Measurement of combined glenoid and Hill–Sachs lesions in anterior shoulder instability

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Abstract

Background: Recurrent glenohumeral anterior instability (RGAI) frequently induces combined glenoid and Hill–Sachs bone lesions and is a risk factor for soft tissue repair failure. This cohort study describes a simple preoperative quantification method for bone loss, the Clock method, the first that combines glenoid and humeral lesions.

Methods: Computed tomography scans of 34 shoulders with RGA were twice reviewed by three independent observers, who measured bone lesions using the new Clock method and existing validated methods. Intra- and inter-observer reliability of the Clock method was evaluated (intraclass correlation coefficient). Pearson correlation was used to correlate Clock method with existing methods, and with function (Western Ontario Shoulder Instability, Quick-Disabilities of the Arm, Shoulder and Hand).

Results: Thirty-two patients met the inclusion criteria: three females and 29 males, mean age 28 years. The intra- and inter-observer reliability was excellent, with intraclass correlation coefficient ranging from 0.817 to 0.938 for the novel Clock method. Humeral Clock and Glenoid Clock strongly correlated with Humeral Ratio ($r = 0.882$, $p < 0.001$) and Glenoid Surface Area and Glenoid Ratio ($r = 0.793$ and 0.717 , $p < 0.001$), respectively. The classic threshold of 25% of the glenoid diameter with the Glenoid Ratio method corresponds to 4 hours with the Glenoid Clock method.

Conclusions: The Clock method is quick and reliable, with more studies being needed to investigate whether it is correlated with surgical outcomes.

Keywords

bone loss, glenohumeral joint, measurement evaluation, preoperative quantification, shoulder instability, simple method

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Introduction

Anterior shoulder dislocation often causes bone lesions in both the humeral head and glenoid cavity.¹ Such a lesion of the humeral head is referred to as a Hill–Sachs lesion^{2,3} and as a bony Bankart lesion for the glenoid.⁴ These combined bone defects have been identified as a cause of recurrent instability of the glenohumeral joint^{5,6} and are reported to be a risk factor in arthroscopic soft tissue repair failure.⁵ Thus, quantification of these combined bone defects can help the surgeon define and plan the most adequate surgical treatment for patients suffering from recurrent glenohumeral instability. When defects are particularly significant, additional procedures, such as glenoid¹⁵ reconstruction and a Hills-Sachs ‘remplissage’, are suggested.⁷

Different glenoid bone loss quantification methods are reported in the literature. One, proposed by Sugaya et al.,⁸ consists of calculating the ratio between the surface of bone loss and an approximate circle applied on the glenoid fossa. Barchildon et al.⁹ describe an approximation of such a surface area ratio, through a ratio of the distance from the bone’s eroded edge to the centre of a best fit circle on the radius of this circle.⁹ For glenoid bone loss, the threshold of 25% of the glenoid

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anterior–posterior diameter is the percentage for which most studies have recommended bone grafting.^{10,11} For Barchildon’s radius ratio method, this corresponds to 50%. As for the Hill–Sachs lesion, no consensus can be found in the literature on the quantification methods, or the threshold. One, proposed by Kralinger et al.¹² and Hardy et al.,¹³ consists of calculating the ratio of the width or of the depth of the lesion, on the diameter of the humeral head. Another is the measurement of an ‘occupancy ratio’ described by Kurokawa et al.,³ which takes into consideration the width and the position of the Hill–Sachs lesion in relation to the ‘glenoid track’, namely the glenoid’s contact zone on the humeral head, a concept introduced by Kurokawa et al.³ There is also a volume measurement method, described by Pinedo et al.,¹⁴ reflecting the volume of bone loss on the normal articular dome of the humeral head. Despite all these methods, there is no consensual quantification of glenohumeral bone loss. Moreover, no method applies to the combined bone defects of the glenoid and humerus, and they all require complex software not available clinically.

