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A New Model-Based Tracking Technique for Measuring and Visualisation of Three-Dimensional Motion of the Lumbar Spine

Stefan Döbele[1], Oliver Erne[2], Werner Schmölz[3], Thomas Freude[4], Christian Konrads[5*]

[1]*Department of Trauma and Reconstructive Surgery, BG Klinik, University of Tübingen, Germany*

[2]*GOM GmbH (a ZEISS company) – Precise Industrial 3D Metrology, Braunschweig, Germany*

[3]*Department of Biomechanics, University Innsbruck, Austria*

[4]*Department of Orthopaedics and Traumatology, University of Salzburg, Austria*

***Correspondence to:** Christian Konrads, Department of Trauma and Reconstructive Surgery, BG Klinik, University of Tübingen, Germany, E-mail: christian.konrads@gmail.com

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Abstract

There are different methods to detect three-dimensional motions in biomechanical testing. Optical motion analysis or ultrasound-based systems seem to be the gold standard and have been described in previous studies. However, measuring the three-dimensional motion of a complex structure such as the lumbar spine is still challenging. With the current study, we introduce a new method to measure and at the same time to visualise the complex three-dimensional motion of the lumbar spine. It is a model-based tracking technique. We matched the three-dimensional motion of a lumbar spine with an optical motion analysis system. This was conducted in a spine testing machine with a 3D reconstruction from a CT scan. This method allows for visualization of the in vitro recorded motion of a lumbar spine using a normal CT dataset. Furthermore, the motion of the lumbar spine could be analysed in areas that were not seen by the two cameras of the optical motion tracking system. This method facilitates future research of the locomotor system using complex motion analysis in biomechanical testing.

Keywords: Biomechanics; Kinematics; Optical Tracking; Movement Analysis.

Introduction

There are different methods to detect three-dimensional motions in biomechanical testing. Optical motion analysis or ultrasound-based systems seem to be the gold standard and have been described in previous studies [1-6]. However, measuring the three-dimensional motion of a complex structure such as the lumbar spine is still challenging.

With the current study, we aimed to develop a new method to measure and at the same time to visualise the complex three-dimensional motion of the lumbar spine. It is a model-based tracking technique. We matched the three-dimensional motion of a lumbar spine with an optical motion analysis system. This was conducted in a spine testing machine with a 3D reconstruction from a CT scan.

This method should allow for visualization of the in vitro recorded motion of a lumbar spine using a normal CT dataset. Furthermore, the motion of the lumbar spine shall be analysed in areas that can't be seen by the two cameras of an optical motion tracking system. This study aims to improve and develop new possibilities for analysing complex motions of the musculoskeletal system. This could be used for future orthopaedic research and biomechanics.

Materials and Methods

Three fresh frozen lumbar spine specimens (L1–5) were used to investigate the biomechanical physiological range of motion in a spine tester (Figure 1).

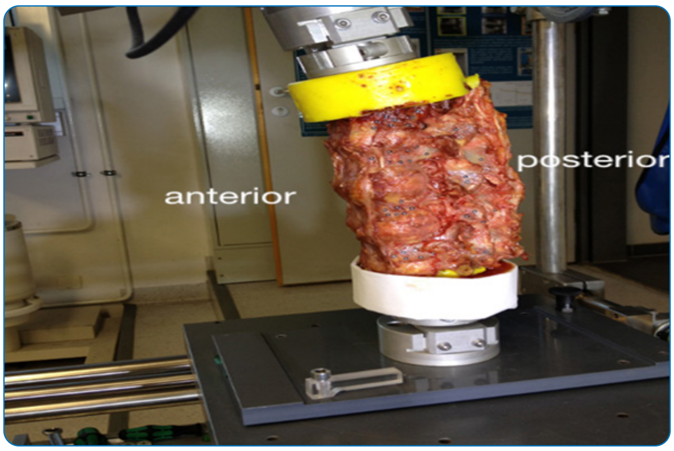

Figure 1: Human lumbar spine in a spine tester to simulate real flexion and extension.

The three-dimensional motion of the specimens was measured with two methods:

1.Zebris: using the motion analysis system Zebris (Isny, Germany). Zebris is a standard measuring system for biomechanical tests based on ultrasound measurements.

2.PONTOS 5M: using the optical motion analysis system PONTOS 5M (GOM, Braunschweig, Germany). With this system it was possible to match the motion measurements with the images of a CT.

Using the dataset from the Zebris system, a validation of the PONTOS system was possible. The Zebris system was fixed to the spine by inserting screws in each vertebral body. To analyse the motion with the PONTOS system, passive markers were attached to each vertebra. Additionally, artificial landmarks were placed on each vertebra using carbon pins.

ACT scan of each spine was performed. The CT dataset was segmented using the software AMIRA. A 3D model of each vertebra was saved as an stl-Dataset. The stl-data was imported to the PONTOS software and matched with the recorded three-dimensional motion (Figure 2). The matching was perform using the artificial landmarks.

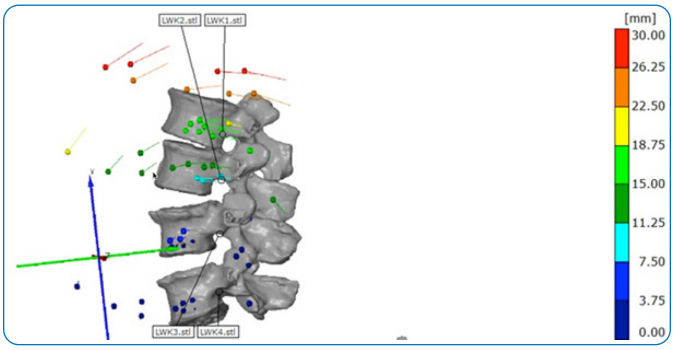

Figure 2: Visualisation of three-dimensional motion of a lumbar spine using a CT dataset and the PONTOS 5M system.

