Shoulder Measurements using CT: What the orthopedic surgeon wants to know

Poster No.: P-0087
Congress: ESSR 2013
Type: Scientific Exhibit
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Keywords: Outcomes, Education and training, Computer Applications-General, CT, Musculoskeletal joint, Musculoskeletal bone, Extremities

DOI: 10.1594/essr2013/P-0087

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Purpose

CT is an excellent imaging modality for visualization of normal bone and demonstration of bony pathology. CT has been used for pathologic and non-pathologic measurements between the bony articulations of the shoulder joint. The objective of this educational exhibit is to review the most common measurements of the shoulder and discuss their impact on management and predisposition to pathology.

Glenoid version, which is the angle that the glenoid center establishes with the plane of the scapula, can be associated with arthritis and shoulder instability. If not properly accounted for, glenoid version can lead to failed surgical treatment.

The Bony Bankart classification refers to the fracture of the anteroinferior glenoid and is subdivided into three basic types. Type 3 is further classified according to the amount of bone loss, measured by the Bankart length measurement.

Measurement of the glenoid bone stock aids the orthopedist in the proper choice of treatment in patients diagnosed with osteoarthritis (OA) and Reumatoid Arthritis (RA). Lastly, the Neer classification of the proximal humeral fractures and the measurement of the Hill-Sachs lesion provide valuable information for the orthopedist in planning of additional procedures.

Methods and Materials

- Review of relevant, basic shoulder anatomy on CT
- Discussion of glenoid version measurement and impact on shoulder arthroplasty
- Greater Tuberosity displacement in isolated fracture
- Neer classification of the proximal humeral fractures
- Description of Hill-Sachs lesions
- Bony Bankart Classification
- Measurement of bone stock and implication on treatment

CT images will be included to best visualize the above teaching points. Brief discussion of pathophysiology will be provided.
Results

A. Basic overview of osseous anatomy of the shoulder on CT (Fig. 1)

B. Detailed Anatomy of the Glenoid

Parameters of glenoid anatomy including height, width and version can affect glenoid component design, instrumentation and implantation techniques in shoulder arthroplasty:

**Glenoid height**: Distance from the most superior and inferior points on the glenoid.

- Churchill et al reported a gender difference with a mean glenoid height of 37.5 mm (range, 30.4-42.6 mm) for men and 32.6 mm (range, 29.4-37 mm) for women.
- There was no difference in glenoid height between Caucasian and African American patients.

**Glenoid width**: Distance from the most anterior and posterior points on the glenoid.

- Churchill et al reported a difference in mean glenoid width of 27.8 mm (range, 24.3-32.5 mm) in male specimens compared with 23.6 mm (range, 19.7-26.3 mm) in female specimens.
- There was no difference in glenoid width between Caucasian and African American patients.
- Checroun et al reported that 71% of the 412 glenoids studied were pear-shaped (upper width smaller than lower width) with the remainder elliptical.

**Glenoid version**: Angular orientation of the axis of the glenoid articular surface relative to the long (transverse) axis of the scapula.

- Normal range varies from 2° anteversion to 9° retroversion
- According to Churchill et al, glenoids from male patients tend to be slightly more retroverted than those from female patients (mean, 1.5° compared with 0.9°, respectively).
- Caucasian patients' glenoids tend to be more retroverted than those from African American patients (mean, 2.7° compared with 0.2°).
- Couteau et al measured glenoid version in 3 subsets of patients: those with early rotator cuff tears, those with primary osteoarthritis and those with rheumatoid arthritis:
  - Early rotator cuff tear: mean glenoid retroversion was 8° with
range of 2°-17° retroversion
- Osteoarthritis: mean glenoid retroversion was 16° with range of 0.2°-50° retroversion
- Rheumatoid arthritis: mean glenoid retroversion was 15° with range of 6°-22° retroversion

Glenoid Version Measurement (Fig. 2 and 3):

Line a: Transverse axis of the scapula: Line drawn from midpoint of the glenoid fossa to the medial end of the scapula.

Line b: Line of neutral version: Perpendicular to line a.

