DATA CUSTOMIZATION PIPELINE FOR IN-VIVO MOTION ANALYSIS AND MODELING

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SUMMARY
This paper proposes a method designed to fuse a large number of clinical data into one serial pipeline including data collection, data processing, data representation and data visualization.

The protocol has been applied here on the ankle and foot joints of three healthy subjects and one patient (Charcot-Marie-Tooth). Heterogeneous and customizable data such as medical imaging (CT), three-dimensional (3D) reconstruction, palpation analysis (manual and virtual), motion analysis, forces plates, foot pressure plate, muscle analysis (length, moment arm, activity) has been implemented into a software interface called « lhpFusionBox » to create subject-specific models. All available data are temporo-spatially aligned.

The information obtained from fusion of clinical data permit to improve our understanding of the dynamics of the human foot during stance and to obtain the specific mechanics of each subject. This method is applicable to others joints and/or functional tasks.

INTRODUCTION
The foot architecture and the foot have a special relationship with the ground during the stance gait and the body weight through the ankle joint complex. This has justified past development of many measurement methods which aimed to improve our general and clinical understanding. Foot pressure is probably one of the first developed methods, and the aim has been to visualize the relationship between foot sole deformation and pressure. Methods vary from simple powder to pressure plate. However, the anatomical relationships between measured data and underlying bone segments is a challenge [1,2]. Foot segment motion description is also a challenge and various foot models have been developed [3,4]. Musculoskeletal models are available, and despite lack of true clinical validation, are opening up new knowledge [8]. Still, this heterogeneity of data and models are difficult to integrate into a common and clinical-useful environment, and more advanced biomechanical methods are required [1].

The presented protocol gathers several previously-published methods related to subject data customization into one serial pipeline including data collection, data processing, data representation and data visualization. These methods have been previously and independently developed by the authors on various aspects of in-vivo subject-specific data customization. This presentation describes these methods gathered into one single and linear data processing pipeline that can be used for fundamental or clinical research.

METHODS
The following protocol has been applied on 4 subjects. Extensive results will be presented during the congress. It has been approved by the Ethic Committee of the ULB Erasme hospital (approval #P2008/284 – CCB: B40620084878). It has been applied on the ankle and foot joint.

Medical imaging and 3D reconstruction. In order to decrease the X-ray dosis absorbed by the subjects, low-dosis medical imaging (LDCT) has been adopted and enabled accurate 3D surface reconstruction of the bones and joints of interest to be obtained [6]. The absorbed X-ray-dosis has been processed in response to current clinical requirements [7].

Anatomical segments. Three anatomical segments-of-interest were analyzed: SHANK (including tibial bone and fibula), HINDFOOT (including talus and calcaneus) and FOREFOOT (including all remaining foot bones). For each segment, a technical cluster including 4 reflective markers was attached prior to motion analysis. The same segments were reconstructed from the available medical imaging models.

Palpation. Manual and virtual palpations of anatomical landmarks (ALs) were performed on the subjects and on the subjects’ 3D bone models, respectively [8]. Manual palpation was performed using the A-Palp method [9]. The obtained AL coordinates were stored for further data fusion and motion representation. Using the available ALs, anatomical frames were built for motion representation.

Addition of muscle information. Using results from previous dissections, muscle lines-of-action (including origins, insertions and wrapping path) were added to obtain a subject specific “static” model (Fig. 1).

Figure 1: Final static model obtained after AL data fusion. This model is entirely built from patient specific data, except...
muscle information which was obtained from specimen dissection and validated using the patient medical imaging dataset. The model includes all information required for extensive musculoskeletal analysis (anatomical frames, muscle line-of-actions, morphological parameter [e.g., navicular drop in pink, etc]).

Gait analysis. All subjects were analyzed during gait analysis, including segment motion tracking by stereophotogrammetry, ground reaction forces, foot pressure plate and for two subjects, electromyography.

Final fusion. In short, spatio-temporal data fusion used the ALs coordinates collected from the various data collection systems to fuse the above-obtained static model (see Fig. 1) with the collected gait data. After fusion, the customized data with dynamic gait analysis information, and is ready for further data analysis and data visualization (Fig. 2).

Software interface (lhpFusionBox). The entire protocol has been implemented into a customized software interface called “lhpFusionBox” built from in-house routines and from the open-source MAF library (www.openmaf.org).

Figure 2: This subject-specific model includes all heterogeneous collected data. Gait analysis data (motion, EMG, ground reaction forces, foot pressure) are visible together with morphological data. Graph are obtained for quantitative analysis (see Results).

RESULTS AND DISCUSSION

The availability of such protocol implemented in a user-friendly software allows to process a high amount of clinically-relevant parameters. Currently data analysis includes: - motion representation according to various conventions; - instantaneous muscle moment arm relative to the mean helical axis; - navicular drop; - Moreau and Corta Bertani angle; - muscle length; - ground reaction force moment arm; - foot pressure areas; - etc. Because all available data are temporo-spatially aligned, data comparison is straightforward (Fig. 3).

CONCLUSIONS

The paradigm behind this protocol is very promising. Current work is currently running in order to bring such tools to clinics through the ICT4Rehab project that will concentrate on cerebral palsy and related muscle disorders.

ACKNOWLEDGEMENTS

This project is by: DhErgo project (European Commission, project n° SCP7-290 GA-2008-21852) and ICT4Rehab project (Brussels government, InnowirL agency, project n°10-PFS-ICT-03). Special thanks to Ms S. Telese Izzi, Mr H. Bajou and Mr JL. Sterckx for their technical assistance. Many thanks to Siemens for providing a medical imaging system for our research.

REFERENCES


Figure 3: Example of result comparison. Left: ankle model with the mean helical axis (in violet) and instantaneous soleus m. line-of-action and level arm (in blue). Right: various are generated on-the-flight. Top graph: motion representation of the ankle joint kinematics (Groot & Suntay). Middle graph: soleus m. moment arm. Bottom graph: soleus m. length. This graph only shows a few results; all above-described data can be visualized into graphs, compared and exported for further use (for example, statistics).