As a solution to these problems, we propose a new measurement method, the Clock method, which would properly quantify combined glenohumeral bone loss for patients suffering from anterior glenohumeral instability. This method uses the best fit circle defined by previous study^{3,8,13} as a clock dial, on the glenoid sagittal view and on the humeral head axial view, to measure the extent of both deficits. The best fit circle is an assumption found in the ‘gold standard’ glenoid bone defect measure described by Sugaya et al.,⁸ as well as in all other two-dimension measurement techniques.^{3,9,13} The sum of the two measures gives an appreciation of the combined bone defects. The clock tool can be printed on an acetate sheet and applied on the computer screen. A smart phone application using computed tomography (CT) scan images is also under development. The first objective of this study was to evaluate the intra- and inter-observer reliability of the Clock method. The second objective was to assess the correlation of the Clock method with the existing bone loss quantification methods, as well as with the results of functional status tests. The third objective was to identify the glenoid Clock method value that corresponds reliably to 25% of the glenoid anterior–posterior diameter for which most bone grafting is recommended.^{10,11} The hypothesis is that the Clock method will be correlated with previous methods with a coefficient of 0.7 or over.

Materials and methods

CT scans of patients suffering from recurrent anterior glenohumeral instability were selected at Hôpital du Sacré-Coeur de Montréal, from a prospective cohort,

between 2009 and 2012. The inclusion criteria were: presenting two or more anterior traumatic shoulder dislocations; presenting humeral or glenoid bone loss on CT scan; having full demographic data available; and patients that had filled initial Western Ontario Shoulder Instability (WOSI) and Quick Disabilities of the Arm, Shoulder and Hand (Q-DASH) questionnaires, prior to surgery.^{5,15} The CT scans were originally used for clinical reasons. No extra visit was needed. The ethics committee gave its approval for the study and all data and images were anonymized.

Glenoid bone defect measurement methods

The three measurement methods were carried out from tridimensional (3D) reconstructions of glenoid CT scans, which were obtained using SliceOmatic (Tomovision Inc., Magog, Canada) and then imported in a computer-assisted design software for bone loss (CATIA V5R20: Dassault system, Vélizy-Villacoublay, France) for analyses.

Glenoid Surface Area Ratio method

The Glenoid Surface Area Ratio method consists of calculating the ratio of the bone’s deficit area on the glenoid’s approximated intact area (Figure 1) based on a best fit circle estimating the inferior extremity of the pear-shaped glenoid.⁸ This validated measure was carried out once by an experienced observer.

Glenoid Ratio method

The Glenoid Ratio method consists of an approximation of the Glenoid Surface Area Ratio, using only two measurements: the radius (r) of the best fit circle and the distance (D) between the anterior glenoid defect edge and the centre of the circle (Figure 1).⁹ This validated measure was carried out once by an experienced observer.

Humeral Head Bone deficit measurement methods

The three following methods were carried out from a CT scan axial view using SliceOmatic (Tomovision Inc.). The scan slice with the largest bone deficit was chosen. The Humeral Volume Method was computed from 3D reconstructions of humerus CT scans, obtained as detailed above.

Humeral Surface Area method

The Humeral Surface Area method consists of calculating the ratio of the bone loss area on the best fit circle area (Figure 2).^{12,13} This validated measure was carried out once by an experienced observer.

Figure 1. Glenoid measurement methods. (a) Area method. (b) Ratio method. (c) Clock method.

Figure 2. Humeral measurement methods. (a) Area method. (b) Ratio method. (c) Clock method. (d) Volume method.

Humeral Ratio method

The Humeral Ratio method consists of calculating the ratio of the depth (De) and of the width (W) of the bone loss on the diameter (Di) of the best fit circle (Figure 2).³ This validated measure was carried out once by an experienced observer.

Humeral Volume method

The Humeral Volume method consists of calculating the ratio of the bone loss volume ($V_f - V$) on the filled helmet-shaped volume (V_f) (Figure 2).¹⁴ This validated measure was carried out once by an experienced observer.

Combined Clock method

The Combined Clock method is to add up the durations of the bone losses measured at the glenoid and the humerus using the Glenoid Clock and the Humeral Clock methods respectively. These methods are described below.

