SPATIAL MECHANISMS FOR KINEMATIC ANALYSIS OF THE KNEE AND ANKLE JOINTS

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INTRODUCTION

In virtually unloaded conditions, the tibiofemoral (knee) and tibiotalar (ankle) joints behave as single degree-of-freedom systems [1,2]. In these conditions, fibres within the ligaments remain nearly isometric throughout the flexion arc and articular surfaces do not deform considerably. Relevant theoretical models show that ligaments and articular surfaces act together as mechanisms to control passive joint kinematics. In the knee, isometric fibres were identified within the ACL, PCL, MCL ligaments, and rigid contacts were associated to the two condylar articular surfaces [3,4]. In the ankle, isometric fibres were identified within the calcaneal-fibular and tibio-calcaneal ligaments, and rigid contacts were associated to the articular surfaces between the tibio-fibular mortise and the talus [5]. Important enhancements have been achieved recently, with more accurate experimental data, more anatomical model surfaces, and more robust mathematical models. The present results would be useful for a more physiology-based comprehension of human diarthrodial joint motion.

METHODS

Based on experimental observations, knee and ankle joints were modelled by means of equivalent parallel spatial mechanisms. In general, the models featured two members (i.e. the rigid bone - cartilage) in mutual contact (at the articular surfaces) and interconnected by rigid links (i.e. the ligaments' isometric fibres). Different models having contact surfaces with increasing approximation were analyzed, i.e. planes on spheres, or spheres on spheres, or using optimal B-Spline surfaces. A further series of models, feature two members interconnected by one spherical joint and two rigid links: the lower number of members makes this model geometrically and mathematically much simpler. Geometrical configuration of these models and validation in terms of comparison between instrumental measurements and model predictions were obtained from experiments in fresh frozen amputated lower limbs, free from anatomical defects. A standard stereo-photogrammetric device was used initially for recording the relative bone motion and for digitizing relevant anatomical landmarks. Passive flexion-extension cycles were performed and relevant data collected. Subsequently, the joints were disarticulated, still with the technical reference frames attached, and articular surfaces and ligament origins and insertions were digitized. Isometric fibre attachment points were determined in the ligament attachment areas and the contact surfaces of the models were obtained by means of best-fit techniques starting from the digitized point clouds. For each model, a bounded optimization procedure was used to find the optimal geometric parameters which allow the different models to best-fit the experimental motion. The position of the B-Spline surfaces was not included in this procedure, because of the critical additional complexity.

RESULTS AND DISCUSSION

Joint kinematics predicted by these models replicated very well corresponding experimental measurements. The difference between the experimentally determined and optimally defined ligament attachment points varied between 0.2 and 10 mm. Mechanisms with a spherical pair replicated passive motion with a good, though lower, precision, but with much smaller computational costs.

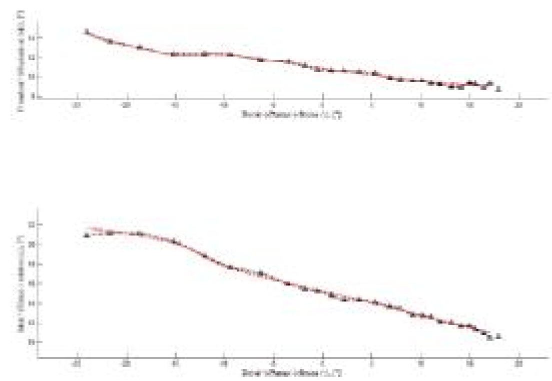

Figure 1: Passive joint rotation in the frontal (top) and transverse (bottom) planes from a typical ankle specimen (experimental samples as triangles, interpolated by a dash-dot line) and corresponding model predictions (solid red).

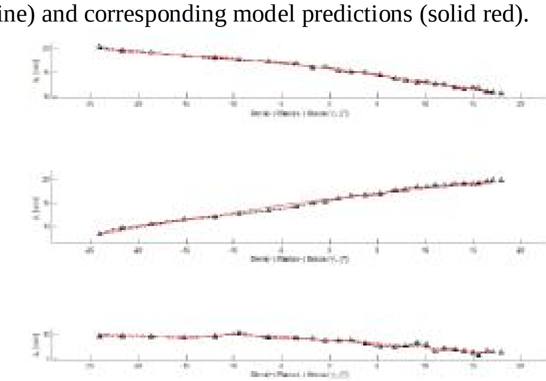

Figure 2: Passive joint displacement along the three anatomical axes (same symbols than Fig 1).

CONCLUSIONS

The present spatial mechanisms are important means for more physiological mechanical models of both these joints and of the entire lower limb.

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