Biomechanical Testing of Spinopelvic Instrumentations Using an Anatomy Based Test Model

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INTRODUCTION: Spinopelvic fixation is often used to stabilize sacral fractures or for caudal anchorage during spinal deformity surgeries. However, such procedures are associated with a high failure rate of the implants [1]. This is most likely caused by the high bending loads following multisegmental vertebral fusions and the complex kinematics in the bridged sacroiliac joints (SIJ) resulting from alternating loading with nutation and counternutation as well as inflare and outflare movement [2]. However, these physiological loading conditions are not a standardized part of the preclinical evaluation of SIJ bridging implants. Therefore, the aim of this work was to develop a test model that represents the basic physiological mechanisms of the SIJ to generate the complex loading situation of spinopelvic instrumentations and, from this, is able to replicate clinically relevant failure modes.

METHODS: Based on the dimensions and the landmarks of an average CT scan of 98 patients, an experimental test model was developed including L4 and L5 vertebrae, sacrum, ilium including SI-joints and pubic symphysis and proximal part of the femur. The articulating SIJ surfaces were shaped as spherical segments with low distal congruency. The model incorporated a sacral slope of 40° and a pelvic tilt of 12°, whereas the top border of L4 was set horizontally. The bony parts were built from 3D printed polyamide and a silicone element was used to create the pubic symphysis. Hip joints have been replicated with hip cups and heads. Pre-tensioned wires and passively activated springs were used to connect the landmark-based attachment points of seven ligaments and muscles. A cyclic proximo-distal displacement of the L4 vertebra leads to a complex movement at the SIJ. The model can be loaded in a symmetrical double leg loading situation, where both femurs are connected to the ground support. Furthermore, the model can be transferred into a right or left sided single leg loading situation by changing the configuration of the ground support with a horizontal actuator. After initial kinematics were measured for the native configuration (ARAMIS 12M, Carl Zeiss GOM), the model was instrumented with a common spinopelvic fusion, consisting of a bilateral pedicle screw construct (L4 to S1), connected to bilateral iliac screws using connectors. These constructs were subjected to the native loading situation using a single leg/ double leg stance mixed cyclic loading protocol until failure.

RESULTS: The test model generates a symmetrical inflare-outflare movement of the two ilia (0.3°), characterized by an opening of the pubic symphysis, in combination with a nutation-counternutation movement (0.6°). Changing the ground support to single leg stance, the kinematics change to an asymmetric situation. When instrumented with a spinopelvic instrumentation, the basic kinematic behavior of the model did not change. By applying cycling loading, the test model was able to generate a failure of the spinopelvic instrumentation, which is close to failure modes reported in literature [1].

DISCUSSION: The described test model creates a complex movement of the SIJ, which is based on physiological mechanisms and is well in line with reported values of biomechanical in vitro and in vivo studies [3]. Changing the loading situation between double leg stance and single leg stance support creates an alternating loading of the implants. Subjecting a spinopelvic instrumentation to this complex loading scenario can replicate clinically relevant failure modes.

SIGNIFICANCE: Replicating clinical failure modes for common spinopelvic instrumentations using a complex test model will help to understand the clinical loading situation. This can evolve preclinical testing and thereby provide a basis for further improvement of spinopelvic implants and the according instrumentation techniques.

REFERENCES: 1. Guler et al. 2014; 2. Kiapour et al. 2020; 3. Casaroli et al. 2020

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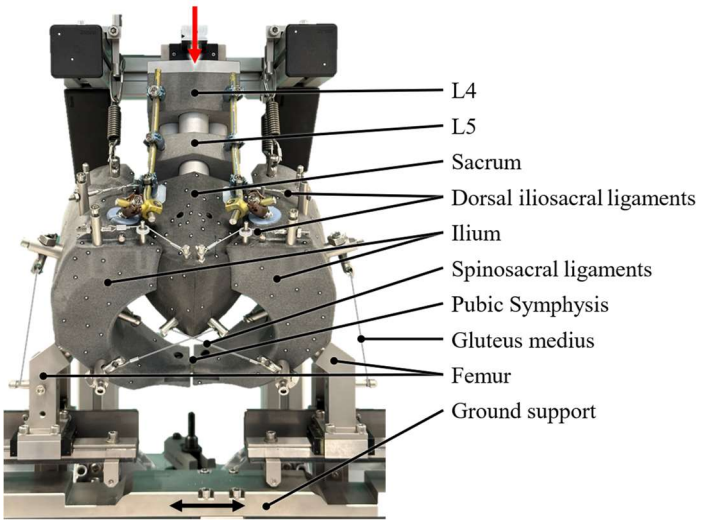

Fig. 1: Anatomy based model of the SIJ with spinopelvic instrumentation.

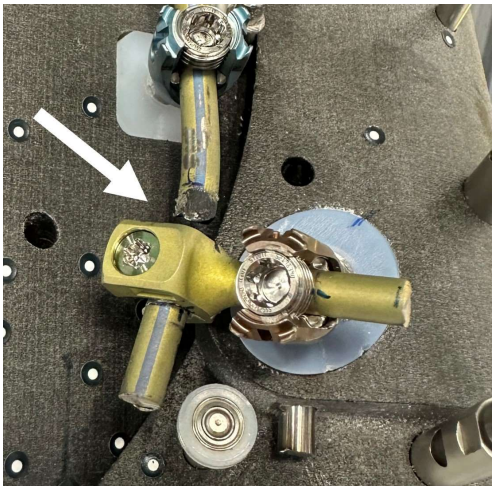

Fig. 2: Failure of the rod within the connector interconnection.