BIOMECHANICAL MODELLING OF THE WRIST FOR PATIENT ADAPTED MODEL GUIDED THERAPY

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INTRODUCTION

From a mechanical point of view, the wrist represents the most complex joint in the body, providing a large range of motion in the flexion-extension (FE) and radial-ulnar-deviation (RUD) planes. Anatomically, the wrist could be divided into two carpal rows. Deeper insight into wrist biomechanics is highly desirable, because the complex wrist structure causes a variety of possible injuries and treatments [Gelberman 2000, Lichtman 1997]. Especially scapho-lunate-ligament (SLL) deficiency remains an unsolved problem in hand surgery [Lee 2014]. To understand and treat wrist injuries and degenerative changes, respectively, it is essential to understand the carpal biomechanics, including the function of the soft tissue.

Although biomechanical models can be used to evaluate the wrist joint of the patient pre- and post-surgery, in current clinical practice the surgical planning is mostly based solely on the clinical diagnosis. The clinical status depended primary to its radiographic appearance, secondary to additional image techniques up to an arthroscopic intervention for the final diagnosis.

We developed a simulation model under the framework of multi-body-systems (MBS) methodologies. Information derived from further biomechanical *in vitro* studies were used to validate the underlying developed model by following the methods of an experimental study of physiological wrist motion and in case of simulated SLL-rupture. The approach of using computer simulation could be useful for e.g. the simulation and validation of surgical techniques, the development of implants, and for preoperative planning of wrist joint surgery. This information cannot be acquired or proofed *in vivo*.

The objective of this pilot study was, to show that the presented simulation model of the wrist joint could be used for dynamic computer based modelling of physiological and pathological motion behaviour of the wrist.

MATERIALS AND METHODS

The implementation of the wrist model was performed with the AnyBody-Modelling-System (AMS) (V.6). The AMS enables inverse-dynamic modelling including a so called force-dependent-kinematics (FDK) approach for the modelling of free form surface interaction of rigid bodies. The new developed MBS wrist model (Fig. 1A) includes detailed information of the two forearm bones radius and ulna, eight wrist bones (scaphoid, lunate, triquetrum, pisiform, trapezoid, trapezium, hamate, and capitate), and five metacarpal bones. Furthermore, 67 ligaments and five forearm muscles were implemented. In case of FDK modelling, the motion of each wrist bone is allowed to move in six degrees of freedom and depend only on the bony and ligamentous constraints. Furthermore, a method for patient-specific model adaption, the so called bone-morphing, was implemented, and a linear scaling approach for considering the cartilage layer of the bones.

For three subjects taken from the open source database from Moore et al. [Moore 2007] we simulated FDK-based the physiological RUD (SLL ligament-stiffness = 66[N/mm]), the pathological motion behaviour of an imitated SLL-rupture (SLL ligament-stiffness = 0[N/mm]), and furthermore, for the case of a virtual reconstructed SLL-rupture (SLL ligament-stiffness = 660[N/mm]). The results were directly compared to their corresponding *in vivo* data. We choose the RUD because during RUD the relative motion of the two carpal rows are more complex [Lichtman 1997].

RESULTS

The results are represented in Fig. 1 and 2. Fig. 1B visualizes the differences between physiological RUD in comparison to pathological RUD behaviour of the SLL-rupture. In case of SLL-rupture the gap between scaphoid and lunate is extended. Also the orientation of the scaphoid and lunate differs in the pathological case from the physiological.

Fig. 2 includes the differences of the simulation results to the experimental data of the Moore-database during RUD in the simulated physiological case, with SLL-rupture, and in the reconstructed case. The reconstructed case shows small differences from the physiological.

DISCUSSION

In present-day society, chronic musculoskeletal disorders are a growing problem. The presented MBS model of the wrist joint seems to approximate the physiological, pathological and virtual reconstructed kinematics of the human wrist joint quite reasonably..

The MBS wrist model was able to reproduce valid physiologic ranges of motion with small differences to the *in vivo* data, and also pathological trends, when compared to experimental results. The model replicated the results of the *in vivo* studies of Moore et al. [Moore 2007] for n=3 in its entirety, with comparably good results for the physiological case. For the physiological and pathological case the acquired kinematic data of the selected carpal bones was in agreement with previously published data e.g. [Werner 2011]. The kinematical behaviour of the scaphoid and lunate for the RUD were within the same range as reported in the literature.