Glenoid Clock method

The Glenoid Clock consists of measuring the angles of the starting point ('Beginning Time') and ending point ('Ending Time') of bone loss on the best fit circle, defined in the previous methods^{8,9}, playing the role of a clock dial (Figure 1). The Beginning and Ending Times consist of the angles between the longitudinal axis and the first and second lines (clockwise for right shoulder), respectively (Figure 1). These angles are then converted into hours, with the longitudinal axis corresponding to 12 o'clock. The subtraction of the Beginning and Ending Times is the duration of the bone loss. These measures were carried out twice by three different independent observers.

Humeral Clock method

The Humeral Clock consists of measuring the angles of the starting point ('Beginning Time') and ending point ('Ending Time') of bone loss on the best fit circle, defined by Hardy et al.,¹³ playing the role of a clock dial (Figure 2). The axis playing the 12 o'clock role is arbitrarily drawn from the centre of the circle and through the bicipital groove. The Beginning and Ending Times consist of the angles between the longitudinal axis and the first and second lines (clockwise) respectively (Figure 2). These angles are then converted into hours, with the longitudinal axis corresponding to 12 o'clock. The subtraction of the Beginning and Ending Times is the duration of the bone loss. These measures were carried out twice by three different independent observers.

Relationship between Glenoid Clock and other methods

The glenoid bone loss threshold for failure of arthroscopic Bankart repair was established at 25% of the anterior-posterior diameter of the glenoid, corresponding to 50% for the Barchildon ratio method.^{10,11} To calculate the relationship between the number of hours (h) obtained with the Glenoid Clock method, and the percentage of the anterior-posterior diameter of the glenoid, we used a template of the glenoid with a best fit circle on the postero-inferior rim. We then simulated glenoid bone losses from 00.00 hours to

06.00 hours of the Glenoid Clock method, in increments of 0 hours and 15 minutes, and estimated the corresponding percentage of the anterior-posterior diameter of the glenoid by calculating the distance between the simulated glenoid defect edge, and the centre of the best fit circle. Lastly, we created a cubic function by interpolating the percentage of the anterior-posterior diameter of the glenoid which were plotted according to the hours of the Glenoid Clock method. For comparative purposes, we used the same method to calculate the relationship between the hours of the Humeral Clock method and the Width Humeral Ratio.

Statistical methods

To confirm the reproducibility of the Clock method, the intraclass correlation coefficient (ICC) was used for intra- and inter-observer reliability. The ICC was calculated with each set of measurements, performed twice by each of the three observers, and for both the Glenoid and Humeral Clock methods. The values of the ICCs range from 0 to 1, with a higher value indicating better reliability. ICCs less than 0.40 were considered as poor; 0.40 to 0.59 as fair; 0.60 to 0.74 as good; and 0.75 to 1.00 as excellent.¹⁶

The results of the Glenoid and Humeral Clock methods were correlated with the previously reported methods using the Pearson correlation coefficient (r). For these comparisons, the average results of the methods for each set of measurements (total of six sets) were used. The correlations are considered statistically significant if the p -value is lower than 0.05 ($p < 0.05$). Furthermore, a linear regression study provided a graphic observation of the comparability between methods. The coefficient of determination (r^2) then measures the percentage of variability described by the linear model.

Moreover, the bone loss measures, carried out with all the methods used in this study, were correlated to the number of sustained dislocations, the age of patients, and the functional status scores from the Q-DASH and WOSI.^{5,15} We also confirmed the correlation between these data and the Combined Clock method. These correlations were studied using the Pearson correlation coefficient (r), with a p -value smaller than 0.05 ($p < 0.05$) being considered as a statistically significant value.

Results

The present study comprised 32 patients suffering from recurrent anterior glenohumeral instability, including two patients with bilateral instability (i.e. a total of 34 shoulders analysed in the present study). Patient

demographic data comprised: 29 men and three women; mean (SD) age of 28 (8) years (range 17 years to 41 years); mean (SD) number of dislocations equal to 17 (23) (2 to >100); mean (SD) WOSI score of 61% (16%) (range 26% to 85%); and mean (SD) Q-DASH score of 36 (22) (range 7 to 89) for the level of disability, 34 (33) (range 0 to 100) for the work module and 61 (31) (range 0 to 100) for the Sports/Performing Arts Module.

