arms work in relaxed shoulder postures and static EMG measured 2–3% MVC, the median is 4–8% MVC and peak is 8–12% MVC. This is substantially lower than previous guidelines suggested by Jonsson (1988). Medium risk has elevation, abduction or flexion of the arm, but minimal effect of tool weight or forces corresponding to a static EMG in the trapezius of about 3–10% MVC, a median EMG of 10–15% and a peak of 18–35%. The high risk level is associated with exertion of large forces and awkward postures, corresponding to

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approximately 8–12% MVC for static, 12–25% MVC for median and >36% MVC for peak EMG.

3. Results

Table 1 shows the combination of hospital locations, sonographers, types of scans and duration of scans for collection of both the postural and EMG data. A total of 24 scans were assessed for posture and seven for EMG, two of which were not simultaneously videotaped for posture assessment. As can be seen from Table 1, the types of scans represented all of the most commonly performed (abdominal, carotid, leg, obstetric), as well as some that are less common (nursery).

The mean duration of the 26 scans is 22.2 min (standard deviation 10.6 min). Very brief scans were recorded for the nursery (3.0 and 3.5 min) while durations longer than 30 min were frequently recorded for obstetrics and leg scans. Four of the 11 sonographers have had a previous injury to their scanning shoulder, but have returned to full-time work. As sonographers were instructed to work as they normally would, some took time to adjust the stretcher height, chair height and where possible, keyboard height. Some sonographers obtained a pillow or towels on which to rest their forearm. In some cases, sonographers asked the patient to move toward the edge of the stretcher as close to them as possible. These adjustments varied across different sonographers.

Table 1
Combination of locations, sonographers, types of scan and durations for 24 postural assessments and seven EMG assessments

Hospital location	Sonographer	Type of scan	Posture	EMG	Duration (min)
1	A	Abdominal	√		12.0
1	A	Abdominal	√		8.25
1	A	Carotid	√		14.5
1	B	Leg	√		20.25
1	B	Obstetric	√		33.25
1	B	Nursery	√		3.5
1	B	Nursery	√		3.0
1	C	Leg	√		17.0
1	C	Carotid	√		10.0
1	D	Obstetric	√		24.5
2	E	Abdominal	√	√	27.0
2	E	Carotid	√	√	20.5
2	F	Echocardiogram	√	√	35.0
2	F	Abdominal	√	√	24.0
2	G	Leg	√	√	27.0
2	G	Renal		√	11.0
2	G	Leg		√	38.0
3	H	Leg	√		31.75
3	H	Leg	√		21.5
4	I	Obstetric	√		42.25
4	I	Obstetric	√		35.5
5	J	Abdominal	√		17.75
6	K	Obstetric	√		16.0
6	K	Abdominal	√		30.0
6	K	Obstetric	√		23.0
6	K	Obstetric	√		30.0

3.1. Postural assessment

The 11 subjects participating in the postural assessment had an average age of 42.5 years (SD 9.3), with 13.4 years experience (SD 8.9), an average height of 167 cm (SD 6.2) and weight of 64.3 kg (SD 7.0). The mean percent time in each range of right shoulder abduction and 90% confidence intervals are shown for the 24 scans in Fig. 1.

Fig. 1 shows the considerable variability between sonographers in the postures assumed. Variability could be due to: (1) The type of scan, as some (such as carotid) involve more reaching; (2) the height of the sonographer; or (3) individual technique and positioning of the patient and equipment. On average, among 24 scans from 11 sonographers, 66.6% of scanning time was spent with the right arm abducted >30° and 44.7% of the scanning time was spent abducted >45°.

Fig. 2 shows the mean percent of time in various ranges of outward rotation of the right shoulder. On average, sonographers spent 62.6% of time with >30° of outward rotation and 42.6% of time >45°.

Static or unsupported arm postures were observed in the right shoulder to hold the weight of the arm and transducer on average for 72.96% of scanning time (standard deviation 24.87%). The large standard deviation in this measure reflects the very different techniques used among sonographers. The range of percent time statically contracting the shoulder varied from a low of 15.7% in some sonographers who nearly always rested their arm/shoulder, to 100% in two sonographers who were never observed to rest their arm/shoulder. The average percentage of time the neck was bent forward, bent laterally, or twisted beyond 20° was 36.98% (standard deviation 30.29%). Once again,

