Three-dimensional measurement and parameters of the glenohumeral joint in a normal cadaver: guidance in the treatment of shoulder instability

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INTRODUCTION

A number of articles have reported the measurement and anatomic analysis of the glenohumeral joint from plain X-rays, computed tomography (CT) scans, and magnetic resonance imaging (MRI) [1,2]. Recently, three-dimensional (3D) measurement in computer software has become increasingly popular, which uses 3D visualization instead of traditional two-dimensional (2D) viewing angle. A 360° visual angle and accurate measurement in computer software will...
reduce the deviation from the measurers. Based on the 3D measurement of normal shoulder, such visualization will provide evidence for shoulder instability and help choose a suitable surgical procedure. The glenoid track is a concept that can be used to evaluate a defected humeral head and glenoid at the same time, which was reported by Yamamoto et al. [3] and Gyftopoulos et al. [4]. Burkhart et al. [1,5] measured the center of the glenoid by arthroscopy, but he pointed out that the arthroscopic method has its limitations and it allows the quantification of bone defects in the glenoid. Therefore, it will be helpful for evaluating the shoulder stability by some measurements and parameters of the glenoid and humeral head, such as the anteroposterior diameter, suprainferior diameter, the depth and curvature radius of the glenoid labrum, and radius of the humeral head. On the other hand, traditional measurements are only done in the 2D plane, so it lacks an overall visual and accurate analysis of a bone defect.

Shoulder stability can be treated using several surgical techniques based on the extent of capsule relaxation, defect of the glenoid and humeral head as well as some calculations. Recent studies have shown that the bony stability assessed by the stability ratio decreased significantly after producing a bony defect larger than 26% of the glenoid width (20% of the glenoid length) [6]. In addition, shoulder stability after Bankart repair was decreased significantly with a bony defect larger than 25% of the glenoid width (19% of the glenoid length) [7]. Pure Bankart repair is a useful way for a glenoid defect less than 25% that is non-engaging. Remplissage can improve the stability but results in a decrease in the range of motion [8]. The Latarjet procedure has been used widely, and its outcome is very satisfactory [9]. Hovelius et al. [10] reported a long-term follow-up of more than 10 years after the Bristow-Latarjet procedure with 83% coracoid fusion, 5% redislocation, and 1% revision surgery. Bone graft is also considered in patients filling a humeral head defect [11-15]. Using a standard surgical technique without violating the coracoclavicular ligament, a coracoid graft greater than 25 mm can be harvested routinely for the Latarjet procedure [16]. Obviously, some measurements and parameters are necessary for the treatment of shoulder instability, and 3D visualization can increase the accuracy compared to a 2D plain. The aim of this study was to perform a 3D visualization and 3D measurements of the glenohumeral joint.

MATERIALS AND METHODS

Specimen
Chinese Digital Man No. 1 and Women No. 1 are "standard Chinese," which were selected from 20 voluntary donors in the Southern Medical University. The "Digital Human" was reconstructed with a 3D anatomic structure through a digital model on a computer. Cadaver specimen "Man No. 1" was a healthy twenty-eight year old male, and "Woman No. 1" was a nineteen year-old female. The cadaver was cut into small slices using a precise slitting wheel. Every section after cutting was photographed using a high efficiency digital camera and scanistor, and the data was then transferred into Digital Imaging and Communications in Medicine (DICOM) format. The 3D reconstruction of a human anatomic structure was the final process. The pixels of the high efficiency digital camera were up to 2.2 million, and the image resolution was 4,040×5,880.

Computer software
Mimics 14.0 (Materialise Software, Leuven, Belgium), Imageware 12.1 (Siemens PLM Software, Plano, TX, USA).

Measure method
DICOM format of the glenoid and humeral head was imported into Mimics 14.0. After a 3D reconstruction, stereolithography (STL) format was exported into Imageware software (Figs. 1 and 2). The anteroposterior diameter, suprainferior diameter, depth and curvature radius of the glenoid labrum, and radius of the humeral head were measured (Fig. 3). The anteroposterior diameter is the widest distance from the anterior margin to the posterior margin.

Fig. 1. Three-dimensional reconstruction model of both glenohumeral joints.
Fig. 2. Three-dimensional model of the scapula, glenoid, and humerus. (A) Model of the scapula (articular surface view), (B) glenoid labrum after segmentation from the scapula, (C) humeral head split from the humerus: the articular surface of the humeral head is used.