Results

The optical motion analysis system PONTOS 5M produced results that were in excellent agreement with the Zebris system. While the detection of the rotation was easy with both systems, the measurement of the deviation in x-,y-, and z-axis was much more easier using the PONTOS system than it was using the Zebris system – because the passive markers of the PONTOS system could be directly attached to the vertebral bodies. The visualisation of the three-dimensional motion helped to analyse and understand the complex motion of the lumbar spine (Figure 3). (Figure 4) shows the amount of motion measured for extension/flexion, side bending, and rotation in the lumbar spine.

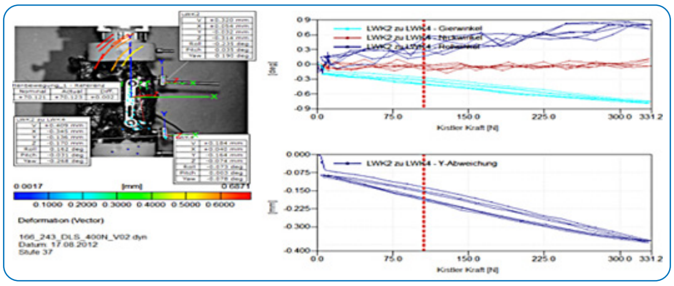

Figure 3: Motion detection measurements of the lumbar spine with the optical motion analysis system PONTOS 5M.

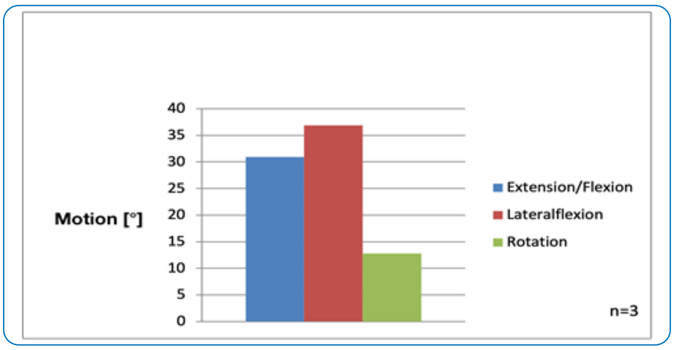

Figure 4: Mean amounts of total motion measured in the lumbar spine specimen for the three standard planes: sagittal, frontal, and axial planes.

Discussion

We demonstrated that angular deviation measurements can be performed using the PONTOS 5M System. There was no compromise regarding the accuracy of measurements using the PONTOS system in comparison with the Zebris system. In fact, the displacement in x-, y-, and z-axis could be measured in an easier and more convenient way using the PONTOS system.

The key benefit of the optical system that was used in this study is the possibility to visualise the three-dimensional motions. This allows for a closer examination also in areas that were not seen by the two cameras of the optical motion system.

The described method was validated using a biomechanical lumbar spine model. For future research, it might be used to analyse different functional units of musculoskeletal system. The method could be beneficial for assessing large joints of the human body or a whole hand as complex functional systems.

For example, at the knee joint, it might be interesting to analyse and visualize normal movements. Furthermore, the described method could help to understand complex patterns of knee joint instabilities, which can only be assessed fully in a three-dimensional setting.

Also, the understanding of artificial joints or total knee arthroplasty (TKA) would probably increase using the method presented here. This could be transferred to other joint of interest.

Especially the complex functional anatomy of the elbow could be investigated further. Elbow instabilities might be better understood. Clinically, the stiff but unstable elbow is still a challenge.

The shoulder joint with its high range of motion (ROM) and its complex interaction of bony, passive and active soft-tissue stabilizers is another anatomical region that could well benefit from further options of biomechanical analysis.

Like the spine, other functional kinetic chains cannot be analysed successfully in an isolated manner. One might think of malalignments of the lower extremities. The planning and conducting of realignment osteotomies still are important topics in musculoskeletal surgery, where further improvements are really needed urgently [7]. For sure, establishing a standard for three-dimensional routine diagnostics and planning of surgery would be a milestone of improvement to orthopaedic surgery and traumatology [8].

Combining the described method with measurements of forces like ground- and joint reaction forces would be another big milestone for the future. All disciplines interested in biomechanics of the human body, musculoskeletal care and reconstructive surgery should work to together to reach this shared goal of simple but comprehensive analysis of three-dimensional movements, moments, and forces of the locomotor system in individual patient. This could then further be used to analyse and improve the technique of athletes in different sports. Deeper understanding and new knowledge in this regard could not only help to reach higher levels of success in sports with more or less demanding techniques, but this information could also be used to promote success in preventive medicine. Pathologies due to wrong sport technique or overuse could be prevented or diagnosed at a subclinical grade. This is especially important in children specializing in a certain sport at an early age.

The main limitation of this study might be seen in the fact that in vitro motion analysis might differ from in vivo spine biomechanics. Given that the aim of this study was to prove the methodical concept in a feasible standard laboratory setting, the authors agreed on the sufficiency of the design chosen in this study.

In conclusion, this study introduces a new method to measure and at the same time to visualise the complex three-dimensional motions of the lumbar spine. It is a model-based tracking technique, that might have the potential to become standard in biomechanical analyses. This method allows for visualization of the in vitro recorded motion of, for instance, a lumbar spine using a normal CT dataset. Furthermore, the motion of the lumbar spine can be analysed in areas that were not seen by the two cameras of the optical motion tracking system. This method facilitates future research of the locomotor system using complex motion analysis in biomechanical testing.

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