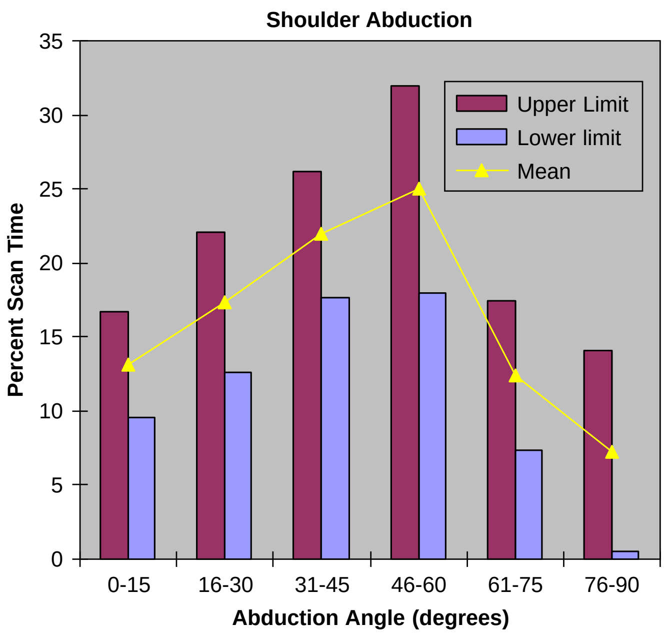

Fig. 1. Percent of time in various ranges of shoulder abduction for 24 scans, means and 90% confidence limits.

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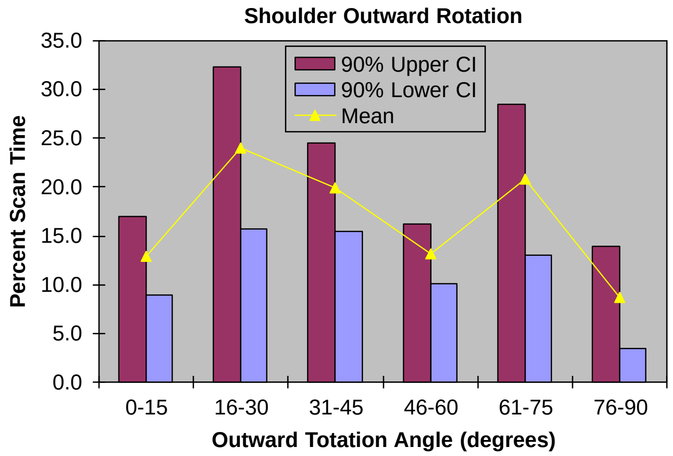

Fig. 2. Percent of time in various ranges of outward shoulder rotation for 24 scans, means and 90% confidence limits.

Fig. 3. A typical posture when performing a leg scan with the right arm abducted, the neck twisted and force applied through the transducer with the right hand/arm.

there was considerable variability in technique with some scans involving no time in bent/twisted neck postures, and others upwards of 80% of time. Typical scanning postures are shown in Figs. 3–4.

There were sufficient numbers of four types of scans (abdominal, carotid, leg and obstetrical) to perform an

Fig. 4. Extreme shoulder abduction and forceful pushing on the transducer. The arm weight may be partially supported by resting the arm for brief periods on the patient.

Table 2
Percent time in each of three shoulder abduction zones according to type of scan

Type	Number of scans	0–30°	31–60°	61–90°
Abdominal	6	10.9	27.7	9.2
Carotid	3	12.7	14.4	22.9
Leg	6	11.5	28.8	8.8
Obstetrical	5	25.7	18.9	3.0
p-value		$P = 0.016$	$P = 0.209$	$P = 0.06$

analysis of variance to investigate differences in posture between scanning types. For this analysis, postural ranges were reduced to three categories: 0–30°, 31–60°, and 61–90°. Table 2 shows results for right shoulder abduction and p-values for tests of significance between the different types of scans.

Table 2 shows there was a significant difference in the percent of time in neutral shoulder abduction (0–30°) between scan types ($p = 0.016$). A post hoc analysis revealed that the percent time in neutral was significantly higher for obstetrical examinations compared with all others (25.7%), but there were no significant differences between the other types. In the range of 31–60°, there were no significant differences between scan type. There was more time (22.9%) spent in extreme shoulder abduction (61–90°) for carotid scans, but this did not reach statistical significance ($p = 0.06$). For outward shoulder rotation, there were no significant differences between scan types for any of the three postural zones.

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Table 3 shows the percentage of time in static shoulder postures for the four types of scans and the percentage of time in non-neutral neck postures. Table 3 shows there were significant differences between scan type in both the percent time with a static shoulder ($p = 0.006$) and in non-neutral neck postures ($p = 0.029$). There was significantly less time in static shoulder postures for carotid scans compared with others, however, there was significantly more time in non-neutral neck postures for leg scans.