The ICCs were calculated for all Clock method sets of measurements. The means, SDs and range of the obtained ICCs were also calculated, both intra- and inter-observer, for the Glenoid and Humeral Clock methods distinctly. The results are presented in Table 1. The Glenoid and Humeral Clock intra-observer ICCs, reflecting intra-observer reliability, were excellent, with very low standard deviations [0.934 (0.024) and 0.938 (0.007), respectively]. The Glenoid and Humeral Clock inter-observer ICCs, showing inter-observer agreement, were a little lower but still excellent with low SDs [0.817 (0.084) and 0.850 (0.035), respectively].

The Pearson correlation coefficient (r) was calculated, and a linear regression study was estimated, to evaluate the correlation between the Glenoid and Humeral Clock methods measurements and the existing methods. The Pearson correlation coefficient results are presented in Table 2.

For the Glenoid Clock method, strong correlations were found with both Surface Area ($r=0.793$, $p<0.001$) and Glenoid Ratio ($r=0.717$, $p<0.001$) methods. The linear regressions (Figure 3) showed

good determination coefficients for both methods ($r^2=0.629$ and 0.514 , respectively). For the Humeral Clock method, a strong correlation was found with the W/Di Ratio ($r=0.882$, $p<0.001$) (Table 2) and the linear regression presented a strong determination coefficient ($r^2=0.778$) (Figure 4). The Area method showed a moderate correlation ($r=0.482$, $p=0.004$), whereas the De/Di Ratio and the Volume methods showed no correlation ($r=-0.301$, $p=0.084$ and $r=-0.226$, $p=0.230$) (Table 2).

Bone loss measured using the different methods, the functional status scores, the age of patients, and the number of sustained dislocations, were compared with results presented in Table 3. The Q-DASH significantly correlated with the Combined Clock ($r=-0.412$, $p=0.036$), the Glenoid Clock ($r=-0.662$, $p=0.001$), as well as the glenoid Area ($r=-0.463$, $p=0.026$) and the humerus Volume ($r=-0.454$, $p=0.034$) methods. The number of dislocation correlated with the Glenoid Clock ($r=-0.440$, $p=0.022$) and the Glenoid Area ($r=-0.569$, $p=0.002$) and Ratio ($r=-0.587$, $p=0.001$) methods. No significant correlation was noted between the WOSI score and the age of patients.

Finally, the relationships between the hours of the Glenoid and Humeral Clock methods and the percentage of anterior-posterior glenoid diameter, the Glenoid Ratio or the Width Humeral Ratio are given in Table 4. It appeared that the number of hours corresponding to the threshold of 25% of the anterior-posterior diameter of the glenoid was 4 hours. The relationships were approximated with the

Table 1. Intraclass correlation coefficient (ICCs) as reliability statistics of the Clock method.

Clock Method	Intra-observer ICC		Inter-observer ICC	
	Mean (SD)	Range	Mean (SD)	Range
Glenoid	0.934 (0.024)	0.917 to 0.961	0.817 (0.084)	0.667 to 0.943
Humerus	0.938 (0.007)	0.930 to 0.944	0.850 (0.035)	0.797 to 0.900

Table 2. Correlation between the Clock method and existing methods.

Clock Method	Pearson correlation coefficient r (p)			
	Surface area		Ratio	
Glenoid	0.793 ($p<0.001$)*		0.717 ($p<0.001$)*	
Humerus	Area	W/Di ratio	De/Di ratio	Volume
	0.482 (0.004)*	0.882 (0.001)*	-0.301 (0.084)	-0.226 (0.230)

De, depth; Di, diameter; W, width.

Figure 3. Correlation between the Clock method and the existing methods for the glenoid.

