

Image-Guided, Robotically Assisted Osteoporotic Bone Augmentation

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The objective of this collaborative effort funded by the National Institutes of Health is to develop a system to help prevent hip fractures in at-risk patients with osteoporosis. This technology involves building a biomechanical model to characterize

the bone loss and fracture risk, planning augmentation material injection in an optimized pattern, and developing a navigated robotic system to assist the surgeon in carrying out the procedure.

There is a wealth of research on the extent to which bone loss may impair strength and increase the risk of fracture. The rate of mortality after hip fracture in elderly patients with osteoporosis is reported to be as high as 30% within 1 year after the incidence of fracture.

It is suggested that augmentation of the hip is an effective countermeasure to reduce the risk of fracture in highly osteoporotic hips. This technique would be especially valuable for those patients at high risk of falls and at the highest risk of mortality and morbidity if they were to sustain a fall. The few clinical case studies that have been performed on augmentation of the femur with poly(methyl methacrylate) (PMMA) cement (Fig. 1) suggest that a successful outcome requires detailed planning, biomechanical analysis, and precise control of the augmentation procedure to avoid generation of areas of high stress at the bone–cement interface.

The long-term objective of this research is to develop a technology that enables the surgeon to precisely determine the extent of osteoporosis and fracture risk level, obtain an optimized surgical plan based on computerized mechanical analysis, perform a rapid and minimally invasive hip augmentation with intraoperative

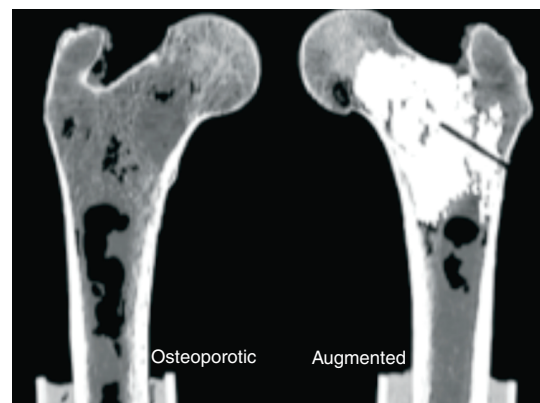


Figure 1. Augmentation of hip with PMMA.

biomechanical feedback, and, finally, verify the outcome in one patient visit. We are developing a surgical workstation for augmenting the femur and, therefore, minimizing the risk of hip fracture in the elderly. The system allows the surgeon to plan and optimize the injection of the augmentation material on the basis of mechanical analysis of the bone strength as well as on calculated stress distribution from a patient-specific 3-D model reconstructed from the computed tomography data before the surgery (Fig. 2).

During the surgery, the injection of the augmentation material will be performed by using a single-axis hand-

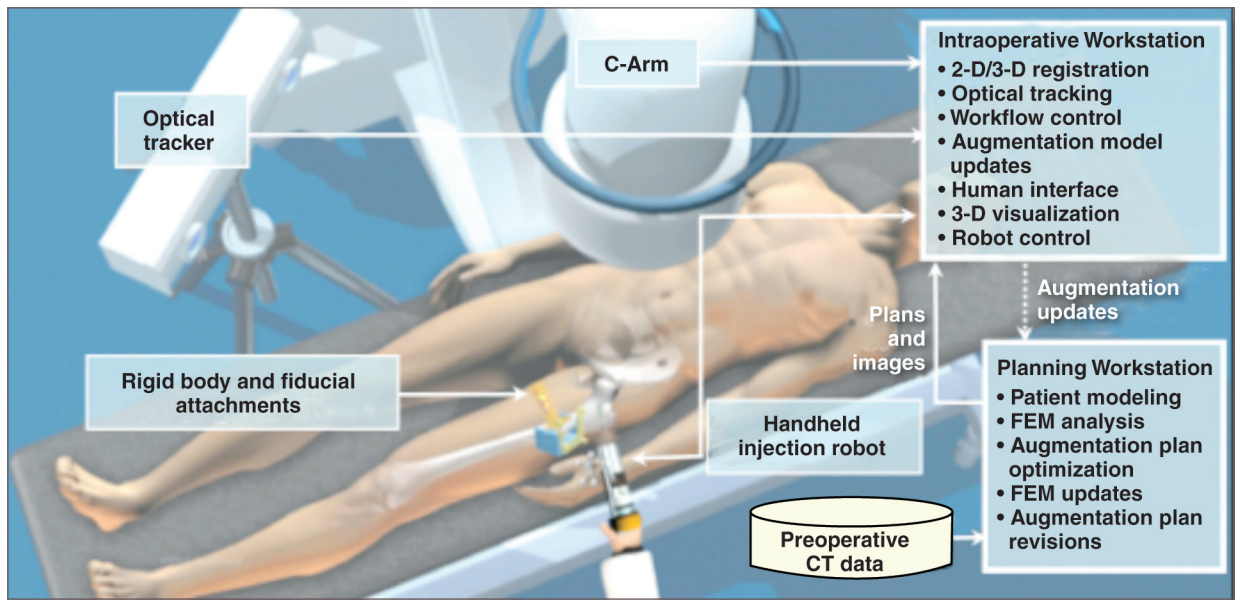


Figure 2. System setup and information flow. CT, computed tomography; FEM, finite element model.

held robotic device (Fig. 3c). The surgeon implements the surgical plan by controlling the point of entry and the alignment of the device using an infrared camera (Polaris, NDI Inc.). The surgical workstation controls the rate and volume of the injection according to the plan. During the process, multiple x-ray images are acquired, and the 3-D model is updated to visualize progress by using a 2-D/3-D registration technique. The updated model also is used for further mechanical analysis of the bone strength and for verification of the results.

Through an ongoing collaborative effort among APL, the JHU Whiting School of Engineering, and the JHU

Bayview Medical Center, we have developed a prototype of the integrated surgical workstation. The components of the planning and intraoperative execution have gone through preliminary tests. We have successfully tested the overall performance of the surgical workstation in two cadaver studies. Currently, we are working toward refining the components of the system and further validating the functional performance of the integrated surgical system. This technology may lead to a highly needed alternative treatment that may be pivotal for patients who are at risk for bone fracture due to osteoporosis.

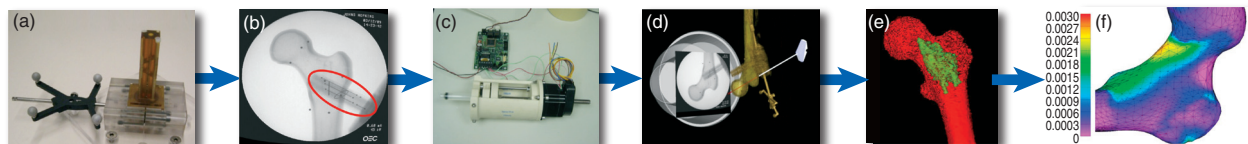


Figure 3. The intraoperative procedure for hip augmentation involves the following steps: (a) attaching a custom fiducial visible in both x-ray and infrared camera, (b) acquiring x-ray image for 2-D/3-D registration to the CT data, (c) navigating a robotic injector to deliver augmentation material, (d) visualizing injection device in real time during surgery, (e) reconstructing the bone model with cement distribution, and (f) updating the FEM for plan verification.

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

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