Radiological Computation of Glenoid Version. Is there an Optimum Method?

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ABSTRACT

Glenoid version assessment has often been crucial in shoulder procedures. There are no consensus regards the proper method of version measurement. However, the Freidman method has been the most familiar method for surgeons, various recent methods were reported to limit variational measurement errors, and to reach a uniform methodology for calibration with the least measurement bias. This study aims at reviewing different measurement strategies and pointing out the merits and limitations of each.

Keywords: Glenoid, version, Freidman, scapular axis vault, CT reconstruction, MRI version.

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INTRODUCTION

Glenohumeral joint loading and stability are impacted by the degree of glenoid version. Version assessment has been crucial for appraisement of bony deficiency in shoulder instability and arthritis(1). Preoperative version assessment usually guides the planning of shoulder arthroplasty, moreover, it possesses prognostic implications post-arthroplasty(2-4).

The glenoid anteversion means anterior tilt of glenoid surface, while the posterior tilt indicates retroversion. The glenoid of normal shoulder often represents s a slight retroversion under 10° (mean 1° to 3°)(5-8). Nonetheless, a wide version ranges from being anteverted (positive value) to retroverted (negative value) has been reported(5,9-11). This article reviews the different radiological measurement methodologies in light of the merits and inconveniences of each.

MEASUREMENT METHODS

A- Conventional axillary radiographs

As described by **Nyffeler et al.**(12), the patient lies supine and his arm in neutral position in 60° of abduction in the scapular plane. Axillary shoulder radiograph is obtained with the X-ray cassette placed against patient's neck and X-ray beam directed from the tube placed near his hip. After drawing a tangential to anteroposterior (AP) glenoid surface and another line along the middle of the scapular body bisecting the first line, subsequently, version angle represents that between first line and a perpendicular to the second one (Figure 1).

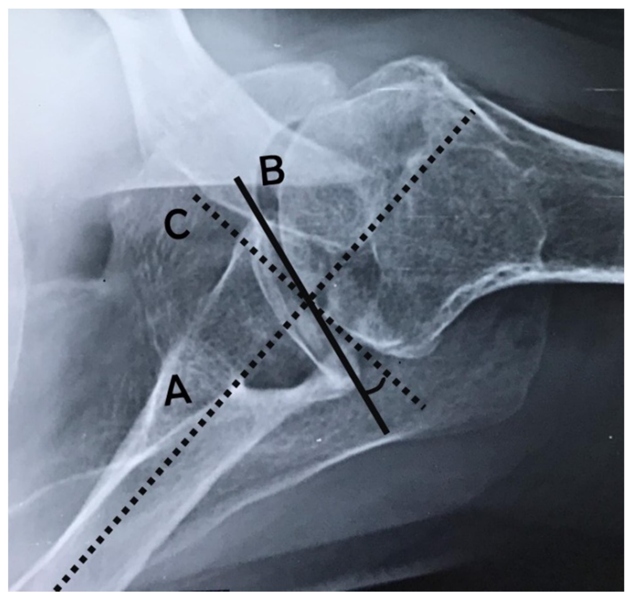

Figure 1: Version measurement on axillary radiograph, (A) is the plane of scapular blade, (B) defines the glenoid plane, and (C) represents a perpendicular to A. Version is calibrated as angle between B and C.

Compared to CT version assessment, the measurement values were elaborated with the reliance upon axillary radiographs in 86% of cases with an average difference of 6.5° (range: 0°-21°) between the two radiological utilities. They attributed this disparity in version to incomplete exposure of the scapular medial border, following the difficulty to place the radiograph cassette much medially relevant to patient's neck. Besides, any positional variation of the X-ray cassette changes the measured version. Similarly, **Ho et al.** reported version overestimation with radiographic measurement compared to CT on preoperative and post-arthroplasty[13].

Later, **Braunstein et al.** explicated easy palpable surface anatomical landmarks, they utilized the fulcrum axis (FA) method for version measurement[14]. This axis is nearly parallel to the glenoid surface in normal shoulders passing through coracoid anterior tip, and acromial posterolateral (PL) corner[14,15]. Glenoid version was demonstrated as glenoid cavity orientation relative to a perpendicular plane to that of scapular body (Figure 2). The FA is reproducible method advocating easily palpable surface landmarks. Besides, preliminary studies have utilized it as a mentor intra-operatively expressing encouraging results[16].

