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Ergonomic Interventional Design of an Articulating Arm for Echocardiography Application: Front-End Design and Pilot Study

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Echocardiography is a growing field due to the dual trends in longer life expectancy and rising obesity levels. Several publications have reported high prevalence of musculoskeletal issues among cardiac sonographers due risk factors that include prolonged probe pinching, forceful exertions, awkward postures, and prolonged maintenance of static postures. A design of an articulating arm that uses a simple locking mechanism was envisioned to reduce these exposures. A participatory approach involving experienced cardiac sonographers was fully integrated into the design process. A functional prototype was assembled, and pilot tested among cardiac sonographers in a clinic setting. The device was well received and thought to have potential in addressing the previously identified issues. However, several design iterations and more comprehensive evaluations will be needed before the device will be ready for implementation in echocardiography settings.

Introduction

Previous publications around the world, including the United States, Canada, Israel, Italy, and the United Kingdom have reported associations between sonographers' activities and development of musculoskeletal issues (Evans et al. 2009, Wihlidal et al. 1997, Russo 2002, Schoenfeld et al. 1999, Magnavita et al. 1999, Ransom 2002). These studies consisted of mostly clinical self-report surveys and some cross-sectional studies from general populations of sonographers. Schoenfeld et al. (1999) concluded that the prevalence of upper limb musculoskeletal disorders among ultrasound sonographers is "etiologically related to occupational factors". Baker & Murphey (2006) reported that there is an increasing rate of frequency and severity of musculoskeletal issues among ultrasound sonographers. The authors claimed that 84% of sonographers experience occupational pain and 20% suffer career ending injuries.

Echocardiography is a specialty field of ultrasound applied to the cardiovascular system. Ehler et al. (2001) reported that echocardiography is "the most commonly used imaging procedure for the diagnosis of heart disease". Echocardiography is currently a growing field (BLS, 2009). This is postulated due to the trends of longer life expectancy and rising obesity levels. Similar to the general sonographers' population, several publications found associations between cardiac sonographers' activities and the high prevalence of musculoskeletal discomfort (Vanderpool et al. 1993, Smith et al. 1997, Horkey & King. 2004). Vanderpool (1993), in a cross-sectional study of cardiac sonographers, found that 86% of the respondents in the United States reported one or more symptoms of musculoskeletal disorders.

Previous recommendations for interventional activities have been concentrated primarily on administrative and behavioral interventions, and less on engineering controls (Horkey & King, 2004). The paucity of engineering controls that address the fundamental issues, such as reduction of probe gripping, pushing force, sustained exertion, and repetitive awkward body postures, reveals a significant limitation in current interventions available to sonographers and their employers. The aim of the current study was to address this void through design and development of an engineering-based solution.

Method

The Process. There were five stages in the design process in this study, as shown in Figure 1. However, the device developed in this project is not in its complete form, so there would be additional stages in the future, mainly focusing on further iterations of design, usability testing, and image quality assurance.

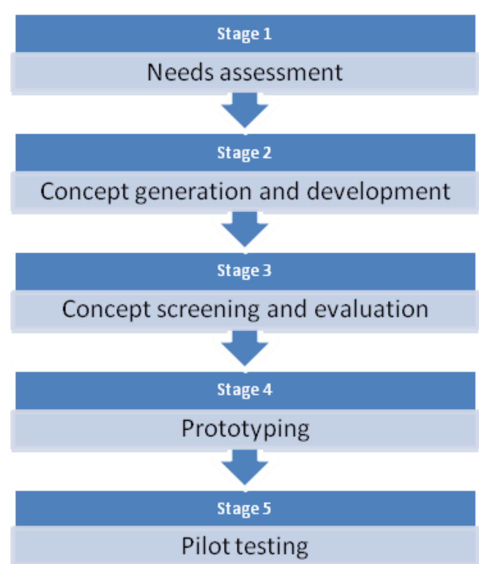

Figure 1. Generic stages of design process used in this study

Stage 1: Needs assessment. The needs assessment was derived from four main activities: review of the literature, participatory workshops, firsthand observation, task simulation, and interviews with echocardiographers. Four recurring issues were identified from these activities: prolonged pinching, forceful exertions, awkward scanning postures, and static postures. These issues have been long established as risk factors for development of musculoskeletal problems. The four identified issues were then translated into design specifications.

