Biomechanics Priorities Conference Personal Statement
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My experience is based on having transitioned from research on whole body forward dynamics simulations of human musculoskeletal movement to developing widely used real-time interactive simulations for medical professionals to learn proprioceptively facilitated procedural decision making. This elaborate phrase basically means that I work on providing a simulated experience for a learner where we compute the interaction of the learner's actions using handheld tools upon the tissue of the simulated body and provide real-time feedback of the resulting tissue manipulation through visual and haptic/load feedback interfaces.

The early days of this field, which we are arguably now in the process of emerging from, were centered on providing learner's with perceptual experiences by whatever means could achieve a sufficient "suspension of disbelief" while not giving the learner overtly incorrect responses to their actions. The field is in transition to a more appropriate science- and engineering-centric approach where the actual mechanical behaviors of tool-tissue interaction are characterized and appropriate engineering mechanics computations are combined with biomechanics-based measurements to underlie the simulations.

While this on-going transition is encouraging, many of the fundamental pieces of data that should inform the creation of these new, more accurate experiences are not available. To construct appropriate interactive experiences, the actual movements of the individuals performing the tissue manipulation in real-life need to be known along with the mechanical state of the tissues (and possibly the state of systemic feedback systems such as cardiovascular hemodynamics) that they are affecting. There are isolated activities now underway using measurement systems in the operating room, yet this quantification between human musculoskeletal action and resultant tissue response warrants an entire of field of study in itself.

Identifying key activities that need to be learned within the myriad of procedures carried out in modern medicine and then fully characterizing the kinematics and kinetics of the person performing the procedure along with the mechanics of the tissue and possibly the systemic response (blood flow for example) to these activities, provides a basis for building simulations that meet many future needs. These simulation approaches will go beyond the prosaic training-focused activities of the present to encompass simulation-based device and procedure design, patient specific pre-procedural rehearsal, and simulation-mediated procedure delivery in the operating room or cath lab. There is already research underway to provide surgical assistants for existing surgical robots to automate specific actions with the robots such as pre-specified, repetitive action patterns (e.g. suturing) combining simulation-based prediction of resultant tissue manipulation with real-time measurement of actual tissue response to ensure an effective outcome.

Moving from the cautious simulations of today, where the goal is to provide a useful training experience, to the profound simulations of tomorrow, where a real-time computation can predict the outcome of the intent of a physician during a procedure and provide cautionary guidance, will require a coordinated effort to define, collect, and organize measures of procedures by peer-reviewed efforts so that a definitive collection of knowledge will be available for simulation development.

The field needs the techniques developed for musculoskeletal movement analysis and orthopedic device design adapted to it. Some specific activities that are needed include:

- Surgical action quantification (both kinematic and kinetic) including range of movement, frequency, two-handed interaction, tool actions, and tissue reaction
- Tissue, organ, and system level measurement of basic physical properties in response to interaction
- Whole simulation scenario validation at the level of human sensory experiences to ensure that simulation is sufficiently equivalent to real-life procedures
- Computation of color/appearance as well as computation of mechanical response, e.g. effects of blood vessel distribution on appearance after being compressed

- Computational bleeding behavior as a function of anatomy, hemodynamics, and interaction, e.g. quantification of vessel distribution and its effect on observed/computed bleeding
- Trauma scene geometry as well as mechanical behavior and visual appearance
- Long term predictive simulation of healing and remodeling as a consequence of surgery

A possible initial avenue to collecting this type of data could be by enhancing the information measured during current robotic surgical procedures to provide a more complete characterization of the robot tool interaction with the tissue. The approach is appealing in that surgical robots are already widely used and there are a number of research groups actively involved in various control systems-centric enhancements of their capabilities so there is a ready base for potential collaboration with researchers already familiar with the devices themselves. By using these robots, it would make for a rich collection of procedures to be assessed at different levels of detail. This would allow scenarios of varying complexity to be measured, from straightforward characterizations of current procedures based on the data available already from the robots to the adding of sensors into the robot end effectors, making its 3D camera quantitative, and possibly even adding external sensors to observe the entire surgical scene. While these robot-centric activities provide a quick means to get going on collecting useful data, more studies focused on non-robotic surgery, both minimally invasive as well as traditional open incision surgery will need to be carried out as well.

Beyond the biomechanical characterization of activities, the fundamental computational aspects of the implementation of simulation will also require expansion. There are many challenges ahead in producing computations that are accurate and can scale while allowing completion in sufficient time to be useful to physicians as they go about their delivery of therapy. There will need to be further advances in providing multi-resolution simulations that provide detailed results of tools contacting tissue, have provision of multiple calculation approaches to ensure accuracy and reliability in timely delivery of results, and have coordination of computations across multiple resources to provide experiences that merge the outcomes of best available algorithms, implementations, and data sets to a name a few of the upcoming challenges. These refined/enhanced computational approaches could be combined with the surgical robot-centric data collected to provide a readily available means of verifying the computations and their generality could be tested by applying the simulation approaches to scenarios whose mechanics have not been included in the data used to develop and refine the simulations. In that way, the predictive capability of the simulations could be characterized at an earlier point than might otherwise be possible.

Development of prioritized strategies of how these needs can be met should shape future research funding to ensure that the right focus is placed at the right time with the right research capabilities in this long term emerging field.