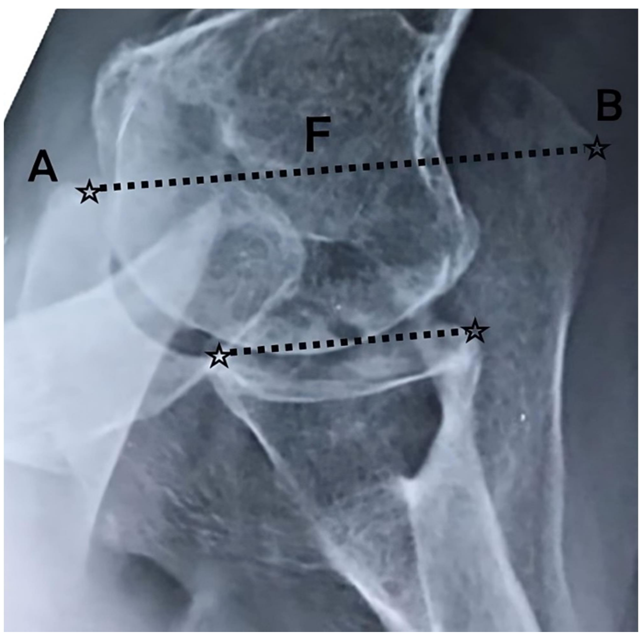

Figure 2: Fulcrum axis and glenoid plane axis in axillary shoulder radiograph. The fulcrum axis (F: superior dotted white line) is figured out between the anterior coracoid tip and the posterolateral angle of the acromion (upper two white asterisks A and B), and the glenoid plane axis (lower dotted white line) connecting anterior and posterior glenoid rims (lower two white asterisks). The alignment of the FA and glenoid plane axis is usually parallel.

Mutch et al.[17] detailed five criteria to accept an axillary radiograph prior to measurement. This includes distinct PL acromion, distinct glenoid face, distinct coracoid, distinct glenoid vault, with absent or minimal glenoid overlap on the ribs (Figure 3). Precise version calculation is not often achieved via traditional radiographs due to different glenoid morphology. Measurement is always more sensitive to variation of scapular orientation[12].

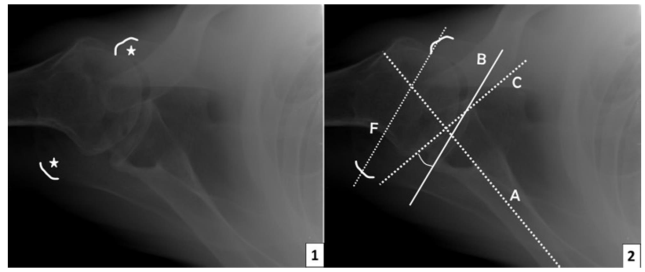

Figure (3-1): Acceptable axillary radiograph showing the posterolateral acromial corner, the anterior coracoid tip (marked in white with asterisks), and most of the scapular body is clear with minimal ribcage overlap. **(3-2):** shows version measurement as mentioned before as the angle between glenoid plane line (B) and a perpendicular (C) to the scapular axis line (A). the fulcrum axis (line F) is identified with line connecting the two marked asterisks.

B- CT measurement

Currently, there is no consensus on the CT evaluation method for an accurate version calculation (18-20), however, Freidman et al.[21] measurement method remains the most widely accepted and utilized.

Friedman method

This technique has been commonly utilized. Figure (4) shows version angle calculated at axial CT slice as an angle between the AP glenoid line (glenoid plane), and a perpendicular to Freidman projection (the line connecting the most medial stop of the scapular body to the center of AP glenoid plane). Considering the precise level for version calculation initially is necessary[12,21-23]. Taking into account the coracoid as a reference point in Freidman method, version is calibrated on the midaxial level corresponding to that 10 mm inferior to the coracoid tip.

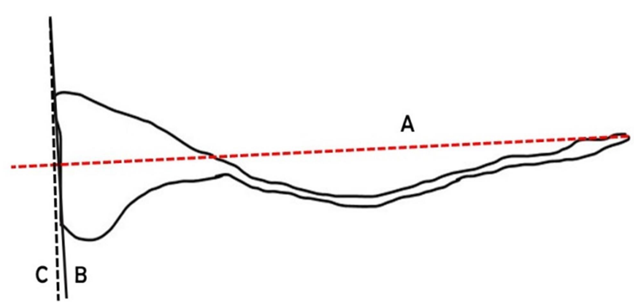

Figure 4: Friedman method for version measurement. Line A: The red dotted line represents scapular transverses axis (Freidman line), line B: The black vertical line represents glenoid plane between anterior and posterior glenoid margins. Version angle is measured between line B and a perpendicular (line C: The black vertical dotted line) to Freidman line.

Although Freidman method remains the most familiar measurement method, many concerns have been raised regards the optimum axial CT slice to measure at. Additionally, the coracoid tip level is not necessarily to traverse the midglenoid. Previous study reported the coracoid tip-inferior glenoid distance and its relation to vertical glenoid diameter and stated that coracoid tip might be distant from middle of glenoid by 1.7±0.53cm[22]. Moreover, this variational coracoid level might limit the ability of this method to consistently allocate the midaxial level[24]. Allocating proper midglenoid level can enable for a precise version assessment which is clinically relevant[22].

Ellipse method

Javed et al.[24] refined the Freidman method, and developed a five-step measurement method, known as the Ellipse method. First, axial, and sagittal footings are demonstrated in concert, on reconstruction software, and glenoid is identified in the sagittal re-format. Then, choosing the best fit ellipse to outline the glenoid. Subsequently, the vertical diameter and radii of this ellipse are measured. Followed by, the midglenoid level (Figure 5). The axial cut corresponding to the midglenoid level is then determined, and version is measured at this level with reliance upon the same landmarks as the Friedman method.

