Use of 3-Dimensional Stereolithographic Polymer Models for Heterotopic Ossification Surgical Excision

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Abstract: Heterotopic ossification is a known complication of traumatic injuries. To minimize iatrogenic complications during excision, an understanding of anatomic relationships is essential. Current imaging modalities, such as computed tomography and plain radiographs, are limited to providing a 2-dimensional representation of a 3-dimensional problem. This study describes the benefits of 3-dimensional stereolithography in the perioperative management of symptomatic heterotopic ossification using models that were fabricated based on high-resolution computed tomography scans. The models facilitated heterotopic ossification excision through frequent intraoperative reference, allowing the authors to avoid iatrogenic neurovascular injuries.

Surgical excision of heterotopic ossification is indicated when it is symptomatic. The location of heterotopic ossification formation and its relationship to critical structures, such as major nerves, arteries, and veins, makes surgical excision complex. The purpose of this article is to describe the benefits of 3-dimensional (3-D) stereolithography in the evaluation, surgical planning, and intraoperative excision of symptomatic heterotopic ossifications. Detailed anatomic information is essential when planning strategies for surgical excision.

Current imaging modalities such as computed tomography (CT) and plain radiographs provide useful clinical information; however, interpretation of the relationships of critical anatomic structures within the heterotopic ossification can be a significant challenge. The authors use 3-D stereolithographic models to assist in preoperative planning and use as an intraoperative reference for the excision of complex, combat-related heterotopic ossifications.

Case Report

Three patients who sustained significant complex, combat-related injuries that were complicated by extensive symptomatic heterotrophic ossification were evaluated. Three-dimensional stereolithography models were created based on high-resolution computer tomography scans. Preoperative planning consisted of comparing the 3-D stereolithography model and diagnostic imaging studies with the patients’ clinical examination. Anatomic relationships and descriptions were then compared with intraoperative findings when the surgery was performed. The 3-D stereolithography model was frequently referenced during the surgical intervention to plan the surgical approach for the excision of symptomatic heterotopic ossifications and to avoid iatrogenic injuries to critical structures intraoperatively.

Postoperatively, patients were administered a 6-week course of a cyclooxygenase-2 nonsteroidal anti-inflammatory drug as a prophylactic against heterotopic ossification.
cation recurrence. Average follow-up was more than 12 months (range, 12-24 months). No postoperative complications were noted.

**Patient 1**

A 21-year-old, active-duty Marine sustained a Gustilo grade IIIc segmental femur fracture (Figures 1A, B) to the right leg that required a superficial femoral artery bypass graft and segmental femoral artery repair. The patient eventually underwent soft-tissue coverage with a right rotational gastrocnemius flap and a split-thickness skin graft. The femur fracture was managed with open reduction and internal fixation.

The patient’s femur fracture eventually healed; however, his recovery was hampered by a restriction in his knee range of motion and pain when lying prone. His symptoms were attributed to symptomatic heterotopic ossification (Figures 1C, D) in the anterior right thigh. Due to concerns that the patient’s superficial femoral artery bypass graft was in close proximity to the heterotopic ossification, a computerized tomographic angiography of the right lower extremity was obtained; it revealed encasement of the superficial femoral artery graft in heterotopic ossification (Figure 1E).

A stereolithography model (Figure 1F) based on the computerized tomographic angiography was obtained that showed the anatomy correlating with the exact location of the bypass graft in 3-D. This information was used by the surgical team to minimize dissection and exploration of the area known to include the superficial femoral artery bypass graft, allowing for safe resection of the symptomatic heterotopic ossification (Figures 1G, H). Follow-up radiographs taken 1-year postoperative revealed no recurrence of the heterotopic ossification.

**Patient 2**

A 27-year-old, active-duty Marine involved in a heli-
copter crash sustained an irreducible left posterior wall acetabulum fracture and hip dislocation. The patient underwent open reduction of his left hip in Afghanistan and was placed in traction to maintain the reduction. Once state-side, the patient underwent open reduction and internal fixation of the posterior wall fracture approximately 2 weeks after the initial injury. Despite postoperative radiation (a single dose of 750 cGy administered 12 hours postoperatively), his recovery was complicated by the development of extensive heterotopic ossification (Figures 2A, B), which severely restricted his hip range of motion (Booker IV).

Preoperative 3-D stereolithography modeling (Figure 2C) provided a representation of the detailed relationships between the heterotopic ossification and critical structures around the hip. The model was referenced frequently intraoperatively and directly correlated with the authors’ operative findings. Partial resection of the bridging heterotopic ossification facilitated a return of hip range of motion (Figure 2D). Follow-up radiographs at more than 2-years postoperative revealed no recurrence of the heterotopic ossification.

