Use of 3-Dimensional Printing for Preoperative Planning in the Treatment of Recurrent Anterior Shoulder Instability

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Abstract: Recurrent anterior shoulder instability often results from large bony Bankart or Hill-Sachs lesions. Preoperative imaging is essential in guiding our surgical management of patients with these conditions. However, we are often limited to making an attempt to interpret a 3-dimensional (3D) structure using conventional 2-dimensional imaging. In cases in which complex anatomy or bony defects are encountered, this type of imaging is often inadequate. We used 3D printing to produce a solid 3D model of a glenohumeral joint from a young patient with recurrent anterior shoulder instability and complex Bankart and Hill-Sachs lesions. The 3D model from our patient was used in the preoperative planning stages of an arthroscopic Bankart repair and remplissage to determine the depth of the Hill-Sachs lesion and the degree of abduction and external rotation at which the Hill-Sachs lesion engaged.

The role of preoperative imaging is paramount in determining the associated pathologies and performing surgical planning in cases of recurrent anterior shoulder instability. Special radiographic views such as the Stryker notch view and anteroposterior view in external rotation can help show Hill-Sachs lesions, whereas the West Point view can better identify osseous Bankart lesions.1,2 Beyond standard radiography, magnetic resonance imaging (MRI) is useful in identifying labral abnormalities and tears of the rotator cuff tendons.1 Computed tomography (CT) scans have become the current standard for quantifying glenoid bone loss, with 3-dimensional (3D) reconstruction scans used to estimate glenoid bone loss by digital subtraction of the humeral head.3,4 However, the gold standard for determining glenoid bone loss remains direct visualization by arthroscopy.

Despite the aforementioned technologic advancements in imaging, these methods only provide a 2-dimensional representation of a 3D object (on a monitor). This can place limits on the surgeon’s understanding of the anatomy. Rapid prototyping or 3D printing provides a solution to this problem. It uses computer-aided design (CAD) to produce solid 3D physical models of objects.5 Its use in orthopaedic surgery as a tool for surgical planning in trauma and spine surgery has already been documented.6,7 However, the use of rapid prototyping for preoperative planning in the treatment of shoulder instability has yet to be described. As a result, we describe our experience with 3D printing of a glenohumeral joint model in a patient with a complex history of recurrent anterior shoulder instability and a large bony Bankart lesion.

Case

A 29-year-old man presented with a history of recurrent anterior shoulder dislocations involving the dominant upper extremity. His first dislocation occurred at the age of 18 years, while throwing a snowball. This required a reduction under conscious sedation in the emergency department. He subsequently had over 20 more traumatic and atraumatic episodes of either anterior dislocation or subluxation. A course of physical therapy for 6 months failed to relieve...
his symptoms. Physical examination of the shoulder showed a positive apprehension sign, relocation test, and positive jerk test negative findings. The Beighton hypermobility score was 4 out of a possible 9 points.8

A radiograph, CT scan, and MRI were obtained preoperatively (Figs 1-3). A 3D reformat of the CT scan was also produced (Fig 4). The imaging showed an anteroinferior labral tear from the 2- to 5-o’clock position, a partially united bony Bankart fragment, and a large Hill-Sachs lesion on the humeral head. Despite the detail provided by the 3D reconstruction of the CT scan, it remained difficult to adequately determine the depth of the defect. As a result, the data from the CT scan were used to create a 3D rapid-prototype model of the patient’s shoulder using CAD digital software (InVeevo Health, Toronto, Ontario, Canada) (Fig 5). The model was then used to further quantify the amount of humeral head and glenoid bone loss, as well as to determine the degree of abduction and external rotation at which the Hill-Sachs lesion engaged (Video 1).

Engagement was measured to occur at 60° of external rotation and 90° of abduction, as well as 90° of external rotation and 0° of abduction.

We attempted to use the instability severity index score (ISIS)9 to help us determine whether to proceed with arthroscopic or open shoulder stabilization. The patient was older than 20 years of age, was no longer participating in competitive overhead activities or contact sports, and had a borderline overall ISIS of 5. Despite the ISIS score of 5, we remained uncertain regarding the optimal operative plan. As a result, we turned to our printed 3D model to assist in the development of a surgical plan. We decided to perform an arthroscopic Bankart repair plus remplissage procedure because the 3D model showed glenoid bone loss of less than 25% with a Hill-Sachs lesion deeper than 15% of the radius of the humeral head.10,11 The solid 3D model also assisted us in determining how many suture anchors would be required for the remplissage procedure, including how many would fit in the Hill-Sachs lesion (Video 2).
Surgical Technique

Patient Positioning and Diagnostic Arthroscopy

After administration of preoperative antibiotics, the patient was put under general anesthesia and placed in the beach-chair position. An examination under anesthesia was performed before the start of the procedure. A standard posterior portal was created for insertion of the arthroscope (Fig 6). A diagnostic arthroscopy was then performed to assess the extent of the labral tear, as well as glenoid and humeral bone loss (Fig 7), and to identify other intra-articular pathology (Video 1).

Arthroscopy showed the Hill-Sachs lesion to engage within the glenoid defect at the same degree of abduction and external rotation as measured on the 3D model preoperatively (Fig 8). Two Twist-In cannulas (Arthrex, Naples, FL) were then inserted in the rotator interval, one just inferior to the long head of the biceps tendon and the other just superior to the subscapularis tendon.

