Fusion of biomechanics data for patient monitoring in pediatric skeletal oncology

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INTRODUCTION

The term *data fusion* indicates the methods and the technologies that allow the synergistic combination of disparate data into a new dataset, which potentially contains more information than the sum of the original data. We applied data fusion to combine medical imaging, movement analysis, muscolo-skeletal modeling, and finite element analysis data, into a coherent representation of local skeletal loading during certain motor tasks. This approach has been used to estimate the risk of fracture under fully unprotected walking in pediatric patients, which underwent a major skeletal reconstruction due to the presence of a bone sarcoma.

METHODS

At each periodic control the patient is examined with a CT scan of the reconstructed and of the contro-lateral regions. In the first post-operative control, we also perform a complete MRI examination of the lower limbs.

Whenever possible, before the imaging session, the patient is instrumented with a redundant set of radio-opaque and reflective markers, firmly attached to the skin. This includes four markers per segment in addition to those used for a standard gait analysis [1]. The movement analysis session is accurately planned in advance among the surgeon, the physiatrist, and the bioengineers, in order to maximize the collected information, while minimizing the risk of spontaneous fractures. This required the development of a special protocol for children, which considers the need, in the early stages of the follow-up, of protected walking.

CT, MRI and all movement analysis data (kinematics, ground reaction forces, EMG) are imported into a data fusion application (Data Manager, B3C, Italy), which allows the complete spatial and temporal registration of all data, using the skin landmarks as fiducial points. Data are then processed to extract the skeletal geometry, the distribution of mineral density inside each bone, the joint centers, the line of action and the lever arm of all relevant muscles, etc. The software provides also a virtual palpation environment that allows the accurate definition of the joint reference systems following the ISB standardization, and let you compute all biomechanical quantities necessary to predict the muscle and the joint forces with static optimization. At the same time the bone data are processed to create a subject-specific finite element model. Loaded with muscle and joint forces, the model predicts the stresses and strains induced in the bone for each time frame of the recorded task [2]. Robust quality insurance protocols are used to monitor all instrumentations. All uncertainties are factored into a Montecarlo simulation that provides a full sensitivity analysis on the stress predictions [3]. The stress results are then imported back in the Data Manager and fused with the rest of the data. Using the advanced interactive visualization features of the Data Manager, the stress results are reported to the medical professionals fused with the anatomical (imaging) and functional (gait analysis) data of the patient (Fig. 1). This dramatically improves the efficacy of doctor-engineer communication.

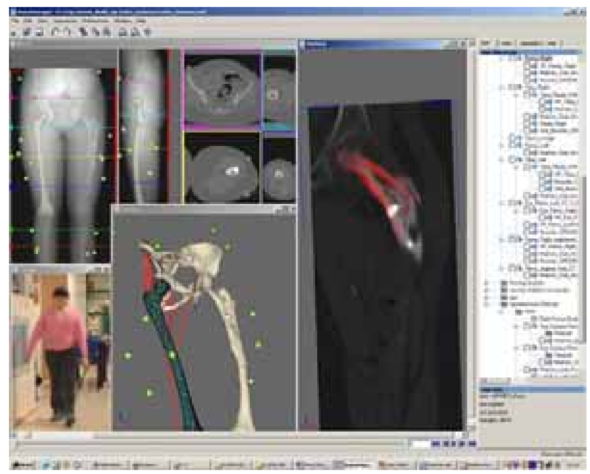

Fig. 1 The DataManager environment. In clockwise order, from top-centre: the CT dataset taken with the markers attached to the patient skin; the FEM results mapped onto the CT volume; the FEM model of the right femur within the muscle-skeletal model used to predict muscle forces; a movie of the walking task. On the right the tree structure used to organize the different data.

RESULTS AND DISCUSSION

So far the method has been used with 4 patients; for 2 of them we already have more than 5 controls. The only warning raised with this procedure so far, was confirmed by sub-capital slippage complication during unprotected walking, occurred a few months later.

The method is becoming in our hospital the *de facto* standard for planning the rehabilitation protocol in these very difficult cases. This poses major problems, as the whole procedure currently requires a large amount of time to collect, process and analyze all these data. However, we are optimistic that improvements in the software algorithms can provide the level of automation that is necessary for large-scale clinical usage. In the meanwhile, preliminary attempts are being made to use this methodology also in the pre-operative planning phase.

REFERENCES

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