BIOMECHANICAL DIGITAL TWINS: CHALLENGES AND BOTTLENECKS

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Yohan PAYAN is currently Senior Researcher at the CNRS (France). His PhD (1997) was awarded by the University Grenoble Alpes, and the French Biomechanics Society awarded him the 2012 Senior Prize for his research on soft tissue biomechanics for computer-assisted medical interventions. During the last twenty years, he has co-supervised 40 PhD students, written more than 400 articles and edited four books. He was a Research Affiliate at the MIT (1999) and visiting professor at University of Chile (2004) and University of British Columbia (2010). Yohan Payan is the Associate Editor of the *Clinical Biomechanics* journal and the co-founder of the *Biomechanics of Living Organs* Series (Elsevier).

Background

This Perspective Talk addresses the design of biomechanical models of living organs, in the context of computer assisted medical interventions. Many models have been proposed by research labs around the world (see [1] for example) but very few have been transformed into medical devices that are used in the clinical routine. Two main bottlenecks seem to explain this. First, it is known that each organ model should be patient-specific, both in terms of geometry of the organ and in terms of constitutive parameters of tissues included in the organ model. Such a personalization of the models can be extremely time consuming and therefore not compatible with the clinical constraints. Secondly, each patient-specific organ model has to be used by the clinician in an interactive way, with simulations that should not require more than a couple of seconds or minutes to compute. Here again, this can be very challenging when complex hyper-elastic models are used.

Recent Advances

Since more than twenty years, our group has proposed and developed a methodology based (1) on the tedious manual design of a reference Finite Element (FE) model built upon the organ geometry of a reference subject and (2) on the automatic transformation of this reference model in order to match the patient-specific organ geometry. This transformation was originally calculated from registrations between the 3D external surfaces of the organ (reference surface matched onto the patient surface) extracted from medical images segmentations [2-3]. More recently, to avoid the complex phase of organ segmentation, our group has proposed to automatically compute this transformation from the full 3D image (CT or MRI) of the organ [4]. Figure 1 illustrates this methodology, with a 3D reference FE model of the human tongue (left panel) that is automatically transformed into a patient-specific model (right panel) through the computation of an image-based 3D non-rigid transformation between the MR image of the reference subject and the MR image of the patient.

To provide patient-specific values for the parameters of the constitutive laws chosen to model each soft tissue that constitutes the organ (e.g. mucosa and muscle for the tongue), *in vivo* measurements have to be provided instead of using generic values estimated from *ex vivo* experimental tests. For this, our group has developed the VLASTIC device [5] that provides (1) local tissue aspirations with suction cups of various sizes, and (2) estimations of tissue stiffness through inverse FE analysis, assuming a bi-layer configuration. This was recently tested on the tongues of 10 patients under general anesthesia [6].

Future directions

Providing FE simulations with computations times of the orders of seconds or minutes is definitively the challenge of digital twins for the coming years. Our group has addressed this issue for the tongue [7]. Many other relevant proposals for Model Order Reductions will have to be explored in the field of biomechanics [8].

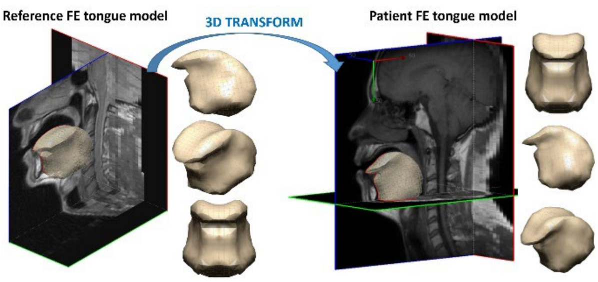

Figure 1: Reference FE tongue model transformed into a patient-specific model thanks to 3D image registration

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