Line c: Through anterior and posterior margins of the glenoid. Osteophytes are not considered a margin.

Alfa angle is the amount of retroversion.

If the posterior margin of the glenoid is medial to line of neutral version, the condition is defined as retroversion of the glenoid cavity. If the anterior margin of the glenoid is medial to line of neutral version, the condition is defined as anteversion of the glenoid cavity.

C. Impact on shoulder arthroplasty

Proper orientation of a glenoid implant is essential for long-term stability of the prosthesis since a malpositioned glenoid will be subjected to increased torques on the fixation surface, leading to early component loosening and clinical failure.

Retroverted glenoids are more susceptible to loosening as compared to anteverted glenoids.

Farron et al evaluated the degree of retroversion on glenoid implant loosening

- Retroverted glenoids cause posterior displacement of the glenohumeral contact points, leading to increase in micromotion and stress during rotation range of motion.
- Glenoid retroversion of #10° should be corrected before glenoid implantation
- If the degree of retroversion can not be corrected, glenoid implantation is not recommended

Shapiro et al investigated contact pressures in a native shoulder, glenoid in neutral position and a retroverted glenoid

- Retroverted shoulder had a smaller contact area and higher contact pressure as compared to a healthy shoulder and shoulder with glenoid in neutral position
- Significant glenoid retroversion has been noted to lead to eccentric loading and implant wear, loosening

Yian et al observed a correlation between greater preoperative glenoid retroversion measurements and poorer functional results after shoulder arthroplasty

**D. Greater tuberosity displacement in isolated fracture**

Account for about 20% of all proximal humeral fractures

Associated with anterior glenohumeral dislocation or impaction injury against the lower surface of the acromion or superior glenoid

Diagnosis/classification is mainly based on plain radiographs; however, these fractures are challenging to identify due to osseous overlap

Degree of fragment dislocation is classified into 3 categories:

- Undisplaced to minor #5mm
- Moderate 6-10mm
- Major >10mm

**Measurement of greater tuberosity displacement in isolated fracture** (Fig. 4, 5 and 6):

- Measure the distance between the upper surface of the humeral head and upper margin of the main fragment or distance between the outer surface of the humeral head and the outer margin of the main displaced fragment.
- Determine direction of displacement: anterior, posterior, cranial or caudal.

**Treatment of greater tuberosity displacement in isolated fracture:**

More than 5 mm displacement in the general population indicates surgical fixation
More than 3 mm in active patients with frequent overhead activity indicates surgical fixation

Drawbacks to operative treatment include heterotopic ossification and appearance of OA

**E. Neer Classification** (Fig. 7)

Fractures are classified by evaluating displacement of any of the four principal fragments which include the head, shaft, greater tuberosity and lesser tuberosity of the humerus. However, several studies have questioned the reliability and reproducibility of the Neer classification system.

Sidor et al investigated interobserver reliability and intraobserver reproducibility of the Neer Classification system:

- Interobserver reliability was assessed by comparison of the fracture classifications as determined by the five observers which included an orthopaedic shoulder specialist, an orthopaedic traumatologist, a skeletal radiologist, and two orthopaedic residents.
- Intraobserver reproducibility was evaluated by comparison of the classifications determined by each observer on the first and second viewings, 6 months apart.
- All five observers agreed on the final classification for 32% and 30% of the fractures on the first and second viewings, respectively. Paired comparisons between the five observers showed a mean reliability coefficient of 0.48 (range, 0.43 to 0.58) for the first viewing and 0.52 (range, 0.37 to 0.62) for the second viewing.
- Reproducibility ranged from 0.83 (the shoulder specialist) to 0.50 (the skeletal radiologist), with a mean of 0.66.
- Simplification of the Neer classification system did not improve interobserver reliability or intraobserver reproducibility.

**One part fracture**: All fractures in which no segment is displaced more than 1 cm or is rotated no more than 45 degrees are considered minimally displaced, regardless of the number or location of fracture lines.

