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A method to perform spinal motion analysis from functional X-ray images

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ABSTRACT

Identifying spinal instability is an important aim for proper surgical treatment. Analysis of functional X-ray images delivers measurements of the range of motion (RoM) and the center of rotation (CoR). In today's practice, CoR determination is often omitted, due to the lack of accurate methods. The aim of this work was to investigate the accuracy of a new analysis software (FXA^{TM}) based on an *in vitro* experiment.

Six bovine spinal specimens (L3-4) were mounted in a robot (KR125, Kuka). CoRs were predefined by locking the robot actuator tool center point to the estimated position of the physiologic CoR and taking a baseline X-ray. Specimens were deflected to various RoM_{preset} flexion/extension angles about the CoR_{preset}. Lateral functional radiographs were acquired and specimen movements were recorded using an optical motion tracking system (Optotrak Certus). RoM and CoR errors were calculated from presets for both methods. Prior to the experiment, the FXA^{TM} software was verified with artificially generated images.

For the artificial images, FXA^{TM} yielded a mean RoM-error of $0.01 \pm 0.03^\circ$ (bias $\pm$ standard deviation). In the experiment, RoM-error of the FXA^{TM}-software (deviation from presets) was $0.04 \pm 0.13^\circ$, and $0.10 \pm 0.16^\circ$ for the Optotrak, respectively. Both correlated with 0.998 ($p < 0.001$). For RoM $< 1.0^\circ$, FXA^{TM} determined CoR positions with a bias > 20 mm. This bias progressively decreased from RoM $= 1^\circ$ (bias $= 6.0$ mm) to RoM $= 9^\circ$ (bias < 1.5 mm).

Under the assumption that CoR location variances < 5 mm are clinically irrelevant on the lumbar spine, the FXA^{TM} method can accurately determine CoRs for RoMs $> 1^\circ$. Utilizing FXA^{TM}, polysegmental RoMs, CoRs and implant migration measurements could be performed in daily practice.

1. Introduction

Diagnostic and clinical investigation of the spine still remains challenging. *In vivo* functional X-ray images are often used to identify spinal biomechanics. Functional radiographs consist of a pair of X-ray images taken at two maximum end positions (for example full flexion and full extension) or between the neutral and one extreme position. One parameter of quantifying spinal biomechanics is the intervertebral range of motion (RoM) (Putto and Tallroth, 1990; Harvey and Hukins, 1998; Iguchi et al., 2004), which provides a base for interpreting the functional status of the spine. In the past, it was shown that proceeding disk degeneration alters spinal biomechanics (Mimura et al., 1994) effecting the intervertebral RoM. A further way to characterize the behavior of motion segments involves the determination of the center of rotation (CoR) between two vertebrae (Cossette et al., 1971; Dimnet et al., 1978), because the CoR displays the vertebral motion path and can be used to detect and quantify pathologies and possibly support the selection of the proper surgical treatment. Artificial disk prostheses and dynamic stabilization methods offer a possibility to preserve physiological spinal mobility. Evaluating the *in vivo* performance of such devices as part of the evidence-based medicine (Rousseau et al., 2008; Wachowski et al., 2009; D.K. Park et al., 2010; J.J. Park et al., 2010) requires accurate measurements of the CoR and RoM.

Limiting factors in clinical practice are possible misinterpretation of functional radiographs due to varying quality, reproducibility and missing standards for measurements (Pitkänen et al., 1994, 1997). Furthermore, it was demonstrated that manual methods are very limited due to substantial inter- and intra-observer variability (Schuler et al., 2004; Leone et al., 2009). Cakir et al. (2006) reported a 95% confidence interval of $\pm 4^\circ$ for the best manual method found, which is still dependent on the level of experience.

A higher accuracy in detecting intervertebral motion is provided by computerized image processing methods (Breen et al., 1988; Weiler et al., 1990). Generally, image processing involves overlaying two X-ray images in such a way that a specific vertebra

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