3.2. Muscle load results

The three sonographers who volunteered to participate in the EMG analysis were on average 40.7 years of age with 10 years experience as a sonographer. The average height was 168.5 cm and weight was 70.3 kg. Two sonographers were female and one was male. None of the sonographers were currently experiencing any musculoskeletal pain or symptoms.

Table 3
Percent time in static shoulder postures and non-neutral neck postures for four types of scans

Type	Number of Scans	Static shoulder	Non-neutral neck
Abdominal	6	86.3	25.1
Carotid	3	41.5	12.3
Leg	6	70.3	64.5
Obstetrical	5	84.5	20.3
p-value		$P = 0.006$	$P = 0.029$

EMG results for the trapezius muscle presented as APDFs (0.10, 0.50 and 0.90) for all seven subject-scans are shown in Fig. 5. The static EMG loads are compared with "low" risk static guidelines of 2–3% MVC and median guidelines of 4–8%. "Medium" risk static EMG ranges are 3–10% MVC and median are 10–15% MVC. "Low" risk peak levels are 8–14% MVC and "medium" risk peak levels are 18–35% MVC.

The mean for APDF 10 or 'static work' is 4.61% MVC (SD 5.21), which is considered "medium" risk according to guidelines by Winkel and Westgaard (1992a, b). Three of the seven EMG static loads exceeded the upper range of medium risk (10%). The 50th percentile or median APDF averaged 10.5% MVC (SD 7.85) and the peak averaged 18.98% MVC (SD 9.9) placing both in the "medium" risk range.

APDFs for the supraspinatus and infraspinatus muscles are shown in Table 4 along with means and standard deviations across the individual-scan combinations.

Mean static EMG levels for supraspinatus and infraspinatus were within "medium" risk range of 3–10% MVC (3.74 SD = 2.17 and 3.18 SD = 1.73). Median levels for both muscles were within the "low" risk guideline of 3–10% MVC. Peak EMG activity in supraspinatus was typically within the "medium" risk range of 18–35% MVC. Peak levels for this muscle were, on average, higher than for trapezius. Peak levels for infraspinatus were on the border of "medium" risk (17.4% MVC).

Muscle activity for the forearm flexors, expressed as kg of force, is presented in Table 5. Table 5 shows the mean for all subjects, as well as APDFs for 0.1, 0.5, 0.9, 0.95 and

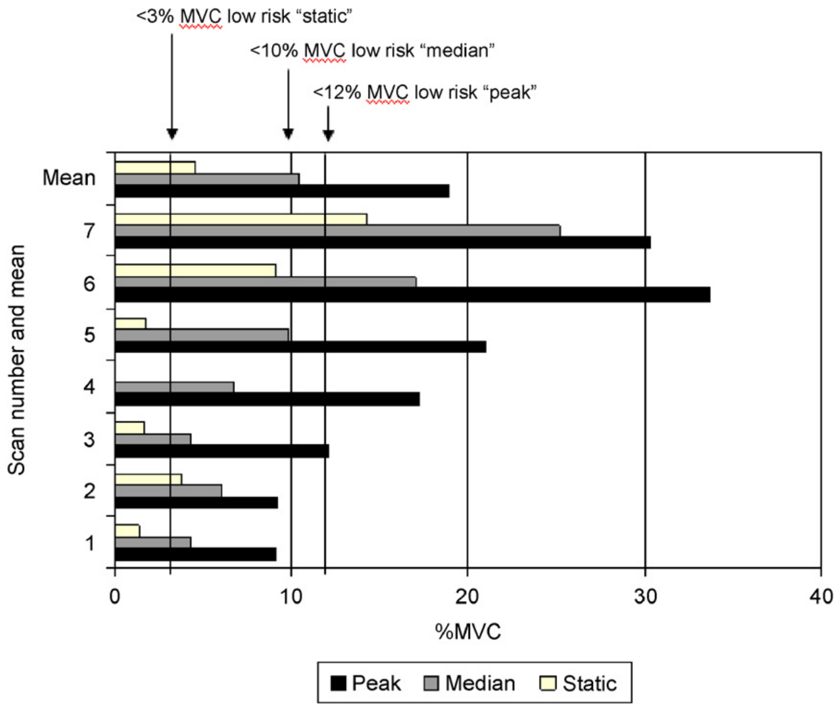

Fig. 5. Amplitude probability distribution functions (static = 0.10, median = 0.50 and peak = 0.90) for the right trapezius muscle for each of seven sonographer–scan combinations and the mean.