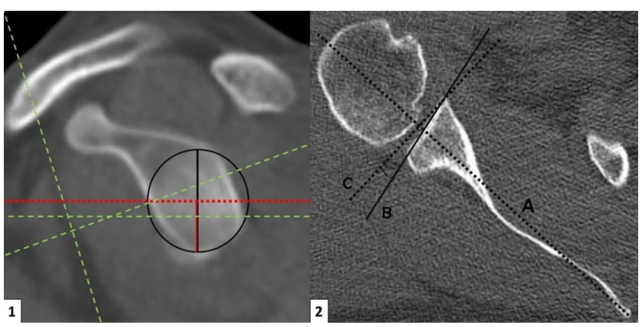

Figure (5-1): Sagittal 2D-CT slice (the lateral most glenoid slice with coracoid included), showing the Ellipse method of version measurement, a best fit-ellipse is identified over the glenoid interface, the vertical radius (red solid line) of the ellipse is then calculated out of the total vertical diameter (black solid line), hence the midglenoid point is identified. **(5-2):** The corresponding axial slice to previously determined midglenoid level, then, the version angle can be calculated after the Freidman method.

The midaxial level can be consistently determined allowing for a uniform measurement. This portrays the clinically significant passage point for the central guidewire amid glenoid implantation, subsequently advertising intraoperative authentication[24]. Ellipse method might be inapplicable when para-sagittal re-formats are not demonstrated in the scapular plane. Nonetheless, the small difference in the mean version values between the Freidman and Ellipse methods (-3.11° and -1.95° respectively), this small difference was statistically significant[24].

Randelli and Gambrioli method

As an alternative, Randelli and Gambrioli utilized the scapula body general axis on axial format. The version was defined as a complementary angle to that contrived via intersecting scapular body axis and glenoid surface (Figure 6)[23].

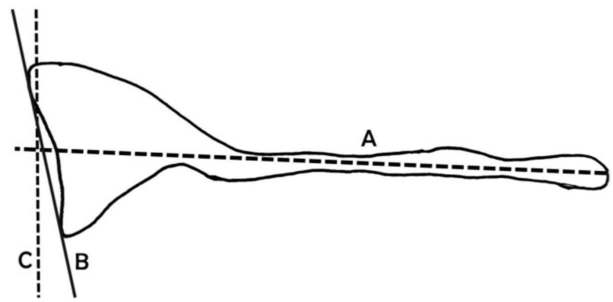

Figure 6: Randelli and Gambrioli method for version measurement. Line A stands for the scapular body axis connecting the medial scapular angle and midglenoid, line B represents the glenoid plane, angle between line B and C (a perpendicular to line A) is Freidman version angle, and the angle between line A and B represents the version as calculated by Randelli method.

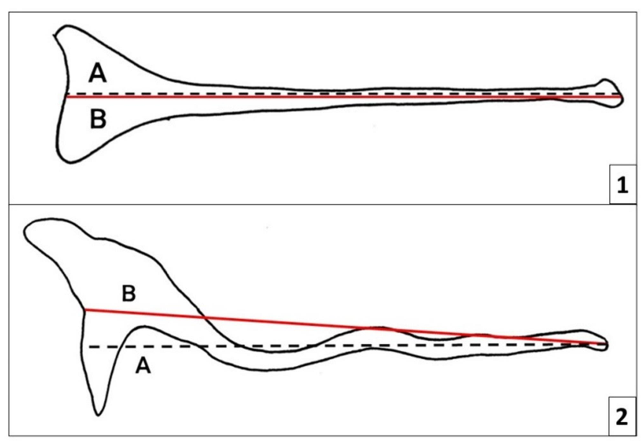

Figure (7-1); Straight body scapula, **(7-2):** Curved body scapula with reference lines A-black dotted (scapular body axis) and B-red line (Freidman line)

With a curved scapular body on axial CT either after nonsound reconstruction format, or with advanced glenoid wear, the scapular body line does not coincide with the Freidman lines (Figure 7). The two lines superpose in case of a more linear scapula

(Figure 7). Hence, the Friedman technique may well be valuable within the nearness of a bended scapula and for all glenoid patterns independent of degenerative changes[25]. Rouleau et al.[1] reported a significant difference in version assessment between scapular body method and Freidman method, with a mean difference of -3.14° higher than Freidman method. They did not conclude a superior method over the other.

Vault method

Free of the scapular body, a new strategy was initially depicted by Poon and Ting[25] and afterward by Matsumura et al.[26] based on the endosteal vault triangle instead of the glenoid confront. At the midaxial slice, a line bisecting the medial angle of this triangle represents the neutral version line, is the line of impartial form. The version angle is bounded by this line and a parallel to glenoid (Figure 8). Besides, arthritic glenoid with overlying osteophytes adds a challenge to properly identify the glenoid articular surface that become incorporated with the osteophytes, thus, it might result in great variability in version values with not clearly identified bony landmarks[25].

