Dynamic Assessment of Engaging Hill-Sachs Lesions Using 3D Animation Techniques

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Authors: J. J. R. Chong, M. Beaumont-Courteau, P. A. Martineau, T. Powell; Montreal, QC/CA
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Aims and objectives

The aim of this poster is to provide a conceptual approach and methodology to the virtual articulation of the glenohumeral joint to assess for the presence of an engaging or non-engaging Hill-Sachs lesion. We hope to:

• Define the importance of engagement and existing definitions of Hill-Sachs lesion evaluation
• Describe a methodology for both the 3D segmentation and animated articulation of the glenohumeral joint and advantages of this method
• Provide examples of engagement/non-engagement
• Propose future directions for future avenues of investigation
Methods and materials

Patient Population

A retrospective review was conducted of the last 6 years of CT examinations at a tertiary academic center to identify cases of Hill-Sachs lesions. A test sample of 9 cases was obtained of patients with pre-operative high-resolution CT imaging demonstrating the presence of a Hill-Sachs defect. Associated examinations including recent radiographs as well as follow-up MRI examinations and reports were also simultaneously obtained.

Image Acquisition

Full resolution DICOM sets of axial images at 0.625mm thickness / 0.0mm separation were obtained and anonymized. The thin-cut axial series on bone-filter was isolated from the remainder of the examination and reconstructions. These axial images were then separated into independent folders and processed using Amira (Burlington, MA) to construct a 3D polygonal mesh. CT threshold settings were set to between 200 - 4000 Hounsfield units (HU) to isolate bone from soft-tissue. The segmented polygonal mesh was then exported into a Wavefront (*.obj) format for import into an open-source 3D animation program, Blender (Amsterdam, Netherlands).

Animation Rigging and Manipulation

The static isosurface was duplicated within Blender and independent meshes of the shoulder girdle and the humerus were created. These separated meshes were then positioned in the original position of acquisition. A center of rotation was established within the humeral head at the centroid of the articular surface. These models were further annotated using the following control points and rays to facilitate joint angle measurements.

Control Point and Rays Definitions

For the purposes of this methodology, multiple standardized control points and rays are defined for position measurement and joint articulation.

HILL-SACHS TROUGH:
The trough of the Hill-Sachs defect is defined as two points defining a ray cast through the deepest portion of the Hill-Sachs defect.
HILL-SACHS RIMS:
As the Hill-Sachs defect is a V-shaped defect, there are two rims that are can be defined surrounding the Hill-Sachs trough that can initially engage with the glenoid. These rays are parallel with the Hill-Sachs trough.

SPHERE OF HUMERAL HEAD ARTICULATION:
The sphere of humeral head articulation is defined as a best-fit sphere that approximates the contour of the articular surface of the humeral head. It can be derived from the placement of four known points on the articular surface using a sphere of best-fit formula. From this sphere, the Center of Rotation (CoR) is derived which is the rotation point upon which all movements (i.e. abduction/adduction/internal/external rotation) of the humerus are made. It is acknowledged that this is an approximation of the true motion of the humerus which is more complex and saddle-like in nature and does not account for glenohumeral translation/elevation. However, previous literature suggests that this spherical approximation is sufficiently accurate with only a minimal amount of vertical translation of the humeral head in experimental studies and was felt to be of a minimal contribution to error in motion.

BICIPITAL GROOVE (INTERTUBERCULAR SULCUS):
The bicipital groove is the fixed landmark chosen to standardize internal and external rotation between studies. CT examinations are made in anatomic position with the palms and bicipital grooves facing anteriorly.

HUMERAL DIAPHYSEAL SHAFT:
The humeral diaphysis is defined as a ray cast through the center of the intramedullary space of the humerus intersecting with the previously defined Centre of Rotation (CoR) of the humeral head.

GLENOID:
The glenoid is a scapular articular surface that is roughly pear-shaped with the narrowest portion at the superior aspect.

GLENOID LONG AND SHORT AXIS:
The rim of the articular surface is defined to be an irregular ellipsoid. From this, the long-axis line segment and a perpendicular short-axis line segment of the ellipsoid is defined.

