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Technical note

Assessment of non-invasive intervertebral motion measurements in the lumbar spine

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Abstract

This study compared the accuracy of new, FDA-approved, image-analysis software to conventional radiographic assessment techniques for the measurement of intervertebral motion. Six adult human cadaveric lumbar spines (L1–S1) were individually mounted in a custom Plexiglas device and electromagnetic sensors were rigidly mounted to the spinous processes of L3, L4, and L5. Lateral radiographs of the spines in neutral, full flexion, and full extension were digitized and analyzed both using the software and manually by three orthopedic surgeons. Compared to intervertebral rotations determined from the electromagnetic device, the errors in rotations reported by the software and surgeons were $0.47 \pm 0.24^\circ$ and $2.16 \pm 0.78^\circ$, respectively. Rotations measured by the surgeons were significantly less accurate and more variable than that of the software ($p < 0.05$).

Keywords: Lumbar spine; Kinematics; Intervertebral motion; Image-processing

1. Introduction

Trauma, aging, infection, tumor, and failed surgery all can adversely affect intervertebral motion (IVM) in the spine. Recently, investigators have developed various non-invasive methods of recording the kinematics of the lumbar spine (Axelsson et al., 2000; Gunnarsson et al., 2000; Kooi et al., 2004; Maigne et al., 2003; Powers et al., 2003; Rogers et al., 2002; Zheng et al., 2003). These methods are important research tools, but do not provide a clinical tool physicians can readily use with conventional radiographs. Although conventional radiographs of the spine are commonly used to assess any possible abnormalities in IVM, several research studies have shown poor accuracy and poor inter- and intra-observer agreement (Blumenthal and Gill, 1993; Brodsky et al., 1991; Kant et al., 1995). New image-analysis software (QMA^{TM}, Medical Metrics, Inc.) has recently been developed and was approved by the FDA to make non-invasive IVM measurements from digital radiographic images. The goal of this study was to use an electromagnetic tracking device to assess the accuracy of the software compared to conventional radiographic assessment techniques in measuring sagittal plane IVM from lateral radiographs.

2. Materials and methods

2.1. Calibration

The 3Space sensors used to measure the actual IVM have a static accuracy of 0.76 mm in translation and 0.15° in orientation (Polhemus, Inc.). To verify the accuracy of the 3Space sensors, eight holes were machined into the surface of a Plexiglas plate to an accuracy of 0.005 mm. The distance between the holes was therefore very precisely defined and facilitated tests of the accuracy of the digitizer. A custom digitizer tip

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designed to press-fit into holes on the calibration plate was affixed to one of the 3Space sensors. Data was collected from each of the eight positions with the sensor in the same orientation, and the distances between the positions were calculated.

2.2. Experimental setup

Six fresh adult human cadaveric lumbar spines consisting of segments L1–S1 were removed of muscles while preserving the spinal ligaments, facet joint capsule and intervertebral discs. The interspinous ligaments and intervertebral discs were partially sectioned to allow the spine to flex and extend with only modest force. Using a fine-tip permanent marker, a small dot was placed on 12 anatomical landmarks corresponding to the anterior and posterior aspects of the superior and inferior endplates of the L3, L4, and L5 vertebrae.

The specimens were fixed in a custom Plexiglas device that could hold the spine rigidly in flexed, neutral, and extended positions with the flexion/extension plane aligned horizontally (Fig. 1). Electromagnetic sensors (The MotionMonitor, Innovative Sports Training, Inc.; 3Space Fastrak, Polhemus, Inc.) were rigidly mounted to the spinous processes of the L3, L4, and L5 vertebrae using Plexiglas bone-mounting pins without infringing on adjacent vertebral structures.

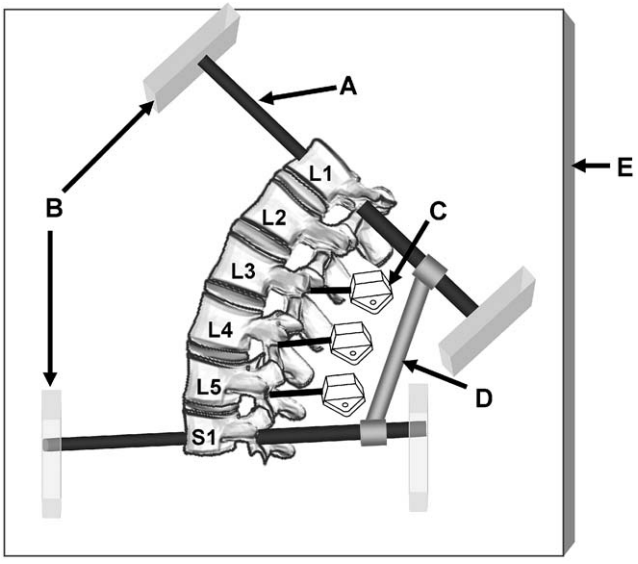

Fig. 1. View from above of the custom Plexiglas device with the spine rigidly fixed in extension. The apparatus is comprised of: (A) Plexiglas k-wires inserted into L1 and S1 for positioning the specimen; (B) blocks to suspend the k-wires and the specimen above the surface of the Plexiglas plates; (C) 3Space sensors inserted into L3, L4 and L5 for recording the position and orientation of the vertebrae; (D) locking rod to be placed posterior to the spine for extension and anterior for flexion; (E) four Plexigas plates situated between the specimen and the X-ray film for attenuation of X-rays. Note: For clarity, the four Plexiglas plates, placed above the specimen for X-ray attenuation, are not shown.

The global coordinate system was defined so that the flexion/extension plane, the $X-Y$ plane of the electromagnetic device, as well as the imaging plane of the X-ray equipment were coincident. Eight one-inch thick plates of Plexiglas were positioned in the path of the X-rays (four above and four below the specimen) to simulate the attenuation and scatter of X-rays that occurs due to soft tissues in clinical radiographs. The X-ray source (Gendex-Del; CPI Millenia Series) was positioned above the specimen, 1 m from the X-ray cassette; X-ray parameters were fixed for all images (82 kV, 200 mA, 160 mS).

2.3. Data collection

Data collection was separated into two phases. The errors in IVM were assessed between the software and surgeons in Phase 1 by comparing intervertebral rotations (L3/L4 and L4/L5) in the absence of any actual IVM, and in Phase 2 by comparing the rotations, anterior and posterior disk heights, and shear, in specimens positioned in neutral, full extension, and full flexion. In both phases, intervertebral rotations were calculated as the difference in rotations relative to the neutral position. Errors were calculated as the difference between the software and surgeon measurements of the rotations (L3/L4 and L4/L5) and the 3Space rotation measures. Errors in disk height and shear measurements were reported as the absolute difference between the software predictions and those calculated from the electromagnetic system.

2.3.1. Phase 1

The entire specimen was radiographed in three positions (neutral, 15° clockwise, and 15° counter-clockwise), without inducing any IVM by rotating the Plexiglas plate on which the specimen was supported. An object of known dimension was placed within the workspace to scale the values obtained from the software. Plain film radiographs were digitized using a high-resolution film digitizer (Eastman Kodak Co.), and imported into the software that quantified rotations. Following the data collection from all six specimens, three experienced spine surgeons assessed the intervertebral rotations from the radiographic films in randomized order using conventional radiographic techniques.

2.3.2. Phase 2

Data were collected with the specimens in neutral, full flexion, and full extension with an object of known size within the workspace to account for scaling within the software. A lateral radiograph was obtained and then the custom 3Space digitizer was used to collect landmark data from the 12 previously marked landmarks. Following digitization, 1.55 mm diameter lead beads