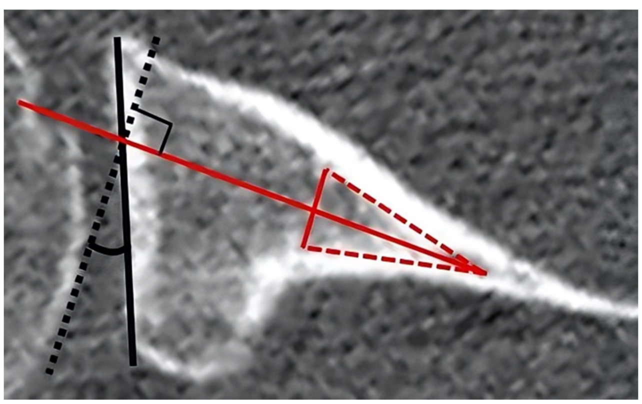

Figure 8: Version vault method of version measurement on the midaxial 2D-CT slice, an isosceles triangle (dotted red triangle) within the medial part of glenoid endosteal vault, staying medial to where the anterior and posterior cortices start to curve. Then, A bisecting line is drawn from the medial corner of this triangle (red solid line) with a perpendicular line (black dotted line) to this bisector is then drawn standing for the line of neutral version. Finally, the glenoid plane line (black slod line) is drawn joining anterior and posterior glenoid rims. The version angle is calculated as the angle between the 2black lines.

When compared to Freidman strategy, Matsumura et al[26] reported a noteworthy distinction utilizing both measurement strategies amid both normal and arthritic shoulders. The average version of normal glenoid with vault method was higher by -7.8° than with Freidman method, alike, in arthritic glenoid, the mean version was higher with vault method by -7.4°. Similarly, Elshahhat et al.[22] compared both measurement methods on dried scapula. The study revealed higher values with vault method. The average glenoid version at midglenoid level of -6.28º±2.69º and -9.22º±3.4º degrees with Freidman and vault methods.

The vault calibration method only depends on the glenoid vault, without considering the entire scapular body in calculation. Thus, it can be supportive where the complete scapula is not included on the CT formats or within the nearness of noteworthy scapular body deformities or past scapular surgeries[27,28].

Scapular triangle method

This method was introduced by Andrin et al.[29] Initially, the average level of the scapular triangle plane on the largest vertical glenoid diameter is identified with multiplanar CT reconstruction. The first line is drawn passing through the centre of the glenoid plane to the tip of the triangle (Figure 9-1), this line stands for the axis of the triangle. Then a second line from anterior to posterior glenoid rim, so, the version angle is measured representing an angle between the second line and a perpendicular to the first line (Figure 9-2). When compared to Freidman method, Andrin et al. reported a mean version of 9.09° and 10.8° with scapular triangle and Friedman methods[29], which was exceptionally near to the detailed value reported in Rouleau et al. consider[1].

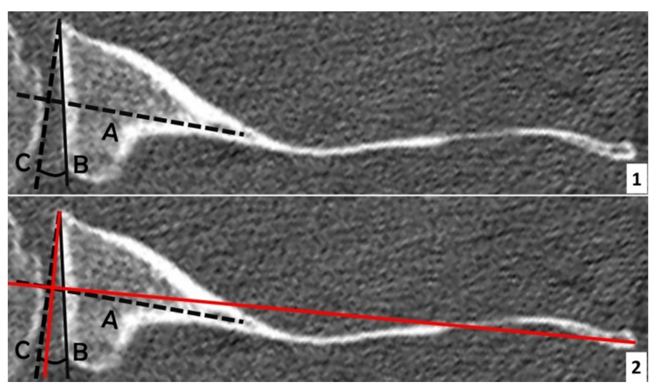

Figure (9-1): The 2D-T axial cut axial for scapular triangle method. Line A (black dotted line) stands for scapular triangle axis. Version angle is calculated between glenoid plane line (line B) and the perpendicular (line C) to scapular triangle axis. **(9-2):** Superimposition of transverse scapular axis (red solid horizontal line) on previously mentioned scapular triangle method, compared to version angle ae per the Freidman method (angle between line B and the vertical red solid line)

This technique is an easy applicable and reliable method. The length of the triangle axis is shorter than that of the whole scapular axis, thus, it can be more productive strategy in clinical practice and can connected to all sorts of shoulder CT formats. Additionally, the level of measurement is frequently steady and allocated at the midglenoid[29]. Requiring whole body scapula CT represents a drawback for this technique, besides, scapular rotation impacts the orientation of coronal CT cuts, by terms, increases measument errors[29,30].

Robertson Method (Partial scapula)

Recently, this method was demonstrated by Robertson et al.[31] Glenoid version is calculated after rectification of the articular-surface-Vault-angle (ASVA) by means of subtraction of a settled adjustment calculate (the correction angle). The midglenoid level is reached using scapula reconstruction digital software, to distinguish the specified pivotal CT cut passing through the center of glenoid and perpendicular to the scapular body plane.

Starting with calibrating ASVA, the primary line is drawn from the point of crossing point of the cortical bone inside the scapula neck to the midpoint of glenoid plane. The AP glenoid plane is then drawn (Figure 10). This angle is a measured one bounded by glenoid plane line and a perpendicular to the former line. Correction angle is figured out from ASVA and Friedman method strategies. It is the average difference between each specimen's Friedman strategy estimation and its ASVA. This settled rectification angle (7°) is subtracted from the ASVA measurements to create the Robertson version measurement method. The primary estimation utilizing this strategy brought about in a more retroverted point compared with Friedman strategy.