This simulation-study indicates that there exist individual changes of the kinematic of the scaphoid and lunate after SLL-rupture compared to the physiological and reconstructed case. Nonetheless, the results of the present study are promising and provide a good biomechanical basis for further investigations in the context of wrist kinematics. A better understanding of the carpal biomechanics could support a patient specific optimization of therapeutically measures based on simulations using image based personalized modelling.

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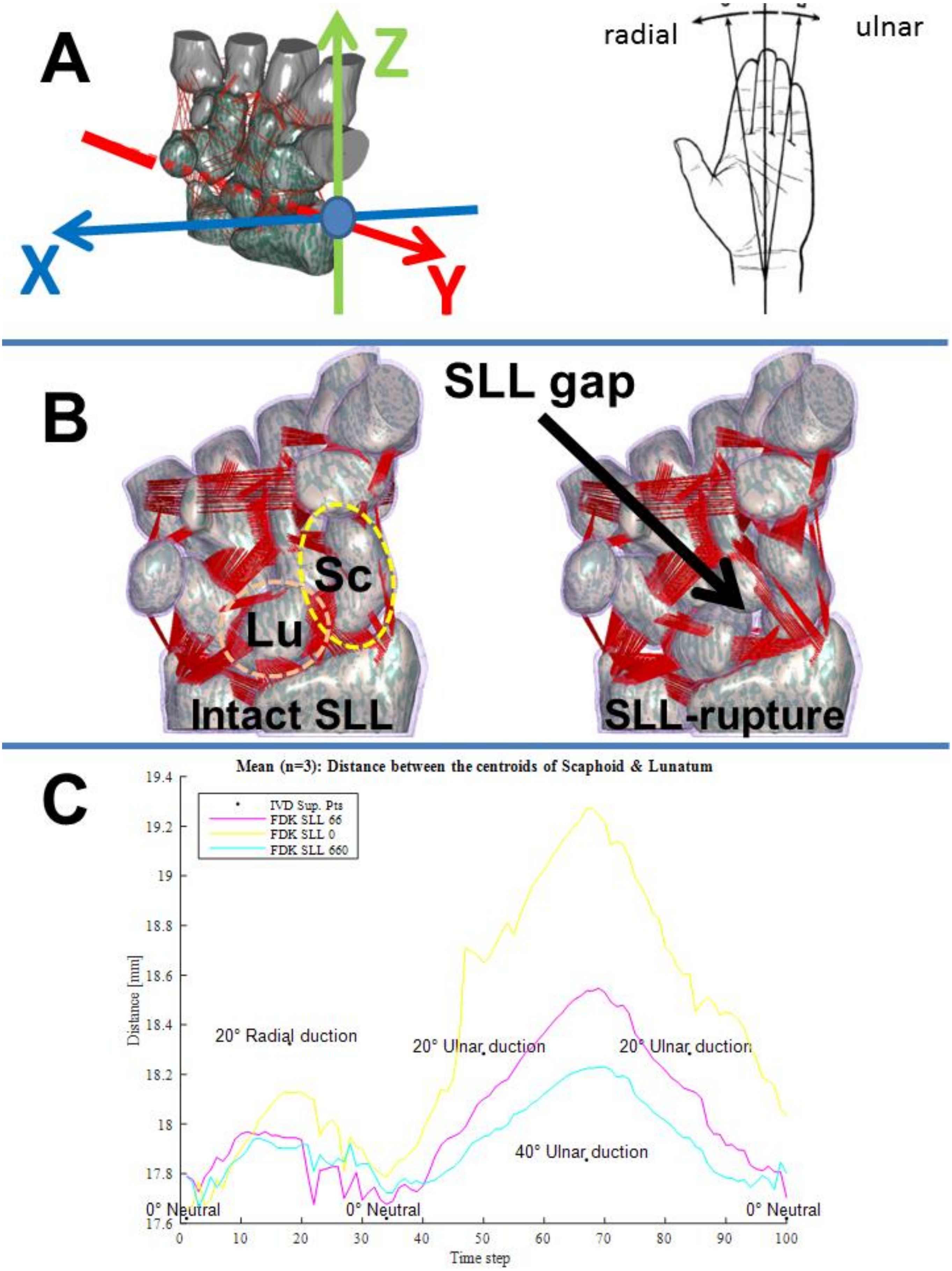