Figure 4. Correlation between the Clock method and existing methods for humerus.

following polynomial equations ($r^2 = 1$). This equation could be used to estimate the selected parameter according to the number of hours (h) of the Clock Method.

$$\% \text{ diameter} = (-0.0011h^3 + 0.0211h^2 - 0.0055h + 0.0019) \times 100$$

$$\text{Glenoid Ratio (\%)} = (-0.0004h^4 + 0.0053h^3 - 0.0022h^2 + 0.0013h - 0.0002) \times 100$$

$$\text{Width humeral Ratio} = (-0.002h^3 - 0.0054h^2 - 0.2705h - 0.0034) \times 100$$

Discussion

We have developed a new measurement method, the Clock method, aiming to quantify the glenoid and humeral bone defects, as well as the combined gleno-humeral bone defects. We found that the Glenoid and Humeral Clock methods are highly reliable measurement methods. Measures conducted by three independent observers of humeral Hills-Sachs lesions and

Table 3. Correlation between measured bone loss and functional questionnaires, age, and number of dislocations.

Bone	Methods	Pearson correlation coefficient <i>r</i> (<i>p</i> value)			
		WOSI	Q-DASH	Age	Number of dislocations
Glenoid	Area	−0.105 (0.626)	−0.463 (0.026)*	−0.163 (0.406)	0.569 (0.002)*
	Ratio	−0.085 (0.694)	−0.396 (0.062)	−0.143 (0.467)	0.587 (0.001)*
	Clock	−0.105 (0.625)	−0.521 (0.011)*	−0.068 (0.729)	0.440 (0.022)*
Humerus	Area	−0.053 (0.794)	−0.120 (0.558)	0.248 (0.179)	−0.007 (0.972)
	W/Di ratio	0.182 (0.364)	−0.164 (0.422)	0.205 (0.268)	0.319 (0.086)
	De/Di ratio	−0.253 (0.203)	−0.076 (0.711)	0.237 (0.199)	−0.314 (0.091)
	Volume	0.029 (0.896)	−0.454 (0.034)*	−0.004 (0.984)	−0.270 (0.182)
	Clock	0.160 (0.426)	−0.162 (0.430)	0.103 (0.582)	0.291 (0.119)
Combined	Clock	−0.023 (0.911)	−0.412 (0.036)*	−0.055 (0.770)	0.348 (0.059)

De, depth; Di, diameter; W, width. WOSI, Western Ontario Shoulder Instability. Q-DASH, Quick Disabilities of the Arm, Shoulder and Hand.

Table 4. Relationship between the number of hours of the Clock method and the Humeral and Glenoid Ratio methods.

Number of hours	% of anterior–posterior glenoid diameter	Glenoid ratio	Width humeral ratio (W/Di)
0 h 15 min	0.1%	0.0%	6.6%
0 h 30 min	0.4%	0.0%	13.1%
0 h 45 min	1.0%	0.2%	19.5%
1 h 00 min	1.7%	0.4%	25.9%
1 h 15 min	2.6%	0.7%	32.2%
1 h 30 min	3.8%	1.2%	38.3%
1 h 45 min	5.2%	2.0%	44.3%
2 h 00 min	6.7%	2.9%	50.0%
2 h 15 min	8.4%	4.0%	55.6%
2 h 30 min	10.3%	5.4%	60.9%
2 h 45 min	12.4%	7.1%	66.0%
3 h 00 min	14.6%	9.0%	70.7%
3 h 15 min	17.0%	11.3%	75.2%
3 h 30 min	19.6%	13.8%	79.4%
3 h 45 min	22.2%	16.5%	83.2%
4 h 00 min	25.0%	19.6%	86.6%

(continued)

Table 4. Continued

Number of hours	% of anterior–posterior glenoid diameter	Glenoid ratio	Width humeral ratio (W/Di)
4 h 15 min	27.9%	22.8%	89.7%
4 h 30 min	30.9%	26.3%	92.4%
4 h 45 min	33.9%	29.9%	94.7%
5 h 00 min	37.0%	33.6%	96.6%
5 h 15 min	40.2%	37.6%	98.1%
5 h 30 min	43.5%	41.7%	99.2%
5 h 45 min	46.7%	45.8%	99.8%
6 h 00 min	50.0%	50.0%	100.0%

Di, diameter; W, width.

glenoid bony Bankart lesions, showed low variability, both intra- and inter-observer, as demonstrated by high ICCs. The Glenoid Clock method was also found to be highly correlated with Sugaya's Surface Area method⁸ and Barchildon's Ratio method.⁹ A high correlation was also found between the Humeral Clock method and the W/Di Ratio.^{12,13} These correlations show some level of interchangeability between methods and, consequently, the Clock method's aptitude to be used similarly to these existing methods.