Fig. 3. Measurement of each parameter in the three-dimensional model. (A) The anteroposterior length of glenoid is measured using the Imageware measurement tool. (B) The depth of glenoid forms a plane of the glenoid rim using the 3 points method, and the vertical distance from the deepest point of fossa to the plane is measured. (C) The supra–inferior length of the glenoid is from the superior point of the glenoid labrum to inferior. (D) The curvature radius is measured after fitting the surface of the glenoid into the surface of sphere. The red (dark) area is the real articular surface of the glenoid. (E) The radius of the humeral head is measured using the same method in (D). The green (dark) area is the real articular surface of the humeral head.
The suprainferior diameter is also the widest distance from the superior margin to the inferior margin. The depth is the vertical distance from the most concave point of the glenoid to the plain of the glenoid rim, which is determined by choosing the three top points of the margin. The curvature radius of the glenoid is about the surface of the glenoid, which is fitted to a sphere using software. The humeral head was split from the humeral shaft and fitted into a sphere; the radius of humeral head was then calculated.

RESULTS

The parameters of Man No. 1
In the left shoulder, the anteroposterior diameter, suprainferior diameter, glenoid labrum depth, curvature radius of the glenoid labrum, and radius of the humeral head was 24.66 mm, 34.70 mm, 4.05 mm, 82.43 mm, and 22.16 mm, respectively. In the right shoulder, the corresponding parameters were 23.70 mm, 33.43 mm, 4.01 mm, 86.35 mm, and 22.22 mm, respectively.

The parameters of Woman No. 1
In the left shoulder, the anteroposterior diameter, suprainferior diameter, glenoid labrum depth, curvature radius of the glenoid labrum, and radius of the humeral head was 20.40 mm, 29.68 mm, 2.48 mm, 115.84 mm, and 20.48 mm, respectively. In the right shoulder, the corresponding parameters were 19.96 mm, 29.35 mm, 2.34 mm, 109.59 mm, and 19.80 mm, respectively (Table 1).

DISCUSSION

These results were obtained from the DICOM data of a normal Chinese digital human, which can be the standard human anatomic structure. To the best of the authors' knowledge, the glenoid labrum is broad with a shallow fossa, and the humeral head is larger than the glenoid labrum, so it will lead to a shoulder dislocation easily. Therefore, it can prove that the curvature radius of the glenoid is much larger than the radius of the humeral head. From the result above, the glenoid and humeral head of males is larger than those of females. In contrast, the curvature radius of females is longer than that of males. Based on the formula, R=1/K, the curvature is inversely proportional to the radius. The smaller curvature of females means the glenoid labrum of females is broader than that of males. This also proves why the depth of the glenoid of females is smaller than males. However the data are flawless because only two sets of data were recorded (Man No. 1 and Woman No. 1). The addition of more standard human data to the group will result in more accuracy and less deviation. On the other hand, these results can be used to assess the shoulder instability. Gyftopoulos et al. [4] indicated that a similar result of a bone defect can be acquired using circle-center way in CT, 3D CT, and MRI, but it requires significant time for analysis. The 3D measurement method also requires a high level of skill from the operator of the computer software who is familiar with the anatomic structure, and involves a higher learning curve.

Using this 83% value as the mean glenoid track width, this study evaluated whether a Hill–Sachs lesion can be determined to be engaging or non-engaging. The greatest horizontal distance of the glenoid (width) was measured on both shoulders. Using the intact glenoid width as a reference, the defect size “d” was calculated as an intact glenoid width—injured glenoid width. If there is a bony defect of the glenoid (d), the distance “d” was subtracted from the 83% line to

| Table 1. Parameters of a normal Chinese human |
|-----------------------------------------------|
| Shoulder site                                  |
| Man No. 1 Left Right                          |
| Woman No. 1 Left Right                        |
| Anteroposterior diameter (mm)                 |
| Suprainferior diameter (mm)                   |
| Depth of glenoid (mm)                         |
| Curvature radius of glenoid (mm)              |
| Radius of humeral head (mm)                   |
| 24.66 23.70 20.40 19.96                      |
| 34.70 33.43 29.68 29.35                      |
| 4.05 4.01 2.48 2.34                          |
| 82.43 86.35 115.84 109.59                    |
| 22.16 22.22 20.48 19.80                      |

| Table 2. Anterior instability categories |
|------------------------------------------|
| Group | Glenoid defect (%) | Hill–Sachs |
|-------|--------------------|------------|
| 1     | <25                | Non-engaging |
| 2     | <25                | Engaging    |
| 3     | ≥25                | Non-engaging |
| 4     | ≥25                | Engaging    |

| Table 3. Treatment options               |
|------------------------------------------|
| Group | Treatment                               |
|-------|-----------------------------------------|
| 1     | Arthroscopic Bankart repair              |
| 2     | Arthroscopic Bankart repair plus remplissage |
| 3     | Latarjet                                |
| 4     | Latarjet ± humeral-sided procedure(humeral bone graft or remplissage), depending upon engagement of H–Saffer Latarjet |
obtain the medial margin of the true glenoid track [17]. If the Hill-Sachs lesion is located within the glenoid track, it is called a "non-engaging" Hill-Sachs lesion. If it extends more medially over the medial margin of the glenoid track, it is called an "engaging" Hill-Sachs lesion. Therefore, an accurate measurement affects the treatment option.