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Table 4
Amplitude probability distribution functions (0.10, 0.50 and 0.90) for the supraspinatus and infraspinatus muscles for each of seven sonographer–scan combinations

Subject	Supra 0.10	Supra 0.50	Supra 0.90	Infra 0.10	Infra 0.50	Infra 0.90
E	4.45	4.99	26.4	1.86	6.36	17.61
E	0	4.45	8.9	0	3.10	11.63
F	6.06	6.06	18.17	3.34	6.52	22.96
F	6.06	6.06	29.93	3.26	8.36	20.3
G	2.59	9.75	19.42	4.56	8.96	17.14
G	2.59	9.75	19.42	4.59	8.96	17.14
G	4.41	14.77	25.11	4.63	8.58	15.13
Mean	3.74	7.97	21.05	3.18	7.26	17.41
S.D.	2.17	3.68	6.9	1.73	2.14	3.6

Table 5
Grip force normalized EMG in kg (mean and 0.1, 0.5, 0.9, 0.95 and 0.99 APDF)

Subject	Mean (kg)	0.10 (kg)	0.50 (kg)	0.90 (kg)	0.95 (kg)	0.99 (kg)
E	1.87	0.46	1.38	3.46	4.97	10.56
E	1.35	0.45	0.92	2.28	4.14	8.34
F	2.53	0.83	2.17	4.89	5.67	7.07
F	1.03	0.00	1.09	1.77	2.53	6.63
G	6.34	1.84	6.21	10.39	12.19	20.68
G	8.31	2.39	8.02	13.63	16.19	27.64
G	6.27	0.94	5.77	11.59	13.77	20.56
Mean	3.96	0.99	3.65	6.86	8.49	14.5
S.D.	2.94	0.84	2.93	4.88	5.41	8.35

0.99. The 0.99 level indicates maximum peak forces generated for up to 1% of the work cycle. This gives some idea of the maximum forces used when holding and pushing the transducer.

The mean force used in gripping the transducer over the entire scan period is 3.96 kg (SD 2.94 kg). One sonographer (G) used an average of 6.3–8.3 kg of force on all three of the scans measured. The 10th percentile APDFs show that rarely does the grip relax below 1 kg. Across all individual-scan combinations, the mean 90th percentile APDF was 6.86 kg and the 95th and 99th percentile APDFs were 8.49 and 14.5 kg. For one individual, peak forces got as high as 27.6 kg.

4. Discussion

4.1. Postural assessment

Postural assessment of 24 scans (totaling 527.5 min, or 8.8 h) performed at six hospitals, showed that, on average sonographers spent 66% of their scanning time with the shoulder abducted more than 30°, and 45% of the time at more than 45°. Thirty degrees of abduction has been shown to result in significant impedance of blood flow in the supraspinatus muscle (Jarvholm et al., 1988, 1990). Significantly more time was spent in neutral abduction (0–30°) when performing obstetrical scans (compared with abdominal, leg and carotid) and slightly more time is spent beyond 60° when performing carotid scans (approaching significance $p = 0.06$). On average, sonographers spent 63% of their scanning time with the shoulder outwardly rotated more than 30° and 43% of the time at more than 45°. This posture puts a load specifically on the supraspinatus muscle, but no significant differences were found between types of scans. On average, sonographers hold their right arm statically for 73% of the scanning time, but the range of time is from 16% to 100% depending upon sonographer technique and type of scan. The shoulder was working statically for significantly longer proportions of time when performing carotid scans compared with other types. The neck is bent forward, laterally or twisted more than 20° for an average of 37% of scanning time. The neck was in awkward postures significantly more when performing leg scans compared with other types of scans. This is not surprising given the amount of trunk twisting and reaching across with the left arm to occlude blood flow when doing leg scans.

While errors in observational posture categorization are possible, and the method used has not been specifically validated, the methods chosen for this investigation are meant to minimize error based on recommendations by others (Leskinen et al., 1997; Paquet et al., 2001). A single-trained observer performed all observations, thus minimizing variability between observers. Stop-motion video recordings were used rather than real-time observation allowing ample time for the posture categorization and measurement of shoulder abduction on the screen if need be. Because the videotape was taken from behind the subject, the posture most likely to have error would be shoulder outward rotation. However, it is anticipated that any errors would be applied systematically within and between subjects.