Stage 2: Concept Generation and Development. Twenty initial concepts were generated through discussion, creative endeavor, internet searches, patent searches, and review of the literature. The concepts went through several iterative processes before reaching a stage where they were sufficiently refined that they could be presented to groups of cardiac sonographers.

Stage 3: Concept Screening and Evaluation. The initial twenty concepts were screened down to eight concepts using a modified Pugh's screening method (Stoll, 1999). A multivote technique proposed by Ulrich and Eppinger (2000) was then utilized to further narrow down to only three concepts. These three concepts were then presented to the cardiac sonographers in two focus group, concept review sessions. Non-functional mock-up models were fabricated to give a physical representation of the ideas. In addition, a poster summarizing the concepts was also presented as a visual aid.

Stage 4: Prototyping. A functional prototype was developed based on discussions with the cardiac sonographers. Several articulating arms available on the market were investigated, and the research team decided that an articulating arm manufactured by Civco Medical Solutions (Kalona, Iowa; Model number 810-200) was closest to the concept the design team envisioned. It is essentially an articulating arm connected by ball joints, and can be locked in place. It is currently marketed for use in other types of ultrasound-dependent procedures. A probe holder and a mounting stand were fabricated in an attempt to modify the device to be more compatible in the echocardiography setting. The prototype was expected to meet the main product specifications that were set forth before the start of the design process, which were:

1. Minimize duration of pinch gripping: Probe holder holds the transducer, thus minimizing the need to grip the probe continuously.
2. Minimize overall duration of force exertion: By utilizing the locking mechanism, the need to maintain the pushing force manually at all times is minimized.
3. Minimize awkward upper extremity postures: By utilizing the locking mechanism, the sonographer can reposition him/herself into a more neutral posture from an awkward posture that may have been required to initially position the transducer in the correct location; the sonographer can also perform small adjustments to the probe via the device, rather than reaching across his/her own body with the right hand to grasp the end of the probe being held by the left hand.
4. Minimize the need to maintain static posture of the left arm: Once the scanning window is found and a quality image is obtained the locking mechanism will hold the probe in place, minimizing the need to sustain during the left arm posture continuously.

Stage 5: Preliminary Pilot Testing. The prototype was pilot tested among six professional cardiac sonographers. Experience with the echocardiography ranged between 1 to 20 years (cumulative experience = 82 years). They were asked to perform a series of tasks, with and without the device, according to their current scanning protocol on a member of the research team. Data collected in this session included video and audio recordings of the session, scanned images for quality assessment, and the sonographer's perceptions exertion, usability, usefulness, and desirability of the device.

Results

Observation. In general, it was observed that scanning with the device reduced the overall duration of pinch gripping, forceful exertion, awkward postures, and static postures. The traditional scanning method requires the cardiac sonographer to pinch the probe for most of the scanning procedure (30-40 min for an examination is typical). The typical posture when performing a left-handed scan is depicted in Figure 2 (left). In addition to prolonged pinching, the sonographer has to push the probe against the patient's chest. Greater pinch force is required when the ultrasound gel migrates to the gripping surface. Additional force is also required if the patient is obese. By utilizing the locking lever, the articulating arm maintains the location of the probe as well as the pushing force against the patient's chest. This provides an opportunity for temporary breaks from pinching and physical exertion during the measurement phases of the exam (see Figure 2, right).

The device was also observed to improve the cardiac sonographer's overall posture. Some sonographers were seen twist and lean their torsos when scanning with the traditional method. Several sonographers were also observed to assume prolonged unsupported abducted arm posture as shown in Figure 2 (left). Figure 2 (right) demonstrates how the device allows for a relaxation of the left arm during a significant portion of the exam.

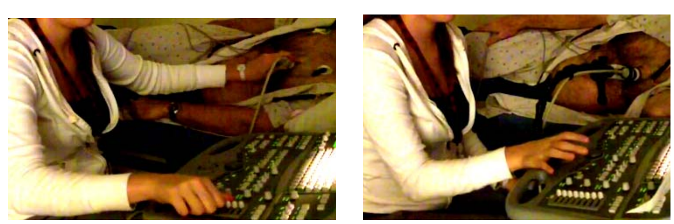

Figure 2. Traditional method is on the left. Observe continuous gripping with left hand, as well as unsupported abducted left shoulder and arm. New method is on the right. Observe that the sonographer released her grasp and lowered her arm while taking measurements with the probe held in place by the prototype device.

