SOFT TISSUE BIOMECHANICAL MODELING FOR COMPUTER ASSISTED SURGERY: CHALLENGES AND PERSPECTIVES

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Background

The clinical objective of Computer Assisted Medical Interventions (CAMI) is to develop systems that assist the physician in the practice of minimally invasive diagnostic or therapeutic actions. The main scientific objectives that result from this clinical goal include the design and development of (1) reconstruction methods, image processing and data fusion, (2) models describing organs and clinical procedures, (3) simulators enabling action planning, monitoring and prediction of outcomes; and finally (4) guiding systems to realize an action as planned. In this CAMI context, biomechanical models of organs and soft tissues can be required to assist surgeons for planning (pre-operative surgical assistance) or to guide their gesture during surgery (intra-operative guidance).

The objective of this Perspective Talk is to introduce the state of the art as concerns biomechanics for CAMI. In particular, the main challenges in this area will be addressed and discussed.

Recent Advances

It should be noted that most biomechanical models of organs and/or soft tissues developed in the context of CAMI are limited to research laboratory with proof of concepts that have difficulties to be transferred into clinical routine. In a recent book [1], less than ten biomechanical modelling works used in a surgical practice were able to be found. This is probably due to the fact that researchers still face some bottlenecks for designing such models and for providing a medical device that can use such models in a clinical routine. Indeed, three main challenges should be addressed: (1) the automatic generation of patient-specific models of organs and soft tissues, (2) the *in vivo* estimation of patient-specific constitutive laws for such tissues and (3) the real-time (or at least interactive-time) computations of these models.

Our group has mainly addressed the first two challenges. The automatic generation of patient-specific models can indeed be a long and tedious task, especially when a Finite Element mesh has to be designed with constraints such as the inclusion of sub-structures (like vessels, glands or muscles inside a larger organ) and the requirement for avoiding linear tetrahedral elements (because of the risk for numerical locking in the case of quasi-uncompressive tissues). We therefore have proposed the concept of "*Mesh-Match-and-Repair*" [2]. The idea is that a generic mesh for a given organ/soft tissue has already been manually designed based on a specific anatomy. The corresponding model is called "atlas". For each new patient (with his own geometry), the atlas mesh is then morphed to fit the anatomy of the patient (figure 1).

With an engineering background, Yohan Payan was hired in 1997 as a professor in Grenoble University. He moved to CNRS in 2002 and has now a Research Director position in that French institution. He received Grenoble Univerisity's Best Thesis Prize on biomechanics for speech production in 1997. Fifteen years later, he received the 2012 Senior Prize of the French Biomechanics Society for the research he and his team have done on biomechanics for Computer Assisted Surgery. He has co-supervised 30 PhD students, written close to 300 papers and edited two books. He has also developed an important link with companies and is the co-inventor of 15 international patents.

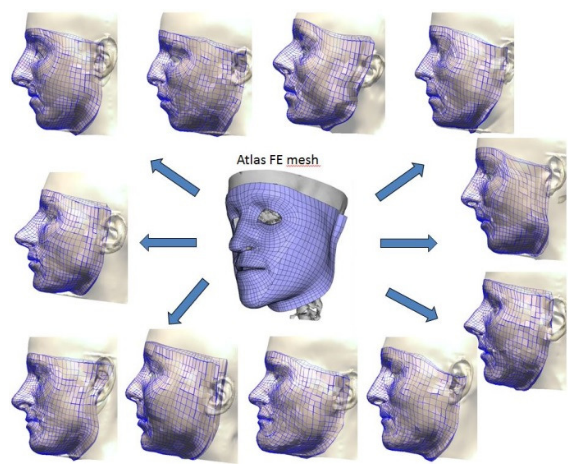

Figure 1: Mesh-Match-and-Repair applied to the face

Future directions

Our group has also addressed challenge (2) with the design of an *in vivo* aspiration device that has been used intraoperatively to estimate constitutive laws [3]. The challenge (3) concerning fast computation of non-linear Finite Element models is still open even if some promising methods have been proposed [4].

References

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4. Gonzalez et al., Annals of Biomedical Engineering, 44(1):35-45, 2016.