Ultrasound in Med. & Biol., Vol. ■, No. ■, pp. 1–9, 2016

0301-5629/$ - see front matter

http://dx.doi.org/10.1016/j.ultrasmedbio.2016.01.001

● *Original Contribution*

DEVELOPMENT AND VALIDATION OF A METHOD TO MEASURE LUMBOSACRAL MOTION USING ULTRASOUND IMAGING

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(*Received* 9 *July* 2015; *revised* 20 *November* 2015; *in final form* 3 *January* 2016)

Abstract—The study aim was to validate an ultrasound imaging technique to measure sagittal plane lumbosacral motion. Direct and indirect measures of lumbosacral angle change were developed and validated. Lumbosacral angle was estimated by the angle between lines through two landmarks on the sacrum and lowest lumbar vertebrae. Distance measure was made between the sacrum and lumbar vertebrae, and angle was estimated after distance was calibrated to angle. This method was tested in an *in vitro* spine and an *in vivo* porcine spine and validated to video and fluoroscopy measures, respectively. R^2, regression coefficients and mean absolute differences between ultrasound measures and validation measures were, respectively: 0.77, 0.982, 0.67° (*in vitro*, angle); 0.97, 0.992, 0.82° (*in vitro*, distance); 0.94, 0.995, 2.1° (*in vivo*, angle); and 0.95, 0.997, 1.7° (*in vivo*, distance). Lumbosacral motion can be accurately measured with ultrasound. This provides a basis to develop measurements for use in humans. (E-mail: w.vandenhoorn@uq.edu.au) © 2016 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Spine motion, Ultrasound, *In vitro* model, *In vivo* model.**

INTRODUCTION

Intervertebral motion can be measured accurately with radiologic techniques (Breen et al. 1989; Dvorák et al. 1991a; 1991b; Pearcy 1985; Pearcy and Whittle 1982). However, repeated exposure to ionizing radiation poses health risks. Alternative methods using markers attached to the skin to represent intervertebral motion (Lee et al. 1995; Mörl and Blickhan 2006; Vanneuville et al. 1994) are not ideal because movement of the skin relative to the vertebral body means that markers may not reflect true intervertebral motion. Although this problem can be overcome by attachment of markers directly to spinous processes (Steffen et al. 1997), this is invasive and impractical for widespread use. Accurate measurement of intervertebral motion in clinical settings requires a method, which is non-invasive, easy to use and readily available.

Measurement of intervertebral motion could help to explore the relation among muscle dysfunction, reduced proprioception and low back pain, and could therefore direct rehabilitation. There is accruing evidence that control of motion at a single segment may be relevant for low back pain (Breen et al. 2012). For example, function of deep erector spinae muscles is affected at a single segment by low back pain (MacDonald et al. 2010) and spinal injury (Hodges et al. 2006) and atrophy and inhibition of these muscles might affect segmental motion (Quint et al. 1998). Reduced segmental motion would affect proprioception (Burke et al. 1978), and lower back proprioception is affected in people with low back pain (Brumagne et al. 2000). A non-invasive method to measure intervertebral motion is necessary to investigate the relation between low back pain and dysfunctions in clinical practice and in large cohorts.

Ultrasound imaging allows direct and accurate imaging of vertebral structures (from reflection of the ultrasound beam at the periosteum) and surrounding soft tissues, is readily available in clinical settings and has the potential to measure intervertebral motion accurately and non-invasively. Anatomic landmarks of the sacrum and lumbar vertebrae can be visualized reliably

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with ultrasound (Zieger and Dörr 1988). We proposed that a set of anatomic landmarks could provide the basis to estimate intervertebral motion with ultrasound imaging.

The aim of the current investigation was to develop techniques using ultrasound imaging to accurately and non-invasively measure intervertebral motion of the lumbosacral spine in the sagittal plane. A second aim was to compare these techniques against measurement of intervertebral motion made either with a video when the technique was applied to an *in vitro* spine model, or fluoroscopy when the technique was applied *in vivo* using an anesthetized pig.