Image quality assessment. In general, the sonographers said they were pleased with the overall image quality while they were scanning with the device during the pilot session. Most sonographers thought that they had better image quality when using the device, while one sonographer expressed that even though it would take a bit more time than the traditional method, comparable image quality could be achieved using the device and that the extra time would be acceptable and "worth it". Image quality was assessed afterwards, independently by two professional sonographers, each having more than 20 years of experience. Results are summarized in Table 1.

Perception of exertion ratings. A general trend observed with all the participants was that their perception of their average exertion during the scan was reduced by at least two points (on a 0-10 scale) when they were scanning using the prototype. This indicated a subjective agreement in that the device noticeably reduced the level of overall force exertion. This result is consistent with the verbal remarks they offered. The sonographers stated that they felt a noticeable difference in loads in their upper extremity because they did not have to continuously pinch, push and maintain their exertion when scanning with the device. Results are summarized in Table 2.

Subjective evaluations of usability, usefulness, and desirability. In general, the cardiac sonographers who tested the prototype gave positive evaluations to the main three sections in the evaluation form. On a scale from 1 to 7, where 1 is "very poor" and 7 is "very good", the average scores for overall usability, usefulness, and desirability of the device were 6.2, 6.2, and 6.1, respectively. These scores, which are summarized in Table 3, indicated that the six participants in the pilot study were generally optimistic with the potential of this articulating arm concept.

Table 1. Summary of the image quality evaluations performed by two highly experienced professional sonographers. 'X' indicates that the image scanned with the device was better or comparable to traditional method while '0' indicates that the image quality was better without the device.

	Views of the heart			
Subject ID	Apical 2 chamber – B-mode	Apical 3 chamber-B-mode	Apical 4 chamber - Doppler	PSAX-M-Mode
6870	X	X	X	0
6403	X	X	X	0
6713	X	X	X	X
6505	X	X	0	0
6502	X	X	X	X
6500	X	X	X	X

Footnotes for Table 1:

- "Apical" refers to placement of the transducer at the cardiac apex in the apical window. PSAX: parasternal short axis view
- B-mode produces 2-d and 3-d gray scale images
- Doppler images show the flow of blood towards and away from the transducer which can reveal regurgitation across a valve or leakage between chambers.
- M-mode provides a time trace of the motion of the heart

Table 2. Perceived levels of exertion among the six cardiac sonographers when performing the scans with and without the device, on a scale of 0 -10 where 0 = no exertion and 10 = maximal exertion.

Subject ID	Average exertion rating - traditional method	Average exertion rating - with the device
6870	6	3.5
6403	4	2
6713	4	2
6505	5.5	2
6502	6	2.5
6500	5	3

Table 3. Subjective ratings on usability, usefulness, and desirability of the device on a scale of 1 -7, where 1 = very poor and 7 = very good.

Points of comparison and development	Probe holder ratings from the pilot session
Avg. Overall Usability Score	6.2
Avg. Overall Usefulness Score	6.2
Avg. Overall Desirability Score	6.1

Discussion

A design process that involved end users throughout the process was found to be very useful in guiding the direction of the design development, from providing information about needs, to contributing some initial concepts and concept refinements, through to initial pilot testing. The participatory approach used in this study takes advantage of workers' subject matter expertise and knowledge of the workplace system (Evanoff et al. 1999). There have been limited studies focusing on human-centered design concepts in the specific area of echocardiography, though we find this approach has yielded significant value in the design process.

The preliminary pilot testing achieved two important objectives: 1) it was determined that the prototype devide could be used to obtain images that were equivalent or better for images from three key views of the heart, and 2) it was determined that physical strain was reduced in the sonographers when using the device. The primary limitation of the pilot test was that neither of the patients was obese, though one of them was considered a challenging patient because of the orientation of his heart.

The main limitation in this study is that the design is not yet complete. The concept is still in the development process, and it will take several more design iterations before the device is ready to be implemented in echocardiography settings. Some constructive feedback related to the limited rigidity of the mounting stand and inflexible portions of the articulating arm are legitimate issues that must be addressed.

Future work with more advanced designs of the device will include additional pilot studies with larger samples of participating sonographers, as well as greater diversity in patients (and their conditions). Quantification of differences in posture and exam time between the traditional and new methods will be required. Eventually field trials in clinic settings will be necessary.

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