Patient 3
A 28-year-old, active-duty US Marine Corps explosive ordnance technician sustained a Gustilo grade 3B proximal ulnar fracture of the left elbow with radial head dislocation (Monteggia equivalent) secondary to an improvised explosive device blast. Following several irrigation and debridement surgeries, the patient underwent open reduction and internal fixation of the fracture and soft-tissue coverage facilitated with a latissimus free flap. Postoperative management was complicated by extensive heterotopic ossification and ankylosing of the elbow (Figures 3A, B).

To facilitate preoperative planning and to identify the location of the heterotopic ossification in relation to neurovascular structures, a 3-D stereolithography model was obtained. The model demonstrated the anatomic relationships including the coursing of the median and radial nerves, as well as the radial artery through the heterotopic ossification (Figure 3C). Through frequent intraoperative reference to the 3-D model, resection was uneventful and facilitated significantly improved functional range of motion (Figure 3D). Follow-up radiographs revealed no recurrence of the heterotopic ossification.

**Discussion**
Traditional diagnostic imaging studies offer significant data when planning strategies for heterotopic ossification resection. However, plain radiographs and even 3-D CT imaging are limited in the amount and type of data they can deliver. Like plain radiographs, 3-D CT images are displayed on a flat screen or radiography film in only 2 dimensions. Being aware of the 3-D configuration of heterotopic ossification facilitates an appreciation of the distorted anatomy and anatomic relationships and allows preparation for surgical heterotopic ossification excision.

Historically, heterotopic ossifications have had to be resected using trial and error (often a time-consuming process) during the operation to minimize iatrogenic injury to critical neurovascular structures. In this context, a copy of the real anatomy in the form of a 3-D stereolithography model allows for preoperative planning and intraoperative reference. Three-dimensional stereolithography models offer the advantage of a life-like copy of the anatomy in question that can be referenced during all phases of the surgical planning and excision. The accuracy of 3-D stereolithographic modeling has been previously confirmed. Schicho et al. reconfirmed the
accuracy of stereolithography models by overlying a CT of the patient’s anatomy to a CT of the stereolithography model.

Through a several step process, the models are created with CT data that is used to direct an ultraviolet laser to selectively polymerize a liquid acrylic solution. Liacouras et al described the method by which stereolithographic models are produced:

First, CT scans spanning the area of interest are imported into Mimics (Materialise, Ann Arbor, Michigan) to create a 3-D stereolithography file. Mimics imports the standard CT scans, calculates the sagittal and coronal views, and, using Hounsfield Units, allows the user to threshold the scans and create 3-D reconstructions. Any artifact is manually removed from the computational file. Computational models are then cleaned and supporting features are added, if necessary, using Magics (Materialise). For the anatomical modeling step, stereolithography files are processed on a build platform using Light Year (3D Systems, Rock Hill, South Carolina). Files are rapid prototyped using the stereolithography 7000 (3D Systems, Rock Hill, South Carolina), a stereolithography apparatus, by local curing resin using an ultraviolet laser layer by layer in the Z-direction in 0.125-mm increments, which accurately recreates canals and foramina depicting the location of critical structures. Models are drained, washed in tripropylene glycol monomethyl ether, rinsed in water, and dried. Supports (lattice structures) are stripped from the model and the models are post cured (Post Curing Apparatus; 3D Systems).

Three-dimensional stereolithography models offer several advantages over traditional imaging and may have other orthopedic applications. Kakarala et al discussed the use of stereolithographic models in the assessment of new surgical techniques and implant designs. The authors explained that the variation and limited availability of cadaveric bones for implant stability tests are challenges in their use. Artificial bones made by stereolithographic techniques produce custom-made bones with realistic geometries. The authors concluded that their study provided a strong indication for stereolithography bones as a valid model for the biomechanical assessment of new techniques in knee surgery and compared favorably with previously used models.

In a pilot study, Brown et al introduced a novel surgical technique for the treatment of acetabulum fractures. Patients were surgically treated using an interpositional template as a surgical guide for accurate positioning of a fixation plate and screw trajectories. It was designed and fabricated based on the stereolithography technique using both laser scanning and CT imaging. The authors concluded that their study provided an effective means for preoperative planning and accurate fixation of acetabulum fractures. They suggested that additional studies were needed to demonstrate a decrease in operative time, morbidity, radiation exposure and improvement in hardware placement.

The literature on stereolithographic modeling in orthopedic surgery, and medicine in general, is limited to a few case reports and discussions about the feasibility of the technique. No prospective studies have demonstrated the use of stereolithographic models.

**Conclusion**

Stereolithographic modeling based on CT of symptomatic heterotopic ossification provides models that correlate with actual surgical findings. They can be fabricated to be true to scale and life-like, provide an...
accurate 3-D anatomic replica (which is a representation of complex and often distorted anatomy to assist in preoperative planning), and serve as an intraoperative reference.

REFERENCES


