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● *Original Contribution*

DEVELOPMENT OF A NEW ULTRASOUND-BASED SYSTEM FOR TRACKING MOTION OF THE HUMAN LUMBAR SPINE: RELIABILITY, STABILITY AND REPEATABILITY DURING FORWARD BENDING MOVEMENT TRIALS

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Abstract—The aim of this study was to develop a new method for quantifying intersegmental motion of the spine in an instrumented motion segment L4–L5 model using ultrasound image post-processing combined with an electromagnetic device. A prospective test–retest design was employed, combined with an evaluation of stability and within- and between-day intra-tester reliability during forward bending by 15 healthy male patients. The accuracy of the measurement system using the model was calculated to be ± 0.9° (standard deviation = 0.43) over a 40° range and ± 0.4 cm (standard deviation = 0.28) over 1.5 cm. The mean composite range of forward bending was 15.5 ± 2.04° during a single trial (standard error of the mean = 0.54, coefficient of variation = 4.18). Reliability (intraclass correlation coefficient = 2.1) was found to be excellent for both within-day measures (0.995–0.999) and between-day measures (0.996–0.999). Further work is necessary to explore the use of this approach in the evaluation of biomechanics, clinical assessments and interventions. (E-mail: acuesta@uma.es) © 2015 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Ultrasound, Tracking motion, Electromagnetic sensor, Human spine.**

INTRODUCTION

Low back pain is one of the most widespread health problems in the world, especially in industrialized countries, but also in developing countries (Lahiri et al. 2005). Between 70% and 85% of the population will have at least one episode of back pain in their lifetime; the prevalence of this chronic disease is 23%. In a high-population-density environment, the problem is compounded, with values reaching epidemic proportions (Deyo et al. 1998). A report issued by the English National Health Service estimated that costs of back pain per y amounted to 1.1 billion pounds, with only physiotherapy services receiving 1.3 million people, involving an expenditure of 150 million pounds (Critchley et al. 2007). Similarly, in 1 y in Spain, approximately 3.17 million people will suffer from back pain, with a prevalence of 68% and a total cost of 9.296 billion euros (1816€ direct cost-indirect cost 7480) (Cátedra extraordinaria del dolor 2006).

A range of measurement tools are available to evaluate motion in the lumbar spine, although many have not been investigated for their reliability. This lack of reliability data compromises their suitability for use in evaluating the effectiveness of clinical interventions for lumbar spine motion. However, it is widely accepted that the use of reliable outcome measures as a means of evaluation is fundamental to evidence-based practice.

There are non-invasive methods for measuring spine movement: inclinometer technique (Dillard et al. 1991; Mayer et al. 1984); Schober technique (Miller et al. 1992); fingertip-to-floor method (Gauvin et al. 1990); video-optical and electromagnetic measuring devices (McGill 1992); fiberoptic devices (Williams et al. 2010). However, these external measurements may not reflect true intersegmental movement, and limitations have already been reported when measuring single-segment movement (Nitschke et al. 1999).

More invasive methods are also in use: 3-D lumbar motion analyses by radiography (Pearcy and Tibrewal 1984); video fluoroscopic or cineradiographic analyses (Cholewicki and McGill 1992); and Kirschner wires inserted into the spinous process (Steffen et al. 1997). Although these studies have provided unprecedented

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insight into intersegmental vertebral motion and validation for future pin/screw-based studies, the transfer of knowledge to clinical applications from invasive methods is limited.

Through use of an inclinometer attached to an ultrasound transducer, with the subject in a prone position, a measure in degrees of the vertebral position relative to the horizontal plane was acquired from an image of the laminae at each level in the spine (representative of vertebra position) (Burwell et al. 1999; Kirby et al. 1999; Suzuki et al. 1989). Furthermore, measures of laminar rotation obtained by this method significantly correlated (at 95% confidence) with vertebral rotation measurements obtained by X-ray, despite differences in test positions. Vertebral rotation was found to be measurable to within ± 3.1° using this approach (Kirby et al. 1999).

A method for tracking motion could be constructed by coupling a synchronized electromagnetic device to the ultrasound transducer, where the resulting image could be used to track the motion of laminar vertebrae. The real motion of laminar vertebrae would be then the sum of the motion of the transducer and whatever is observed in the image (Heneghan et al. 2009). In this study, Heneghan et al. acquired an ultrasound image of T1 spinal laminae in the horizontal plane to track the axial rotation in C7–T1. However, the study did not use image processing to track the movement in ultrasound images before adding the motion of the transducer with the sensor data. Intra-tester reliability (intra-class correlation coefficient [ICC] = 2.1) was excellent within a day (0.89–0.98) and good/excellent between days (0.72–0.94) (Heneghan et al. 2009). In this way, accurate measurements of intervertebral motion may be possible by inducing out of plan motion. However, incorporation of image processing and a coordinate transform system could improve this method.

The aim of this study was to develop a method for visualizing and quantifying intersegmental motion in the human lumbar spine in an instrumented motion segment L4–L5 model, by combining ultrasound imaging with an electromagnetic device. The stability and reliability of data over repeated measures during forward bending in healthy male patients were evaluated. Stability is the ability of a tool to produce consistent results during measurements of the same entity on repeated occasions (Sim and Wright 2000). Note that because of the viscoelastic properties of tissues (stress relaxation and hysteresis), range of motion may change with increasing repetitions. Once stability is established, intra-tester reliability may be investigated. Within- and between-day intra-tester reliability provides an indication of how useful a method is at detecting changes in motion after clinical interventions.

METHODS

Study design

A prospective test–retest design was employed, combined with evaluation of stability and within- and between-day intra-tester reliability. A convenient sample of asymptomatic male patients (n = 15) was recruited based on a power calculation, where it was determined that >13 patients were needed to achieve a 5% significance level for reliability (ICC) powered at >0.70 (Walter et al. 1998). Ethical approval was obtained from the Faculty of Health Science of University of Malaga, and all participants were asked to sign an informed consent.

Participants

Patients were excluded if self-reporting revealed they had a current or previous neuromusculoskeletal spine condition, pre-existing systemic rheumatological condition, previous abdominal surgery or chronic respiratory condition.

Equipment

The Polhemus Liberty (Polhemus, Colchester, VT, USA) was used for motion analysis. Ultrasound images

Fig. 1. The electromagnetic sensor (black hexagonal) was fixed, using a specific wooden piece, to the top of the transducer to avoid interference, and the source transmitter was mounted in front of the patients.