Why Most of the Intra-Operative Medical Robotic Devices Do Not Use Biomechanical Models? Some Clues to Explain the Bottlenecks and the Needed Research Breakthroughs

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Abstract This invited lecture addresses the frontier that biomechanics is now facing with the development of computer-assisted devices that can provide intra-operative assistance of the surgical gesture. The underlying idea is to use patient-specific biomechanical models during surgery, i.e. in the operating theatre. In that case, three main challenges need to be solved to be compatible with the clinical constraints: (1) a very fast generation of patient-specific models, (2) an in vivo estimation of the patient-specific constitutive equations of the soft tissues, and (3) interactive numerical simulations

TIMC-IMAG Laboratory (www-timc.imag.fr) is a 250 people laboratory devoted to translational and fundamental research at the intersection between Medicine and Information Science and Technology (from Applied Mathematics to Computer Science and Robotics). In that lab, since the 1980s, the Computer-Assisted Medical Intervention group has been developing devices to assist the physician or the surgeon in the successful execution of diagnostic or therapeutic gestures by minimizing invasiveness whilst improving accuracy.

Computer-assisted surgery (CAS) is now a mature domain. Researchers, clinicians and industrial partners have developed CAS applications by building links with classical domains such as computer science, robotics, image processing and mathematics. Orthopaedics was the first clinical domain mainly addressed by the pioneer CAS applications [1]. The reason for this was probably that bones are the human body structures which were considered as the most easily includable into a CAS application: they were assumed to be rigid, i.e. with a fixed 3D geometry, they are strongly identifiable onto computed tomography exams, and their relative

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position during surgery is easily tractable by fixing rigid bodies onto their external surfaces (these rigid bodies being, for example, tracked with the use of an optical device, thus providing "surgical navigation").

The connection to biomechanics (i.e. the mechanics of living tissues) is more recent. Biomechanicians were first asked to work onto CAS applications when orthopaedic surgeons were looking for tools able to predict risks of fractures in the case of prosthetic implants. In that case, bony structures could no more be considered as rigid but on the contrary had to be modeled as a deformable continuum with a nonhomogeneous distribution of the internal stresses. For example, a patient-specific finite element model of the femur could be designed to estimate the internal stresses generated by a hip prosthesis and therefore to help limit fracture risks [2]. In these continuous biomechanical models, bones were usually considered as linear elastic material that underwent small deformations, which permitted easy calculation of numerical solutions.

More recently, CAS has addressed a larger spectrum of clinical domains such as cardiology, neurosurgery, urology or abdominal surgery. For these applications, biomechanics faces a new challenge since the involved tissues are required to move and be deformed by stress generated by clinical actions. Moreover, soft tissues are difficult to model accurately since they typically exhibit complex, time dependent, non-linear, inhomogeneous and anisotropic behaviors. Most of the corresponding biomechanical models need to include large deformation effects and visco-hyperelastic constitutive laws. Such models are very computationally demanding and are therefore limited to pre-operative use, since the simulations often require many minutes or hours to compute.

Our group did contribute to such pre-operative use of biomechanical models, for example in the domain of orthognatic surgery [3], tongue cancer treatment [4] and orbital surgery [5].

More recently, we have addressed the new frontier that biomechanics is now facing with the development of CAS devices that can provide *intra-operative* assistance [6]. The underlying idea is to use patient-specific biomechanical models during surgery, i.e. in the operating theatre. In that case, three main challenges need to be solved to be compatible with the clinical constraints:

1. Patient-specific models should be easily generated (no more than some minutes to elaborate such a model).
2. Patient-specific constitutive equations of the soft tissues have to be estimated through in vivo experiments, some of them only being possible during surgery if the organs are not accessible pre-operatively (e.g. the brain tissues).
3. The implementation of the models should provide real-time (or at least interactive) numerical simulations.

During this talk, we will try to address these new challenges and discuss the reason why most of the intra-operative medical robotic devices provided by industrial companies still do not use biomechanical models.

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