However, the value for the Combined Clock method as a predictor of arthroscopic Bankart failure is still to be determined. Arciero et al.¹⁷ showed that a combined bone defect affects stability and that the presence of a Hill–Sachs lesion makes a smaller glenoid deficit 'significant'. The number of hours from the Glenoid and Humeral Clock methods can be used as a strong estimation of the more sophisticated bone defect measurement techniques, as shown by our calculations in Table 4. Furthermore, because 'significant' bone loss value may vary depending on the surgeon or according to patient risk factors for instability recurrence, Table 4 can be used to translate hours into percentage of bone defect and enable a comparison scores by any surgeon in any hospital.

Of the two functional status scores chosen to be assessed, WOSI and Q-DASH, only the Q-DASH showed a correlation with the amount of combined bone loss estimates by Combined Clock method. These data are of interest because they could help demonstrate that increased bone loss decreases the function of the upper limb, although this needs to be validated in a larger cohort. The fact that the WOSI was not correlated raises some questions. One hypothesis is that the decreased function may not be the result of a perceived increased 'instability' but, instead, to pain related to

cartilage deficit and inflammatory reaction. This needs to be assessed further. The magnitude of glenoid bone defect is correlated with the number of dislocations. We cannot say whether the bone loss increased at each dislocation, or whether a greater initial glenoid bone defect will cause more instability and easier dislocations. It is probable they are both partly responsible.

The present study suffers from several limitations. First, the accuracy of the Clock method has not been validated against a gold standard. However, the Clock method showed a very good correlation with validated methods for glenoid and humeral bone loss quantification, which is very encouraging. Future work should be conducted on cadaveric specimens with known bone defect, and the results obtained compared with those obtained using the Clock method with a CT scan. Second, the scan slice for the humeral measurement was selected by an orthopaedic surgeon, which raises the issue of subjectivity as a potential cause for error. Nonetheless, this selection process corresponds exactly with clinical practice. Third, we have assimilated deficits to a straight line, whereas this is far from the case. Indeed, our method was designed to be the simplest and quickest possible for clinical practice and, although the present study has required complex software, the Clock method will be implemented in a smartphone or tablet application. The user will only need to take the appropriate image and draw a circle and two lines on it to obtain quantification of bone loss. Currently, a simple acetate sheet with a clock can be applied on the screen.

Long-term work should examine the Clock method as a predictor of arthroscopic Bankart repair failure. The Instability Shoulder Index Score can already help with this decision, although bone quantification using CT scan measures could help strengthen the decision process.¹⁸ Furthermore, when the Bankart arthroscopic

repair presents an excessive chance of failure, it is hard to know whether it is preferable to perform an arthroscopic ‘remplissage’, or whether a Latarjet should be prioritised.⁷ Future analysis of the Clock method may be helpful in the treatment algorithm of shoulder traumatic instability with combined bone loss.

Because of the challenges posed by the proper quantification of combined glenohumeral bone loss, we propose the Clock method. This method will be implemented on a smartphone and tablet application to provide clinicians with a tool that is easy to use, and does not require calculations to assess glenoid and humeral bone loss in traumatic anterior shoulder instability. If the Glenoid Clock corresponds to 4 hours, surgeons must interpret the data as equivalent to 25% of loss. The Humeral Clock method and the Combined Clock method are reliable, although further studies are needed before it can be used as a strict surgical guideline by surgeon.

Declaration of Conflicting Interests

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Ethical review and patient consent

Institutional Review Board approval was given for this study: no. 2013-890.

Level of evidence

Basic science study (Level II)

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