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Use of Digital Human Model for ultrasound system design: A case study to minimize the risks of musculoskeletal disorders

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ABSTRACT

The aim of this paper is to present and discuss the use of Santos™ Digital Human Model for Ultrasound System (US) Design, in particular for the transducer design. The incidence of work-related musculoskeletal disorders (WRMSD) among sonographers ranges between 82% and 88%. The most frequent causes of musculoskeletal disorders in sonography include the US equipment design. Diagnostic Ultrasound systems are characterized by real-time examination, which forces to manage the US Probe with one hand (usually the right one in most clinical applications) and the US system User Interface (UI) with the other hand. The transducer design seems to be the best predictor of hand-wrist complaints and it is significantly related to the increasing severity of symptoms in the hand, wrist and forearm area. Sub-optimally designed US systems UI and Probe ergonomics led to a high presence of WRMSD among US system users. Digital Human Models (DHM) have been developed in order to increase the level of quality of the Ergonomic Design Process. In this investigation, the relation between the geometry of a conventional-designed probe model and a new-designed appleprobe transducer (Esaote S.p.A., Firenze, Italy) has been evaluated. Results and Analysis are based on qualitative data produced by the simulations. The new design is well promising to minimize the risk of WRMSD at the wrist and at the hand level. This work discusses how these tools can be reliable in the assessment of the ergonomics of the US transducer, comparing simulated data with qualitative data collected from professional sonographers.

Relevance to industry: The interest in Ultrasound Ergonomics is of main importance among the Ultrasound producers worldwide. The capability to design ergonomically valid systems and probes represents a strong market plus of a certain producer with respect to competitors. DHM allows to perform the evaluation of the system and probe design well in advance of the marketing phase, enabling the simulation phase as soon as a CAD model is available.

1. Introduction

The attention to sonographers' work-related musculoskeletal disorders (WRMSD) is really crucial. Several studies demonstrate that the ergonomic evaluation and assessment of sonographers' workspace are very important, as a consequence of the incidence of WRMSD among sonographers that ranges between 82% and 88% (Val Gregory, 1998; Murphy and Russo, 2000). Furthermore, the Society of Diagnostic Medical Sonography (SDMS) demonstrates that sonographers, on average, experience pain or Musculoskeletal disorders (MSDs) within 5 years from entering the profession (SDMS, 2000).

The upper limb and the torso are the body sites that are mostly affected by MSDs, and in particular the shoulder, the neck, the low back, the wrist and the hand/fingers (Society of Diagnostic Medical Sonography (2003); Village and Trask, 2007). Sonographers suffer of one or a combination of disorders, and the most frequent are reported as nerve syndromes, tendon related disorders, muscular disorders (Val Gregory, 1998; Vaderpool et al., 1993; Brown and Baker, 2004). The origins of discomfort within a real clinical environment are different, with various effects on diverse areas of the sonographer's body. Sonographers' higher experienced discomfort anatomical sites are: shoulder (76%), neck (74%), back (58%), wrist (59%) and hand/fingers (55%) (Murphy and Russo, 2000).

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Sonographers are exposed to a variety of ergonomics-related risk factors when they perform specific tasks, dealing with the transportation of equipment, the positioning of patients and equipment and the daily use of Ultrasound (US) systems.

The most frequent causes of musculoskeletal disorders in sonography include two main domains (Morton and Delf, 2008; NIOSH, 1997): the sonographers' workspace environment and the equipment design. In particular, the environmental factor involves the frequent assumption of unnatural postures for prolonged time (i.e shoulder in sustained abduction and the spine in an unnatural alignment (Fig. 1) or the forceful exertions of sustained pressure and force to generate accurate images.

Ultrasound (US) system design includes keyboard/screen height and position, equipment maneuverability, transducer grip, adjustable or non-adjustable chairs and examination couches. As an example, the transducer design seems to be the best predictor of hand-wrist complaints and muscular efforts (such as gripping the transducer, applying sustained pressure and scanning with a flexed or hyper-extended wrist) and it is significantly related to the increasing severity of symptoms in the hand, wrist and forearm area (Magnavita et al., 1999).

Ultrasound Ergonomics and Design is a complex task involving many aspects:

- User level of technical and clinical experience,
- User habit to a product and general personal attitude,
- Clinical Application considered (and related Clinical Guidelines and Advices),
- Clinical workflow to be followed (depending on Country, Hospital – Clinical Dept. rules, etc…),
- Typology of Ultrasound system and Market segment.