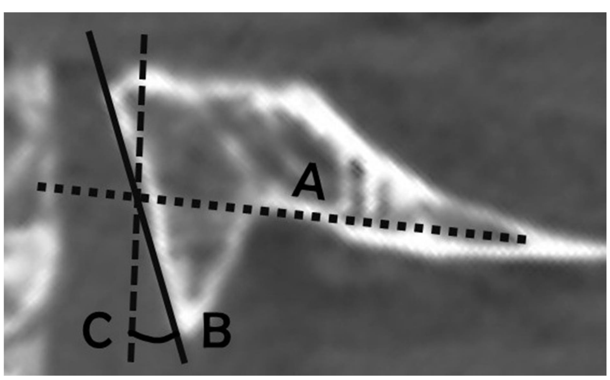

Figure 10: The Robertson measurement method. Line A (dotted horizontal line) joins the scapula neck cortical bone intersection to the midpoint of glenoid plane (line B), Line C is perpendicular to line A. the articular surface-vault angle is then measured between lines B, C. The final step subtracts a fixed correction factor (not illustrated).

The Robertson method obviates the need to visualize the medial scapular border, which is mandatory in Freidman method. The medial scapular portion is often excluded in cross-sectional shoulder imaging aiming at increase spatial resolution; hence, a partial scapula field view is only available. This method only requires the lateral portion of the scapula.

Mutch et al. method[17]

Three axial cuts are superimposed: the first slice clearly views the posterolateral corner of the acromion, the second slice shows the most anterior aspect of coracoid tip, and the third shows the midglenoid clearly. The version angle is then measured following the traditional Freidman method (Figure 11).

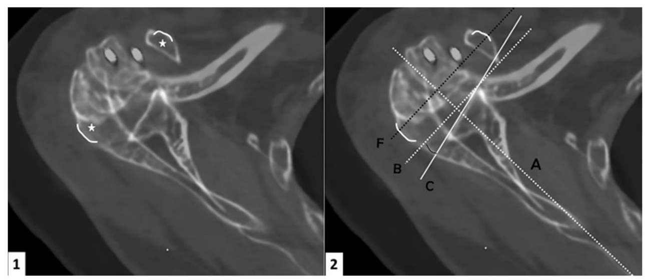

Figure (11-1): A superimposed image of axial 2D-CT slices showing the posterolateral acromial corner and the anterior coracoid tip (white marks and asterisks), with clear glenoid face. (**11-2):** Version measurement between glenoid plane line (B) and a perpendicular (C) to scapular axis (A). the fulcrum axis measurement is defined between lines F and C.

Limitations of 2D-CT measurements

The 2D-CT measurement methods have some limitations (27). Many concerns were raised as per their accuracy since of varieties in scapular rotation amid image procurement as well as variable ebb and flow of the scapular body[8,12,32]. Normally, the glenoid is twisted from superior to inferior and version varies at different glenoid levels[22], and this presents a measurement error with the routine 2D CT formats[33].

Bokor et al.[30] assessed the impact of scapular coronal rotation upon glenoid version. They demonstrated that that the measured version seem shift by 10.5° with scapular rotation of only 20°. The glenoid articular surface plane changes with scapular rotation either in abduction or abduction, so, version measurement is altered. Bryce et al. reported that measurement variation can range from 4.7° anteversion to 10.6° retroversion depending on scapular orientation. Abduction orientation greatly changes version value than adduction does. 1° and

20° abductions can alter version by 0.42° and 9.4° respectively, and 1° and 20° adductions can change version by 0.16° and 2.4° respectively[19,34].

Three-dimensional-corrected glenoid version

Three points of interest are chosen on the 3D demonstrate counting scapular inferior tip, glenoid surface midpoint, and medial scapular pole[33]. The three placed scapular points are imported into a software. The coronal scapular plane passes over the three focuses. The scapular axis is the line passing through the glenoid center and the medial scapular pole. A perpendicular to the former plane is the transverse scapular plane and passes through the scapular pivot. The 3D corrected version angle is measured following the Freidman method.

Budge et al.[19] utilized this software, a 2D-CT was obtained taking the advantage of the transverse scapular plane produced from the initial CT information set. They reported the mean version angle via the Freidman method. Besides, the average 2D version angle was compared to the 3D version angle. Reported average 2D version value was -3.3±6.2, the average 3D version angle across was 4.5±3.8, and The difference between the mean 2D and 3D measurement was not measurably noteworthy.[19]

Mutch et al. 3D version measurement

As forementioned, Mutch et al.[17] confined three bony landmarks to be detected prior to calculation; the acromial posterolateral part, anterior aspect of coracoid tip, and glenoid vault. The version angle is then measured as the angle between the glenoid plane and a perpendicular to the scapular plane (Figure 12).

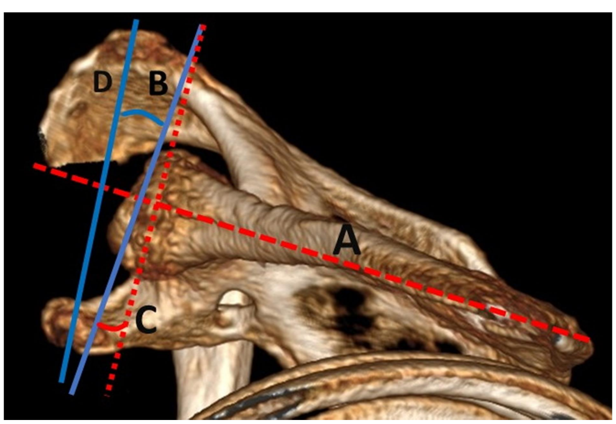

Figure 12: A 3D-CT reconstructed ad views acromial posterolateral aspect and anterior coracoid tip joined via line D. version is measured between glenoid plane (line C) and a perpendicular (line B) to scapular axis (line A). the fulcrum axis is measured between lines B, D.

