Computer-Assisted Orthopedic Surgery with Real-Time Biomechanics

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The objective of this collaborative effort, funded by the National Institutes of Health, is to develop a system that provides surgeons with better information during orthopedic surgeries. Our system tracks the alignment of a patient's hip by using a 3-D infrared camera and simultaneously calculates the mechanical stress within the joint by using a computational model. This biomechanical guidance system (BGS) may improve decision making during joint surgeries by predicting the underlying mechanical loading of the joint. The BGS was developed to improve a type of hip realignment known as periacetabular osteotomy (PAO); however, the application of this work can be extended to other areas of computer-assisted orthopedic surgery.

PAO surgery is used to treat acetabular dysplasia (shallow hip socket), which is a significant cause of osteoarthritis in young adults (Fig. 1). The affected patients are usually unable to walk long distances, suffer from chronic pain, and usually limp. The major goals of the PAO surgery are (*i*) to reduce the patient's pain and maintain his/her ability to perform normal daily physical activities and (*ii*) to slow down or prevent the process of joint degeneration by reorienting the acetabulum to contain the femoral head and, therefore, reduce joint subluxation while improving contact pressure distribution around the hip joint (Fig. 1).

To achieve these goals, it is important for the surgeon to understand the distribution of stress within the joint and how to realign the joint to reduce these stresses. The BGS provides the surgeon with this information not only when planning the procedure but also during the operation, so that cost–benefit scenarios can be assessed and an optimal realignment can be achieved given all surgical factors (e.g., alignment, structural stability, and range of motion of the leg).

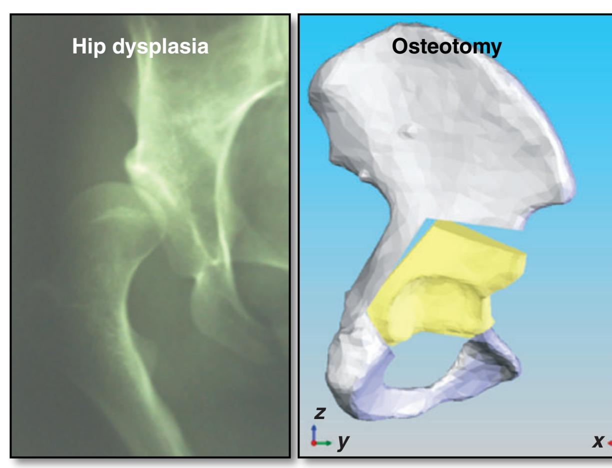

Figure 1. Radiograph of a dysplastic hip demonstrating insufficient coverage of the femoral head (left). In periacetabular osteotomy the acetabular fragment (yellow) is detached and realigned to increase the coverage of the femoral head (right).

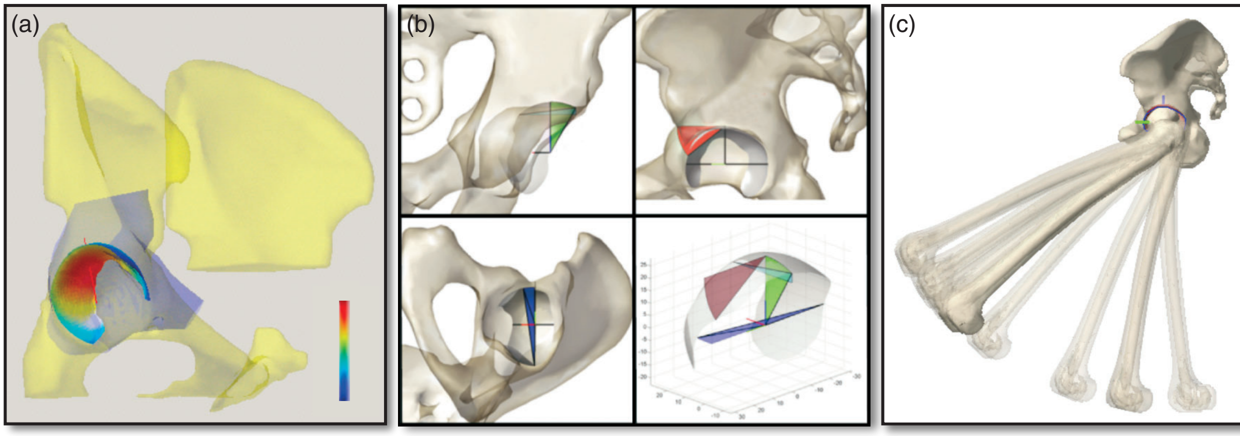

Figure 2. (a) Simulation of osteotomy cuts around the acetabulum and joint contact pressure distribution after PAO. (b) Characteristic anatomical angles computed by BGS during PAO surgery. (c) Hip range of motion measured by BGS during PAO surgery.

The BGS includes a planning module based on preoperative computed tomography data that allows visualization of the patient's anatomy in 3-D, specification of the required surgical cuts (Fig. 2a), realignment of the joint, and calculation of both angular alignment (Fig. 2b) and biomechanical response (Fig. 2a). During the surgery, the 3-D model shows the current progress of the procedure by visualizing the tools and bone fragments and by performing biomechanical and geometrical analysis (Fig. 2).

Through an ongoing collaborative effort among APL, the JHU Whiting School of Engineering, JHU Bayview Medical Center, and Orton Orthopaedic Hospital, a multi-threaded approach is implemented to further develop the BGS navigation system, enhance its theoretical foundation for the real-time calculation of the contact pressure within the joint, and evaluate its functionality and reliability through cadaveric tests and clinical research. To date, we have performed 13 cadaver tests to validate the current version of the BGS and have successfully performed 11 clinical tests (Fig. 3).

Figure 3. Ongoing clinical research with BGS at Orton Hospital in Helsinki, Finland.

For further information on the work reported here, see the references below or contact mehran.armand@jhuapl.edu.

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