MATERIALS AND METHODS

Traditionally, angle between two segments is defined by two anatomic landmarks identified on each segment (Morrissy et al. 1990). Lines can be drawn through these pairs of anatomic landmarks and the angle between the two lines used as a representation of the angle between these segments. This technique was tested using two points identified on the L5 vertebra and sacrum in a single image. An alternative method to estimate intervertebral angle change may be based on one anatomic landmark per segment when it is difficult to accurately track two points on two structures as the structures move relative to each other. This technique is based on the assumption that the distance between bony landmarks on adjacent segments changes with spinal movement in the sagittal plane and, when calibrated against a known angle change, a change in distance between posterior elements of adjacent vertebra could be used to estimate intervertebral movement. Both methods were evaluated in two separate experiments. In the first experiment, lumbosacral motion of an *in vitro* spine model was measured with ultrasound imaging and digital photography. In the second experiment, motion measured with ultrasound imaging was compared with measures made *in vivo* with fluoroscopy in an anesthetized pig.

EXPERIMENT 1: MEASUREMENTS OF INTERVERTEBRAL MOTION USING AN *IN VITRO* SPINE MODEL

Experimental set-up

A synthetic anatomic model of the spine (3B Scientific, Lumbar Spinal Column, Hamburg, Germany) was used to simulate lumbosacral motion. The model was modified by placing a one-degree-of-freedom hinge at the position of the approximate instantaneous axis of rotation (approximately one third of the distance from the dorsal aspect of the vertebral body) (Pearcy and Bogduk 1988). The hinge allowed motion in the sagittal plane (Fig. 1a). With the sacrum fixated, L5 could be moved manually (approximately 4°/s) through a physiologic range of motion (ROM) of 14° (White and Panjabi 1978).

The model was placed in a water-filled tank to facilitate coupling for ultrasound imaging (Fig. 1b). The transducer (7–10 MHz linear array) of the ultrasound system Logiq 9 (GE Healthcare, Little Chalfont, Buckinghamshire, UK) was submerged and held

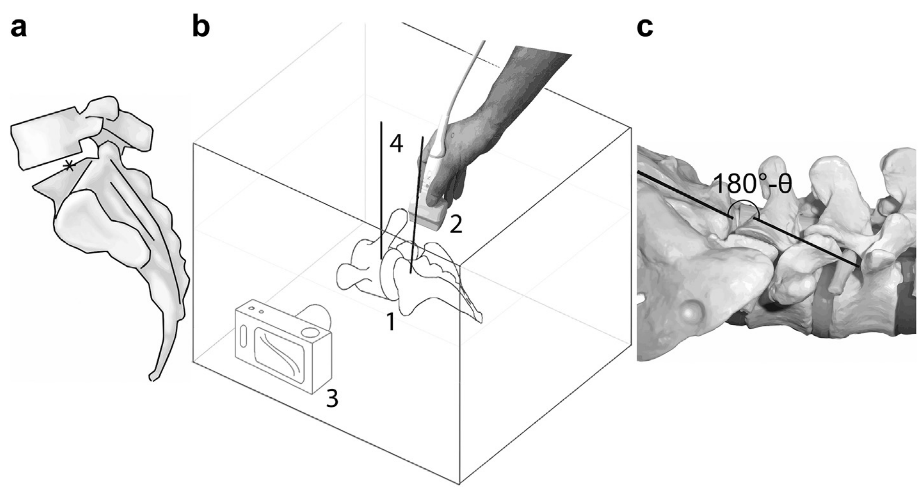

Fig. 1. Experiment 1 set-up. (a) Sagittal plane image of the spinal model used, * indicates the estimated position of the axis of rotation of L5. (b) The spinal model (1) was submerged in a water filled tank for ultrasound coupling. The ultrasound transducer was held manually. Motion of L5 in relation to the sacrum was recorded simultaneously by the ultrasound transducer (2) and digital camera (3). The angle between the sacrum and L5 estimated from the ultrasound measures were compared to the angle between the rods (4) inserted into L5 and the sacrum. (c) Angle between a line drawn through two prominent landmarks of the sacrum and a line drawn through the lamina and mammillary process of L5 used in the ultrasound measure (experiment 1, method 1).