Glenoid vault model

Scalise et al.[35] portrayed this demonstrate with a custom 3D software program to assess glenoid version in osteoarthritic patients. The vault was positioned in a best fit position for the scapula. The version angle was calibrated as an angle between a line drawn parallel to the glenoid confront and a line along the sidelong confront of the situated demonstrate[35]. Glenoid version was assessed in three different models (Figure 13); the first model with parallel lines and sound vault, the second with parallel lines and central glenoid wear, the last with posterior glenoid wear, crossing lines, and excessive retroversion. This model might help surgeons to decide amount of glenoid correction while glenoid component positioning in arthroplasty.

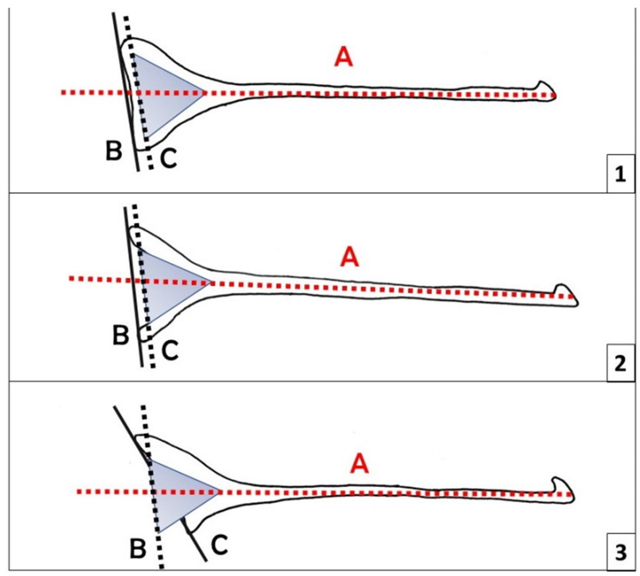

Figure 13: The glenoid vault model: line A defines the transverse scapular axis, line B is a tangent to glenoid plane joining anterior and posterior glenoid rims, and line C is a tangent to the vault model. The three models are: (1) Normal shoulder with equal retroversion of the vault and glenoid. (2) Central glenoid wear with glenoid bone stock loss calculable from the vault model. (3) Posterior glenoid wear with normal vault retroversion different from the arthritic glenoid.

The 3D-corrected-version deliberation

Advances in software technology and imaging modalities has facilitated the multidimensional scapular analysis as a free body notwithstanding its orientation within CT machine, subsequently, 3D-corrected version can be measured in any desired self-assertive plane[19]. Three dimensional technology can obviate measurement errors due to scapular rotation[8,12,32], and patient positioning, thus, it can facilitate preoperative planning for glenoid bone deficiency[18,33,35]. and eases intraoperative decision making[10,35].

Nonetheless, this advanced technology usually requires expensive software and experienced operators. Also, it does not eliminate user variability. Identifying reference points for scapular axes determination is still mandatory. In addition to correlating these findings to clinical application and outcome needs to be further set up.

Value of glenoid version

Normal glenoid version showed a wide range in different studies. It ranges from anteversion (positive value) to retroversion (negative value). Depending upon the midglenoid for measurement, Cyprian et al.[36] reported -8° of version using conventional radiographs. Other studies revealed the average version via 2D-CT to range from +2°[21] to -8° [37]. The mean glenoid version ranged from -1°[7] to -7° [35,38] utilizing the 3D-CT-scans.

Moreover, glenoid version is not consistent over the entire glenoid. Superior glenoid portion is more retroverted than the midglenoid[22,27,28]. Similarly, a recent study reported version values of different glenoid levels after dividing the glenoid into three nearly equal thirds. Freidman method of measurement revealed mean versions of 6.65º, 6.29º, and 5.47º for upper, middle, and lower glenoid thirds respectively[22].

C- MRI measurement

Tetreault et al. conducted MRI-version measurement at axial slice just below supraspinatus muscle. It was demonstrated as an angle bounded by the axis of supraspinatus fossa (SFA) and the glenoid cavity[39]. Taking advantage of the first MRI cut revealing a clear posterior edge of glenoid neck, the SFA was identified and represented a line drawn from the base of glenoid neck and the base of scapular spine as it converged with the scapular body (Figure 14)[39]. The mean version of normal patients was -3±4°, however, patients with rotator cuff tears (RCT) showed an average 8° higher than controls[39]. Patient with anteversion would most likely have posterior RCT, while patient with retroversion would most likely have anterior RCT.

Later, Lowe et al.[40] studied the exactness of MRI to CT version assessments, the version was measured through the Freidman method on CT and MRI utilizing the axial slice just inferior to coracoid process. The mean versions were -15.5° and -18.6° on CT and MRI, respectively.