Bankart Repair

During our diagnostic arthroscopy, the bony Bankart lesion was found to be diminutive; as a result, we decided to incorporate it into the repair. We achieved this by first elevating the labrum off the medial glenoid with a liberator. Next, we prepared the glenoid surface using a rasp and shaver. Anchors were then inserted along the glenoid face at the 5-, 3-, and 1-o’clock positions. A 45° SutureLasso (Arthrex) was used to shuttle the suture through the labrum, creating an inferior-to-superior shift of the capsule. The labrum was then secured by tying arthroscopic SMC knots.

Remplissage Procedure

We introduced the arthroscope through the posterolateral portal and placed a Twist-In cannula through the posterior portal. The bony bed of the engaging Hill-Sachs lesion was prepared using a rasp and shaver. We then placed a 5.0-mm Corkscrew anchor (Arthrex) into the Hill-Sachs lesion (Fig 9). The cannula was backed out of the shoulder to an extracapsular position. A BirdBeak instrument (Arthrex) was passed through the cannula and then through the infraspinatus to retrieve the suture. This process was repeated to grab the other limb of the suture. An SMC knot was then tied to create a tenodesis of the infraspinatus to the Hill-Sachs lesion. A second Corkscrew anchor was placed in the Hill-Sachs lesion, and the previous step was repeated to create a second point of fixation.

Fig 3. Magnetic resonance imaging scans depicting (A) axillary and (B) sagittal views of right shoulder. A large Hill-Sachs lesion (red arrow) is seen on the axillary view. A small bony Bankart lesion (blue arrow) is seen on the sagittal view.

Fig 4. Three-dimensional computed tomography scan reconstruction of right shoulder: (A) superior, (B) oblique, and (C) anteroposterior views. A large Hill-Sachs lesion is visualized on the superior view (arrow).
arthroscope was placed back in the posterior portal, and the shoulder was placed into abduction and external rotation. Engagement of the Hill-Sachs lesion past the glenoid was no longer possible.

Postoperatively, the patient was placed in an internal rotation sling for 6 weeks, with passive range-of-motion exercises beginning immediately. Active range-of-motion and resistive exercises began after 6 weeks. At the 6-month follow-up, the patient showed full range of motion except for a 15° external rotation deficit, showed full rotator cuff power, and had no further episodes of instability.

**Discussion**
The use of 3D printing overcomes many of the limitations of 2-dimensional imaging by generating a graspable 3D object. The process of creating a 3D model consists of 3 major steps: image acquisition, image post-processing, and rapid prototyping. First, the images are acquired using either a CT scan or MRI; then, the image data can be transferred to a dedicated image post-processing workstation, on which 3D segmentation and visualization are performed to create a CAD model of the structure. Lastly, a 3D printing machine uses these data to create a solid 3D object through the addition of material layers. At this time, 5 established rapid prototyping techniques exist (stereolithography, selective laser sintering, fused deposition...
modeling, laminated object manufacturing, and inkjet printing techniques), all of which have their own advantages and disadvantages including varying degrees of accuracy and cost.\(^5\)

In our patient we found that the use of rapid prototyping was instrumental in determining the degree of bone loss associated with both the Hill-Sachs and Bankart lesions. The ability of the model to provide an understanding of the depth of bone loss was helpful in selecting the surgical treatment for our patient. We also found the model useful for preoperative simulation and determination of the placement and number of suture anchors that would be required during the operation. Although we did not make note of this finding in our case, recent case reports in orthopaedic trauma surgery have suggested that the use of preoperative 3D printed models has led to reduced surgical time, decreased time under anesthesia, decreased intraoperative blood loss, and better reduction of complex fractures.\(^12\) Finally, the rapid prototype also functioned as an educational tool for junior trainees and medical students in the operating room.

Despite the promising features of 3D printing technology, there remain some limitations associated with this technology. One drawback is the time required to create a 3D model. It often takes several hours to produce; as a result, 3D printing in emergency cases is not possible.\(^12\) In addition, the availability and cost of 3D printing remain obstacles to its widespread use. Cost often varies depending on prototyping technique, as well as volume and dimension.\(^5\) For instance, the cost of the glenohumeral model in our study was approximately $150, whereas the cost of an adult pelvis could be as much as $1,100.\(^6\) On the other hand, the cost may actually be offset by the savings gained from decreased surgical times.\(^12\) Lastly, the utility of 3D printing in preoperative planning for arthroscopic stabilization procedures is limited by the absence of the surrounding soft tissues; as a result, the model may not be truly representative of intraoperative conditions. Nonetheless, we found 3D modeling useful during preoperative planning because it enhanced our understanding of the depth and size of bony lesions in our patient with recurrent shoulder instability (Table 1).

### References


### Table 1. Benefits and Limitations of Using 3D Printed Models for Cases of Recurrent Anterior Shoulder Instability

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Limitations</th>
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<tbody>
<tr>
<td>A true 3D representation of an object (graspable) is generated.</td>
<td>Access to 3D printers is not widespread.</td>
</tr>
<tr>
<td>Physical quantification of bone loss is possible.</td>
<td>It requires several hours to produce the model.</td>
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<tr>
<td>Greater appreciation of the depth of a Hill-Sachs lesion is allowed.</td>
<td>Cost can vary depending on prototyping technique, volume, and dimension.</td>
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<tr>
<td>The model serves as a tool for preoperative planning, as well as determination of suture anchor placement.</td>
<td>The surrounding soft tissue is absent; thus the model is not representative of the intraoperative environment.</td>
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<tr>
<td>The model serves as an educational tool for trainees.</td>
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3D, 3-dimensional.