GLENOID (OSSEOUS BANKERT INJURY) ANTERIOR MODIFIED EDGE:
In circumstances where there is significant osseous injury to the glenoid articular surface, an alternate edge of engagement is defined that is parallel to the new anterior edge of the glenoid.
Definition of Engagement and Functional Ranges of Motion:

An engaging Hill-Sach's defect was defined as a lesion in which the trough of the defect was parallel to the anterior edge of the glenoid with the shoulder in functional positions of abduction and external rotation. In circumstances where the glenoid was intact, this anterior edge was defined to be parallel to the long-axis of the glenoid articular surface. In circumstances where there was an osseous injury to the glenoid, multiple analyses were performed using both the long-axis of the articular surface, as well as the true anterior edge of the damaged glenoid taking into account the osseous defect.

Functional shoulder range of motion was defined as abduction 0-130 degrees and external rotation (with arm pre-abducted to 90) 0-60 degrees upwards.
Results

As per the previously described methodology, the sample test cases were each segmented with points and measurement rays positioned into the 3D models. Each limb was articulated into functional positions of (1) 0° abduction / 0° external rotation, (2) 90° abduction / 0° external rotation and (3) 90° abduction 90° external rotation observing for the relationship between the Hill-Sachs trough and the glenoid rim in all positions.

An example of such a setup is described as follows:

Example

![Ray cast through the trough of a large Hill-Sachs lesion.](image)

**Fig. 1**: Ray cast through the trough of a large Hill-Sachs lesion.

**References**: McGill University Health Centre - Montreal/CA
Fig. 2: Large anterior osseous defect secondary to previous traumatic injury. Anterior edge of glenoid is defined in this example relative to the true anterior edge and not the long-axis of the articular surface. A ray is cast through this anterior edge, making it the likely surface to initiate engagement with the Hill-Sachs defect.

References: McGill University Health Centre - Montreal/CA
Fig. 3: In this frontal projection, the glenoid and humerus are brought together into articulation. Note the transparent green sphere representing the expected articular surface of the humerus with a center of rotation.

References: McGill University Health Centre - Montreal/CA
Fig. 4: Lateral view of the same joint showing an approximately 25° degree offset between the Hill-Sachs trough and the anterior edge of the damaged glenoid. The trough is positioned laterally making this function position non-engaging.

References: McGill University Health Centre - Montreal/CA
**Fig. 5:** The same humeral head has been articulated into an engaging position. This frontal view demonstrates a parallel Hill-Sachs trough and the anterior edge of glenoid.

**References:** McGill University Health Centre - Montreal/CA
**Fig. 6:** Lateral view demonstrate near parallel rays of engagement. Engagement of the glenohumeral joint is highly likely to occur in this position.

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The preceding case example depicts a Hill-Sachs lesion with a very large trough that is shown to engage and not engage with the glenoid depending on articulated position. The blue lines depict the relative axes of the trough and glenoid rim with parallel orientation being the position of greatest engagement. A primary expectation of this methodology is that if a large lesion is not parallel with the glenoid, the probability of it engaging is relatively low in spite of the large size of the lesion. Utilizing this articulated methodology allows this relationship to be explored virtually and to determine if the patient is likely to encounter engagement in day-to-day living.
Fig. 1: Ray cast through the trough of a large Hill-Sachs lesion.

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Fig. 2: Large anterior osseous defect secondary to previous traumatic injury. Anterior edge of glenoid is defined in this example relative to the true anterior edge and not the long-axis of the articular surface. A ray is cast through this anterior edge, making it the likely surface to initiate engagement with the Hill-Sachs defect.

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**Fig. 4:** Lateral view of the same joint showing an approximately 25° degree offset between the Hill-Sachs trough and the anterior edge of the damaged glenoid. The trough is positioned laterally making this function position non-engaging.

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Fig. 5: The same humeral head has been articulated into an engaging position. This frontal view demonstrates a parallel Hill-Sachs trough and the anterior edge of glenoid.

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Fig. 6: Lateral view demonstrate near parallel rays of engagement. Engagement of the glenohumeral joint is highly likely to occur in this position.

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Fig. 7: Oblique view better depicting the orientation of the trough with the anterior edge of glenoid.

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Conclusion

We believe that the method presented here is a more functionally accurate and relevant approach to the assessment of the clinical significance of a Hill-Sachs lesion and takes better into account both the orientation of the lesion in addition to usual parameters like lesion size and depth. In doing so via a 3D animated paradigm, we allow for an intuitive visualization of the clinical significance of a Hill-Sachs lesion which is highly relevant to both the patient as well as the referring orthopedic surgeon. It respects the need for repeatable, objective, and functional measurements that can be correlated to findings on physical examination. Further investigations building on this methodology in a retrospective case-control trial will help further validate the utility of this method.