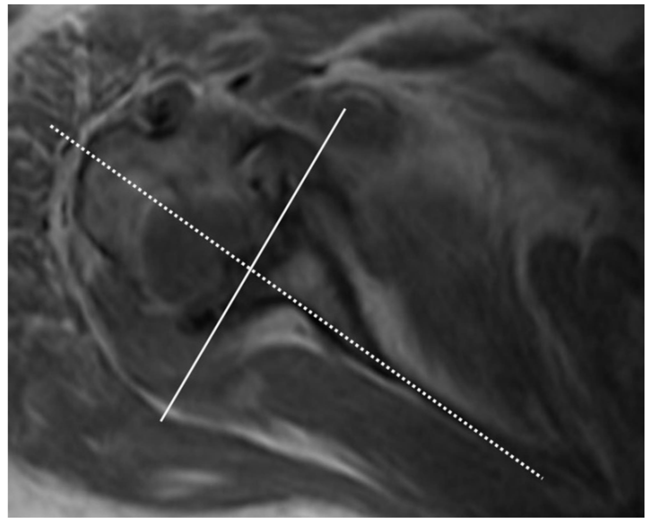

Figure 14: Version measurement using MRI-axial slice just below supraspinatus muscle with clear posterior edge of glenoid neck. Version is the angle between the SFA (white dotted line from the base of glenoid neck and the base of scapular spine as it converged with the scapular body) and the glenoid cavity (white solid line).

CONCLUSION

Glenoid version evaluation stays a matter of concern particularly in shoulder replacement surgeries. The wide range of version values should be considered. Freidman is still the most surgeon-familiar validated measurement method. Novel measurement techniques are evolving using the 3D-technology to limit any variational measurement errors with scapular rotation or patient positioning.

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REFERENCES

1. Rouleau DM, Kidder JF, Pons-Villanueva J, Dynamidis S, Defranco M, Walch G. Glenoid version: how to measure it? Validity of different methods in two-dimensional computed tomography scans. J Shoulder Elbow Surg. 2010;19(8):1230-7.
2. Cil A, Sperling JW, Cofield RH. Nonstandard glenoid components for bone deficiencies in shoulder arthroplasty. Journal of shoulder and elbow surgery. 2014;23(7):e149-e57.
3. Elshahhat A, Selim N, Basyoni Y, Nour K. Clinico-radiological correlation of reverse shoulder arthroplasty outcomes. International Journal of Research in Orthopaedics. 2023;9(1):149.