**Two part fracture** (Fig 8): One fragment is displaced more than 1 cm or is rotated more than 45 degrees. Four possible types include:

- Surgical neck
- Greater Tuberosity
- Anatomical Neck
- Lesser Tuberosity
Three part fracture (Fig 9): Two fragments are displaced more than 1 cm or are rotated more than 45 degrees. Two possible types include:

- Greater tuberosity and shaft are displaced with respect to the lesser tuberosity and articular surface which remain together
- Lesser tuberosity and shaft are displaced with respect to the greater tuberosity and articular surface which remain together

Four part fracture/fracture dislocation/head splitting fractures (Fig 10):

- Articular segment displaced out of contact with glenoid, no soft tissue attachment, no tuberosity contact

F. Hill-Sachs Lesion (Fig. 11)

Definition: Impression fracture of the humeral head

Due to impaction of the posterolateral aspect of the anteriorly dislocated humeral head with anterior rim of the glenoid

Common in patients with recurrent shoulder dislocation

Glenohumeral instability depends on size, orientation, and location of the defect

Cho et al compared the width, depth, and Hill-Sachs angle of engaging and non-engaging Hill-Sachs lesions

- **Engaging lesions**: 52%(w) and 14%(d) of the humeral head diameter on axial, 42%(w) and 13%(d) on coronal images respectively. H-S angle 25.6° +/- 7.4°.
- **Non-engaging lesions**: 40%(w) and 10%(d) of the humeral head diameter on axial, 31%(w) and 11%(d) on coronal images respectively. H-S angle 13.8° +/- 6.2°.
- Increased failure rate of arthroscopic Bankart repair due to significant bone defect in engaging Hill-Sachs lesions

- Bankart repair is contraindicated when depth of H-S lesion as a percentage of the humeral head diameter is >16%
- Additional procedures or open surgery may be required

G. Bony Bankart Lesion

*Definition:* Anterior tear of the rim of the glenoid labrum that is associated with anterior dislocation of the shoulder

*Classification of Bankart lesions:*

- **Type 1:** Displaced avulsion fracture with an attached capsule
- **Type 2:** Medially displaced fragment malunited to the glenoid rim
- **Type 3:** Erosion of the glenoid rim

A: Bone loss < 25%

B: Bone loss > 25%

CT scan: Used to quantify the amount of bone loss

Bony Bankart Measurement (Fig. 12)

*Impact on treatment:*

- In patients with glenoid bone loss of 0 up to 25%, the instability may successfully be treated with arthroscopic repair
- In patients with glenoid bone loss of >20-25%, bone augmentation procedures such as the Latarjet, iliac crest bone-grafting, or allograft technique should be considered

H. Bone Stock (Fig. 13 - 17)

Determination of bone stock is critical in the preoperative assessment of patients undergoing shoulder arthroplasty, especially patients with Rheumatoid Arthritis (RA) and Osteoarthritis (OA)

- Glenoid bone stock was found to be deficient anywhere from 20.7% to 62% of treated shoulders
- **Rheumatoid Arthritis**

- Two patterns of erosion include: posterior wear (more common)

and anterior wear
- Best (supported) bone was found at the anterior half of the upper/middle levels with remaining surface composed of unsupported bone
  
  - Osteoarthritis

- More supported bone in comparison to RA patients at all levels

- Best (supported) bone was found anteriorly at the upper level and centrally at the middle/lower level

Knowledge of extent and location of the unsupported bone allows for proper placement of the keel or peg of the glenoid component into good trabecular bone

Images for this section:

Basic overview of osseous anatomy of the shoulder on CT

IMAGE A: AXIAL CT
Blue Arrow: Humeral Head
Green Arrow: Coracoid Process
Black Arrow: Glenoid

IMAGE B: CORONAL CT
Blue Arrow: Greater tubercle
Green Arrow: Acromion
Black Arrow: Clavicle
Purple Arrow: AC Joint
Fig. 1: Basic overview of osseous anatomy of the shoulder on CT

Fig. 2: Glenoid version measurement
Fig. 3: Glenoid Version Measurement
Fig. 4: Measurement of greater tuberosity displacement in isolated fracture

Fig 4a-c: Axial, Coronal, and 3-D Reconstruction Images show displaced greater tuberosity fracture (orange arrow). Fig 3b shows a 4.5mm greater tuberosity displacement in relationship to the humeral head.
Measurement of greater tuberosity displacement in isolated fracture

Fig 5a-c: Axial, Coronal, and 3-D Reconstruction Images show displaced greater tuberosity fracture (orange arrow), Neer one part fracture. Fig 4b shows a 7.5mm greater tuberosity displacement in relationship to the humeral head.

