8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Visible Biomechanics: 4D-Visualization of Human Ankle Joint Flexion based on Dynamic Radiology (MRI)

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Key Words: *Biomechanics, 4D-Visualization, Human Ankle Joint, Dynamic MRI.*

ABSTRACT

Introduction: Better understanding of soft tissue functional biomechanics, especially of human extremities, is subject of intensive research. For soft tissue organs such as muscles, skin, or cartilage, 3D-reconstruction only provides a snapshot of continuously deforming structures. In contrast, 4D-viualization enables rendering time dependent behaviour. This article is dedicated to 4D-visualization of human ankle joint flexion (Fig. 1) by a highly trained volunteer (male, 38 Y) based on dynamic magnetic resonance tomography (MRI). It is part of a detailed research project concerning 4D-visualization based on dynamic radiology [2].

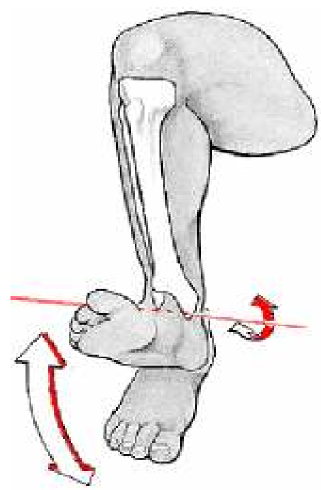
Fig. 1: Ankle joint flexion and extension [3].

Methods: Generally, dynamic radiological data sets consist of series of static radiological data sets sequentially acquired recording time dependent patient's behaviour. This study is based on a series of 6 high resolution MRI data sets each comprising 40 sagittal slices with 1.1 mm x 1.1 mm pixel size and 2 mm slice distance (Siemens Symphony, 1.5 T, vibe_tra_bh_nativ_5 imaging sequence: special fast, fat suppressed MRI protocol without contrast agent). As real time MRI is still beyond actual technical possibilities, the ankle joint was stepwise flexed, but without muscles' relaxation which we call "quasi continuous" dynamic data acquisition. After refined image processing of the MR images, the anatomical structures were visualized by means of direct volume rendering using different color maps and degrees of transparency. Continuous update for every time step provided dynamical sequences of ankle joint flexion. All image processing, visualization, and reconstruction steps were performed using the visualization platform Amira 4.1 [1, 4]. Due to very high hardware requirements, a Celsius V-Serie Computer (Siemens-Fujitsu) was used equipped with a nVidia Quadro FX4000 graphics board.

Results: Dynamic sequences of whole lower leg and foot during ankle joint flexion were provided. The actual visualization was performed with special focus on muscles, tendons, and vascular structures (Fig. 2). By dynamic MRI, we get information about

changing shape as well as, referring to the grey values of the MR images, about altered inner condition of the considered organ, see e. g. for the gastrocnemius muscle and the Achilles' tendon in Fig. 2.

Discussion and outlook: The presented approach is still very demanding. Notably, besides being in highly trained physical condition, the concerned volunteer had detailed medical background. High resolution MRI with fast acquisition time as well as 4D-visualization is subject of ongoing research. Actually, we are contributing to functional anatomy and biomechanics by providing insight to the dynamics of the entire anatomical entity including bone, tendons and tendon sheaths, muscles, ligaments, vascular structures, nerves, and surface. With regard to various kind of simulation, we are able to contribute to validation as well as by providing constraints resp. boundary conditions as mostly the whole structure is too complex for the simulation. Future research will be dedicated to further reduction of acquisition time, refinement of the visualization with regard to anatomical details, and automization of the data processing as one of the next steps will be the application of this methodology to clinical cases.

Fig. 2: Dynamic sequence of lower leg and foot during ankle joint flexion.

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