4. Gilot GJ. Addressing glenoid erosion in reverse total shoulder arthroplasty. Bulletin of the NYU Hospital for Joint Diseases. 2013;71(2):S51.
5. Churchill RS, Brems JJ, Kotschi H. Glenoid size, inclination, and version: an anatomic study. Journal of Shoulder and Elbow Surgery. 2001;10(4):327-32.
6. Von Schroeder HP, Kuiper SD, Botte MJ. Osseous anatomy of the scapula. Clinical orthopaedics and related research. 2001;383:131-9.
7. Matsumura N, Ogawa K, Kobayashi S, Oki S, Watanabe A, Ikegami H, et al. Morphologic features of humeral head and glenoid version in the normal glenohumeral joint. Journal of shoulder and elbow surgery. 2014;23(11):1724-30.
8. Moineau G, Levigne C, Boileau P, Young A, Walch G. French Society for Shoulder & Elbow (SOFEC). Three-dimensional measurement method of arthritic glenoid cavity morphology: feasibility and reproducibility. Orthop Traumatol Surg Res. 2012;98(6 suppl):S139-S45.
9. Codsi MJ, Bennetts C, Gordiev K, Boeck DM, Kwon Y, Brems J, et al. Normal glenoid vault anatomy and validation of a novel glenoid implant shape. Journal of shoulder and elbow surgery. 2008;17(3):471-8.
10. Couteau B, Mansat P, Darmana R, Mansat M, Egan J. Morphological and mechanical analysis of the glenoid by 3D geometric reconstruction using computed tomography. Clinical Biomechanics. 2000;15:S8-S12.
11. De Wilde L, Berghs BM, Audenaert E, Sys G, Van Maele G, Barbaix E. About the variability of the shape of the glenoid cavity. Surgical and Radiologic Anatomy. 2004;26(1):54-9.
12. Nyffeler RW, Jost B, Pfirrmann CW, Gerber C. Measurement of glenoid version: conventional radiographs versus computed tomography scans. J Shoulder Elbow Surg. 2003;12(5):493-6.
13. Ho JC, Youderian A, Davidson IU, Bryan J, Iannotti JP. Accuracy and reliability of postoperative radiographic measurements of glenoid anatomy and relationships in patients with total shoulder arthroplasty. Journal of shoulder and elbow surgery. 2013;22(8):1068-77.
14. Braunstein V, Korner M, Brunner U, Mutschler W, Biberthaler P, Wiedemann E. The fulcrum axis: a new method for determining glenoid version. Journal of shoulder and elbow surgery. 2008;17(5):819-24.
15. Braunstein V, Kirchhoff C, Ockert B, Sprecher C, Korner M, Mutschler W, et al. Use of the fulcrum axis improves the accuracy of true anteroposterior radiographs of the shoulder. The Journal of bone and joint surgery British volume. 2009;91(8):1049-53.
16. Le SV, Conrad B, Wright TW. Application of the fulcrum axis to estimate the central scapular axis. Journal of shoulder and elbow surgery. 2014;23(8):1143-9.
17. Mutch J, Sidler M, Sidler-Maier C, Axelrod T, Nam D. The fulcrum axis: an accurate measure of glenoid version on radiographs and computed tomography. Shoulder & Elbow. 2017:1758573217728291.
18. Hoenecke HR, Jr., Hermida JC, Flores-Hernandez C, D'Lima DD. Accuracy of CT-based measurements of glenoid version for total shoulder arthroplasty. J Shoulder Elbow Surg. 2010;19(2):166-71.
19. Budge MD, Lewis GS, Schaefer E, Coquia S, Flemming DJ, Armstrong AD. Comparison of standard two-dimensional and three-dimensional corrected glenoid version measurements. J Shoulder Elbow Surg. 2011;20(4):577-83.
20. Chalmers PN, Salazar D, Chamberlain A, Keener JD. Radiographic characterization of the B2 glenoid: the effect of computed tomographic axis orientation. J Shoulder Elbow Surg. 2017;26(2):258-64.
21. Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. J Bone Joint Surg Am. 1992;74(7):1032-7.
22. Elshahhat A, Aziz AMA, Basyoni Y, Nour KA. Version reckoning of variant glenoid levels: a radiological study on dry human scapulae. International Journal of Research in Orthopaedics. 2022;8(6):613.
23. Randelli M, Gambrioli PL. Glenohumeral osteometry by computed tomography in normal and unstable shoulders. Clin Orthop Relat Res. 1986(208):151-6.
24. Javed S, Hadi S, Imam MA, Gerogiannis D, Foden P, Monga P. The Ellipse modification of the Friedman method for measuring glenoid version. The Bone & Joint Journal. 2020;102(2):232-8.
25. Poon PC, Ting FS. A 2-dimensional glenoid vault method for measuring glenoid version on computed tomography. J Shoulder Elbow Surg. 2012;21(3):329-35.
26. Matsumura N, Ogawa K, Ikegami H, Collin P, Walch G, Toyama Y. Computed tomography measurement of glenoid vault version as an alternative measuring method for glenoid version. Journal of Orthopaedic Surgery and Research. 2014;9(1):17.
27. Lewis GS, Armstrong AD. Glenoid spherical orientation and version. J Shoulder Elbow Surg. 2011;20(1):3-11.
28. Monk AP, Berry E, Limb D, Soames RW. Laser morphometric analysis of the glenoid fossa of the scapula. Clin Anat. 2001;14(5):320-3.
29. Andrin J, Macaron C, Pottecher P, Martz P, Baulot E, Trouilloud P, et al. Determination of a new computed tomography method for measuring the glenoid version and comparing with a reference method. Radio-anatomical and retrospective study. Int Orthop. 2016;40(3):525-9.
30. Bokor DJ, O'Sullivan MD, Hazan GJ. Variability of measurement of glenoid version on computed tomography scan. J Shoulder Elbow Surg. 1999;8(6):595-8.
31. Robertson DD, Sharma GB, McMahon PJ, Karas SG. Glenoid Version Assessment When the CT Field of View Does Not Permit the Friedman Method: The Robertson Method. Orthop J Sports Med. 2022;10(5):23259671221083589.
32. Iannotti JP, Ricchetti ET, Rodriguez EJ, Bryan JA. Development and validation of a new method of 3-dimensional assessment of glenoid and humeral component position after total shoulder arthroplasty. Journal of shoulder and elbow surgery. 2013;22(10):1413-22.
33. Kwon YW, Powell KA, Yum JK, Brems JJ, Iannotti JP. Use of three-dimensional computed tomography for the analysis of the glenoid anatomy. J Shoulder Elbow Surg. 2005;14(1):85-90.
34. Bryce CD, Davison AC, Lewis GS, Wang L, Flemming DJ, Armstrong AD. Two-dimensional glenoid version measurements vary with coronal and sagittal scapular rotation. JBJS. 2010;92(3):692-9.
35. Scalise JJ, Codsi MJ, Bryan J, Iannotti JP. The three-dimensional glenoid vault model can estimate normal glenoid version in osteoarthritis. J Shoulder Elbow Surg. 2008;17(3):487-91.
36. Cyprien J, Vasey H, Burdet A, Bonvin J, Kritsikis N, Vuagnat P. Humeral retrotorsion and glenohumeral relationship in the normal shoulder and in recurrent anterior dislocation (scapulometry). Clinical Orthopaedics and Related Research. 1983(175):8-17.
37. Couteau B, Mansat P, Mansat M, Darmana R, Egan J. In vivo characterization of glenoid with use of computed tomography. Journal of shoulder and elbow surgery. 2001;10(2):116-22.
38. Ganapathi A, McCarron JA, Chen X, Iannotti JP. Predicting normal glenoid version from the pathologic scapula: a

comparison of 4 methods in 2-and 3-dimensional models. Journal of shoulder and elbow surgery. 2011;20(2):234-44.
39. Tetreault P, Krueger A, Zurakowski D, Gerber C. Glenoid version and rotator cuff tears. Journal of orthopaedic research. 2004;22(1):202-7.
40. Lowe JT, Testa EJ, Li X, Miller S, DeAngelis JP, Jawa A. Magnetic resonance imaging is comparable to computed tomography for determination of glenoid version but does not accurately distinguish between Walch B2 and C classifications. J Shoulder Elbow Surg. 2017;26(4):669-73.