**Fig. 5:** Measurement of greater tuberosity displacement in isolated fracture
Measurement of greater tuberosity displacement in isolated fracture

Fig 6a-c: Axial, Coronal, and 3-D Reconstruction Images show displaced greater tuberosity fracture (orange arrow). Fig 6b shows a 10.1mm greater tuberosity displacement in relationship to the humeral head.

Fig. 6: Measurement of greater tuberosity displacement in isolated fracture
Fig. 7: Neer Classification
Fig 8a-b: Axial and 3-D Reconstruction Images show a two part fracture involving the greater tuberosity (orange arrow). Green arrow marks the humeral head.

**Fig. 8:** Neer Classification: Two part fracture
Fig 9a-b: Axial and Coronal Images show a three part fracture involving the greater tuberosity (blue arrow) and shaft of the humerus (green arrow). The lesser tuberosity remains intact (orange arrow).

Fig. 9: Neer Classification: Three part fracture
Neer Classification: Four part fracture

Fig 10a-c: Axial, Coronal and 3-D Reconstruction Images show a four part fracture involving the greater (blue arrow), lesser tuberosity (orange arrow) and shaft of the humerus (Green arrow).

Fig. 10: Neer Classification: Four part fracture
Fig 11a: Measurement of width (W) and depth (D) of Hill-Sachs lesion on axial image of right shoulder.

Fig 11b: Measurement of bicipital angle of the Hill-Sachs lesion on axial image of the right shoulder. Bicipital groove (B).

**Fig. 11:** Hill-Sachs lesion measurements
Bony Bankart Measurement

Fig 12a-b: Best-fit circle is drawn on the inferior two-thirds of the glenoid fossa to aid with quantification of the percent bone loss (A). The osseous defect is outlined (B). The percent bone loss is quantified according to the following equation:

\[
\text{Percent Bone Loss} = \left( \frac{B}{A} \right) \times 100\%
\]

**Fig. 12:** Bony Bankart Measurement
Fig. 13: Bone Stock Measurement

Fig 14: Normal Shoulder Measurement of Bone Stock at upper level:
Line A: Maximum AP diameter (Blue Line)
Line F: Width of the scapular neck at the upper level (Red Line)
Line C: Medial displacement from the base of the coracoid to the joint surface at the upper level (Yellow Line)

Fig. 14: Bone Stock Measurement
Fig 15a-b: Normal Shoulder Measurement of Bone Stock at middle and lower levels. There is no evidence of unsupported bone posteriorly or anteriorly.

Line B: Position and extend of supported bone (Red Line)

Line Cm, L: Medial displacement from the base of the coracoid to the joint surface at the middle/lower level (Yellow Line)

**Fig. 15: Bone Stock Measurement**
Bone Stock

Fig 16a-c: Axial images of bone stock in patient with Osteoarthritis.

**Fig. 16:** Bone Stock
Bone stock

Fig 17: Coronal image in patient with advanced Rheumatoid Arthritis shows significant loss of bone stock.

Fig. 17: Bone Stock
Conclusion

Before planning for surgery, the orthopedist needs basic measurements of bony pathology which cannot be obtained at the office. The role of the Radiologist is to provide the referring physician with relevant information for optimal patient management. We hope to familiarize the practicing Radiologist and the in-training Resident with the most common shoulder measurements on CT to better the quality of the report.

Topics discussed include:

- Glenoid version
- Greater Tuberosity displacement in isolated fracture
- Neer classification of the proximal humeral fractures
- Hill-Sachs lesions
- Bony Bankart Classification
- Bone stock

References


Personal Information