This study focused on a normal specimen, but future studies should examine a glenoid and humeral head defect. Using this method, the shoulder stability can be evaluated to help guide the treatment option (Tables 2 and 3). On the other hand, there is no shoulder instability model; hence, further study will be needed. A 3D model can provide a more vivid vision of the glenohumeral joint. An accurate 3D measurement technique of the glenoid and humeral head can be performed using computer software, and the parameters will guide surgeons in the treatment of shoulder instability.

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CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Burkhart SS, De Beer JF, Tehrany AM, Parthen PM. Quantifying glenoid bone loss arthroscopically in shoulder instability. Arthroscopy 2002;18:488-91.
2. Skupiński J, Piechota MZ, Wawrzynek W, Maczuch J, Babińska A. The bony bankart lesion: how to measure the glenoid bone loss. Pol J Radiol 2017;82:58-63.
3. Yamamoto N, Itoi E, Abe H, Minagawa H, Seki N, Shimada Y, et al. Contact between the glenoid and the humeral head in abduction, external rotation, and horizontal extension: a new concept of glenoid track. J Shoulder Elbow Surg 2007;16:649-56.
4. Gyftopoulos S, Hasan S, Bencardino J, Mayo J, Nayyar S, Babb J, et al. Diagnostic accuracy of MRI in the measurement of glenoid bone loss. AJR Am J Roentgenol 2012;199:873-8.
5. Burkhart SS, De Beer JF, Barth JR, Cresswell T, Roberts C, Richards DP. Results of modified Latarjet reconstruction in patients with anteroinferior instability and significant bone loss. Arthroscopy 2007;23:1033-41.
6. Yamamoto N, Itoi E, Abe H, Kikuchi K, Seki N, Minagawa H, et al. Effect of an anterior glenoid defect on anterior shoulder stability: a cadaveric study. Am J Sports Med 2009;37:949-54.
7. Yamamoto N, Muraki T, Sperling JW, Steinmann SP, Cofield RH, Itoi E, et al. Stabilizing mechanism in bone-grafting of a large glenoid defect. J Bone Joint Surg Am 2010;92:2059-66.
8. Giles JW, Elkinson I, Ferreira LM, Faber KJ, Boons H, Litchfield R, et al. Moderate to large engaging Hill-Sachs defects: an in vitro biomechanical comparison of the remplissage procedure, allograft humeral head reconstruction, and partial resurfacing arthroplasty. J Shoulder Elbow Surg 2012;21:1142-51.
9. de Beer JF, Roberts C. Glenoid bone defects--open latarjet with congruent arc modification. Orthop Clin North Am 2010;41:407-15.
10. Hovelius L, Sandström B, Olofsson A, Svensson O, Rahme H. The effect of capsular repair, bone block healing, and position on the results of the Bristow-Latarjet procedure (study III): long-term follow-up in 319 shoulders. J Shoulder Elbow Surg 2012;21:647-60.
11. Rockwood CA Jr. The shoulder. Philadelphia: Saunders; 1998.
12. Gill TJ, Micheli LJ, Gebhard F, Binder C. Bankart repair for anterior instability of the shoulder. Long-term outcome. J Bone Joint Surg Am 1997;79:850-7.
13. Montgomery WH Jr, Wahl M, Hettrich C, Itoi E, Lippitt SB, Matsen FA 3rd. Anteroinferior bone-grafting can restore stability in osseous glenoid defects. J Bone Joint Surg Am 2005;87:1972-7.
14. Bühler M, Gerber C. Shoulder instability related to epileptic seizures. J Shoulder Elbow Surg 2002;11:339-44.
15. Miniaci A, Berlet G. Recurrent anterior instability following failed surgical repair: allograft reconstruction of large humeral head defects. J Bone Joint Surg Br 2001;83:19-20.
16. Young AA, Baba M, Neytou L, Godeneche A, Walch G. Coracoid graft dimensions after harvesting for the open Latarjet procedure. J Shoulder Elbow Surg 2013;22:485-8.
17. Di Giacomo G, De Vita A, Costantini A, de Gasperis N, Scarso P. Management of humeral head deficiencies and glenoid track. Curr Rev Musculoskelet Med 2014;7:6-11.