Figure 1: A: Reference coordinate system of the wrist and on the right side: schematic RUD motion; B: left side - orientation of the scaphoid and lunate during RUD with intact SL-ligament; right side - orientation of the scaphoid and lunate during a simulated SL-ligament rupture with an extended gap between both bones; C: Mean distances between the centroids of the scaphoid and the lunate during RUD motion for n=3

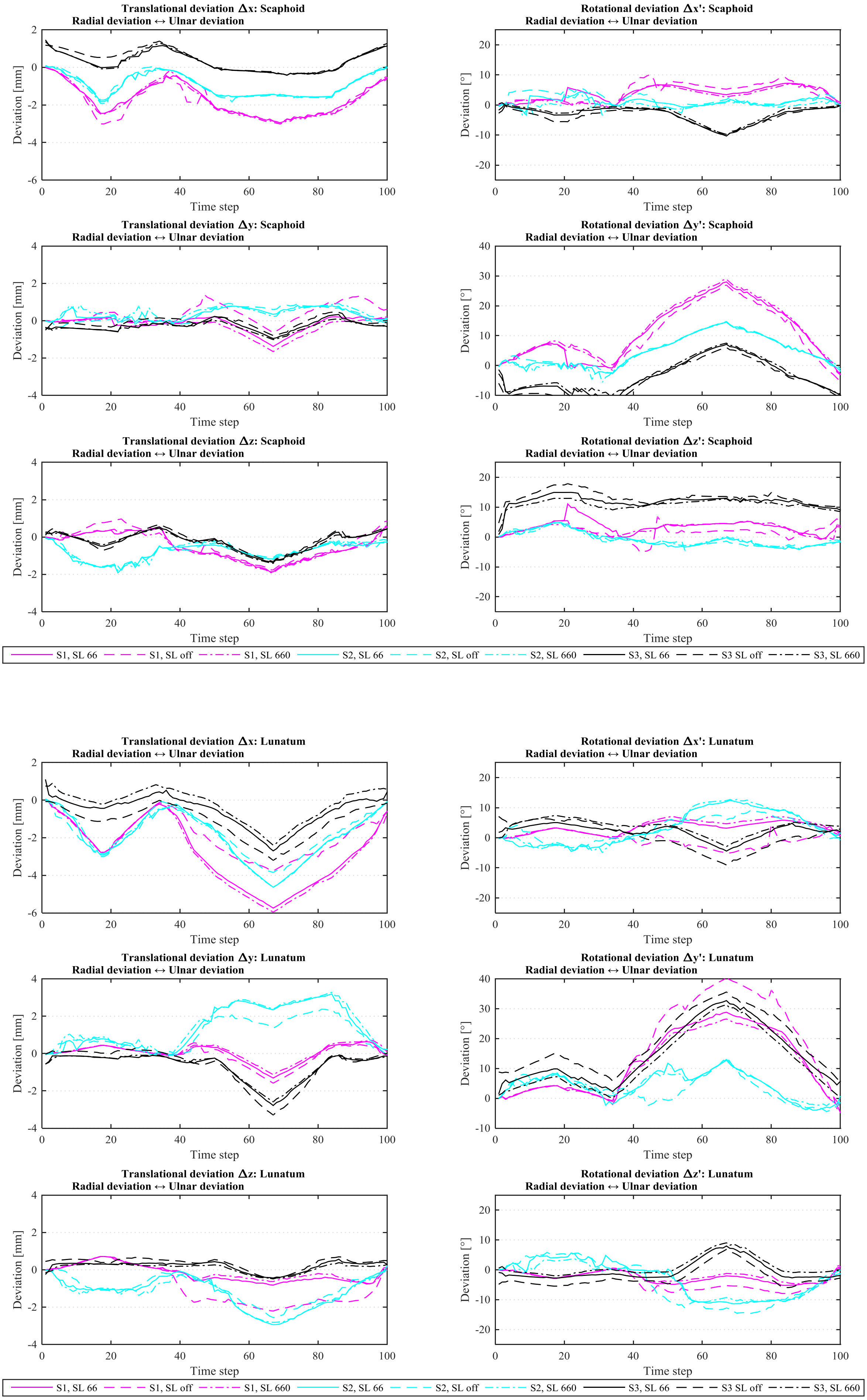

Figure 2: RUD simulation results of scaphoid and lunate of the MBS-model of the wrist joint in different cases: physiological, SL-ligament rupture, and reconstructed SL-ligament