4.2. Shoulder muscle load

All three shoulder muscles were found to work 90% of the time (statically) at or above a mean contraction of 3–10% of maximal voluntary contraction. This corresponds to a “medium” risk rating for occupational

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shoulder–neck disorders and is consistent with levels reported in assembly work (Winkel and Westgaard, 1992a, b; Aaras, 1994). On average, median (50th percentile APDF) trapezius muscle activity levels were also in the "medium" risk range of 10–15% MVC. Peak levels (90th percentile) were also within or near the medium-risk range (18–35% MVC) for both trapezius and supraspinatus muscles. It could be that some sonographers may shift muscle effort to the supraspinatus and infraspinatus muscles while reducing their trapezius muscle activity. Studies have indicated that unconscious muscle reorganization occurs when the trapezius muscle fatigues, is in pain, or has suffered previous injury (Edwards, 1988). Aaras (1994) measured similar static EMG levels in the trapezius muscles of telephone assembly workers (4.3% MVC in assembly compared to 4.6% MVC in our sonographers). Aaras (1994) reported that when workstations were altered and the EMG levels reduced to 1.4%, there was a significant decrease in sick leave from 7.9 (percent per man–labour years) to 5.7, and a reduction in duration of sick leave from 22.9 days to 1.8. Among the data entry workers, a reduction in static EMG loading from 2.7% to 1.2% MVC was associated with a significant decrease in reported neck/shoulder pain ($p<0.01$).

Large standard deviations were found in all EMG measures reflecting the variation between sonographers and scan types and also the low number of subjects in our study. Large inter-individual variations in shoulder EMG has been reported by others (Vasseljen and Westgaard, 1997). Unfortunately, the EMG measured in sonographers by Murphy and Milkowski (2006) cannot be compared with our data since a different calibration procedure was used (reference posture vs. maximum voluntary contraction). However, their findings of a 46% reduction in supraspinatus EMG (10th percentile) with a reduction from 75° abduction in the shoulder to 30° and a 78% reduction with support under the forearm would help explain some of the large inter-individual variations in our study; we found a wide range of postures adopted, with some workers supporting their arm more than others. Some of the variation could also be explained by worker anthropometrics; Carnide et al. (2006) found shorter workers had higher trapezius muscle EMG loads than taller workers for the same task.

There is also some evidence that in addition to static work and elevated shoulder postures, the addition of precision work and mental workload increases the muscle activity at the shoulder. Sporrong et al. (1998) describe two types of precision: Positional precision and precision of pressure of the hand tool. They found an average increase in shoulder muscle activity of 22% with a precision grip, with the greatest relative increase in EMG among the supraspinatus, infraspinatus, levator scapulae and trapezius muscles. Au and Keir (2006) found that the addition of a mental load to a physical task caused a redistribution of the muscle forces in the shoulder. The muscle activity in the middle deltoid decreased, while the suprasinatus and infraspinatus increased 10% of MVC. The static grip force also increased 30–50%.

4.3. Grip force

Forearm flexor muscle EMG corresponds to an average grip force over the duration of the scanning time of 4 kg (8.8 lbs). These high forces in a precision-power grip are a combination of holding the transducer, applying precision finger forces to move the transducer to the optimal spot and orientation, and applying pressure to enhance the scanning image. For 90% of the scanning time, the applied force is a minimum of 1 kg (2.2 lbs) providing little or no opportunity for the hand/wrist to rest and recover. Occasional peak forces were measured as high as 27.6 kg (60.7 lbs). The shoulder is therefore not simply supporting the weight of the arm when reaching with the transducer, but is also stabilizing for the high grip forces generated in the hand. Silverstein (1985) reported increased risk of hand/wrist disorders when workers frequently used pinch grips exceeding 0.9 kg and power grips exceeding 4.5 kg. Clearly the sustained grip force and periodically high intermittent forces in the hand also increase strain to the wrist and elbows of sonographers.

5. Conclusions

Quantification of the posture and muscle loads of sonographers performing actual scans shows long durations of static and awkward shoulder abduction and outward rotation, measured both with stop-motion video tape postural assessment and with electromyography of the shoulder muscles. High and sustained grip forces were found, which have not previously been quantified for the hand/wrist. These risk factors are consistent with the high prevalence of neck and upper limb musculoskeletal disorders and symptoms reported by many sonographers in studies conducted in the US and Canada.

The wide variability in posture and muscle load among sonographers measured in our study warrants further investigation to develop effective controls measures to reduce risk of injury.

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