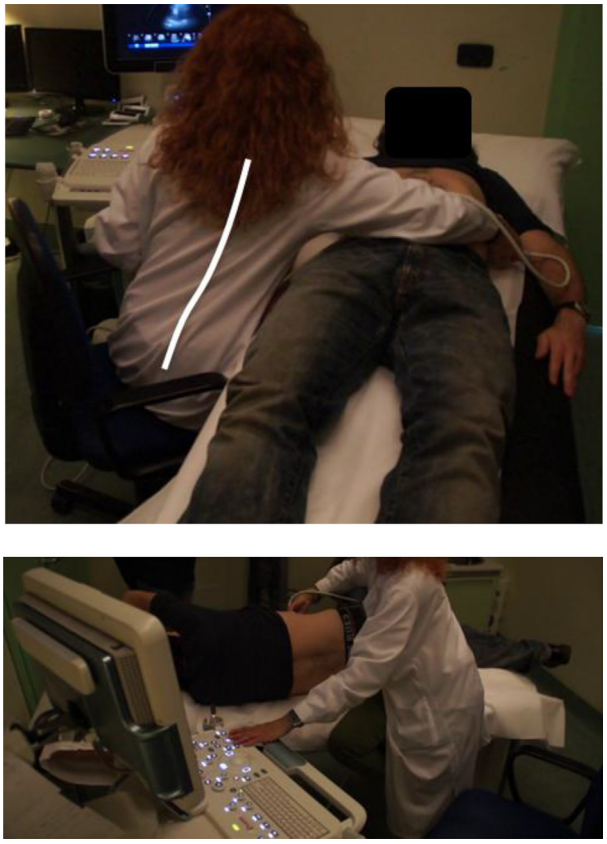

Fig. 1. On the left: An example of the spine displacement during an exam performed by a professional sonographer. On the right: an example of a standing posture with the shoulder abducted for a prolonged time without any arm support (single fitting, in column).

The ultrasound system during scanning has to be usable with only one hand, while the other one has to handle the probe. The real-time nature of Ultrasound obliges the designer to develop controls to be easily found also when the attention focus is on the patient, while using only one hand and looking at the system monitor, in clinical or emergency setting, in a lab or on the field, depending on the ultrasound system used.

As stated before, the issue of ultrasound systems Ergonomics is treated in many standards and guidance documents from regulatory organizations, Healthcare Institutions and Sonographers Associations. Work-related musculoskeletal disorders are widely common among sonographers.

Today no industrial standards or technical guidelines are available dedicated to the design of ultrasound systems; therefore numerous workflows and different ways of usage are present within the ultrasound systems available on the market: for the user the best design is the more naturally usable and less stressing one in its operation and handling.

The ergonomic intervention strategies should intervene with the aim to minimize musculoskeletal disorder risks in these areas. Several studies identified nine major factors of interest (Andreoni et al., 2013a, b; Murphy and Russo, 2000; Smith and Saintfort, 1989; Paschoarelli et al., 2008). Among these factors, the transducer design, the US system user interface and control panel design and the sonographer's body posture seem to be relevant for injury and risk prevention. An example of how an effective ergonomic design could represent a possible solution was proposed by Esaote, who redesigned the conventional probe handle shape, proposing more ergonomically effective designed probes, appleprobe design transducers, that offer the possibility to be grasped with two or more different positions in order to reduce the sonographer's hand/wrist stress (Vannetti et al., 2014, Roberto and Fabio, 2008, Rezzonico 2011). The sonographer have been involved as direct consultants knowledgeable about both the technical and the clinical aspects of the diagnostic ultrasound systems, as a consequence of their reputation demonstrated by their track records in scientific literature about ergonomics in ultrasound systems.

As proposed by Martin (Martin et al., 2008), the field of ergonomic design of medical devices is quite challenging. Ultrasound devices represent a complex system; they are mainly composed of two separate parts, the console (including the user interfaces, such as the keyboards, the mouse trackball, the monitor and always more common, a touch screen integrated within the physical control panel) and the probes. The console can be adjustable/non-adjustable according to the producer's design constraints, with implications in the ergonomics of the system. The sonographers' workplace also includes a sitting support (chair) and the patient's bed, both being adjustable/non-adjustable (Fig. 2). In addition, the sonographers' workplace is often characterized by the presence of multiple users and where the user's possibility to personalization is in contrast with the need to limit the user intervention to minimize the risk of errors.

As proposed by Val Gregory (Val Gregory, 1998), from an industrial design point of view, being proactive in the US equipment design represents the ideal solution to foster en Ergonomic approach and try to minimize the risk of MSDs since the first phases of the design process and through a design solution.

Measurements and evaluations of ultrasound design and workflow with a multifactorial approach, considering different outputs and analysis/measurement technologies regarding biomechanical analysis and cognitive usability assessment, can be