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Title: Reliability of the glenoid plane.

Article Type: Original Article

Keywords: glenoid cavity; anthropometry; plane of reference; variability; retroversion; prosthetic surgery; inferior glenoid circle; scapular plane.

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Abstract: Hypothesis: The purpose of this study was to investigate the three dimensional orientation of the glenoid plane and the scapular plane. Different definitions of the glenoid plane were used and different planes were measured and we hypothesed that the 3-D plane with the least variation would be best to define the most reliable glenoid plane.
Methods: We studied 150 CT scans from non-pathological shoulders from patients between 18 and 80. The scapular plane and five different glenoid planes were determined: an inferior, anterior, posterior, superior and neutral glenoid plane. Of all planes version and inclination angles were measured. Because all examinations were done in a standardized position to the coronal, sagittal and transverse plane of the body the scapular plane could be defined versus the coronal, sagittal and transverse planes of the body.
Results: The version (mean: 3.76) of the inferior glenoid plane showed a significantly lower standard deviation than the version of the anterior ($p<0.001$), posterior ($p=0.001$) and superior ($p=0.001$) glenoid plane (ANOVA). For inclination all planes have a similar variance. The scapular plane was different between gender ($P=0.022$) and correlated with age.
Conclusion: This study showed that the retroversion of the inferior glenoid is reasonably constant. The osseous anthropometry of the inferior glenoid can offer a reproducible point of reference to be used in prosthetic surgery of the shoulder.

***Response to Reviewers**

Revision of the MS. Ref. No.: JSES-D-09-00274

Comments from the Editors and Reviewers:
Associate Editor's comment:
Unfortunately the reviewer are not convinced that this study adds much useful new data to literature.
Weak points are:
Indication for CT scan examination of the contralateral shoulder not given:
The patients that were included had a CT scan examination of the contralateral (pathologic) shoulder for instability (30), AC-joint arthritis (33), Rotator Cuff tears (33), (partial (5), Full thickness (28)), calcifying tendinitis (12), frozen shoulder (8), subacromial impingement (17), tendinitis of the long head of biceps brachii (12), fractures of the proximal humerus (5). Those pathologies are included in the manuscript.

A special selection (Instability, osteoarthritis, cuff tear arthropathy) might have influenced the results.
This is a study about the normal shoulder and we hope to do in the future studies on the pathological shoulder as one might expect this might differ from the normal shoulder. The clinical examination of the shoulder as well as the history was negative of the included shoulder and this is mentioned in the manuscript.

Ethical considerations: Was the consensus of the patients for the scan of the contralateral shoulder and the ethical committee given (difference of exposure both versus one shoulder?).
Ethical approval was cleared from the ethics committee (EC/2009-099/Svdm). The patients received no extra irradiation because it is difficult to impossible to positioning one shoulder more central in the CT-scan to narrow the window of exposure and give less irradiation during the examination. This is mentioned in the manuscript.

Weak methodology:
a) In many osteoarthritis cases the posterior-inferior wear of the glenoid and the presence of osteophytes make probably precise measurements with this method difficult even with the use of the 3-D-software. Reference points which are less influenced by common glenoid deformities would be better.
This study is only a study of the glenoid plane in patients without pathology of the shoulder. To our knowledge this is the first and only study defining this plane in vivo in non pathologic human shoulders . In omathrosis a posterior-inferior wear with loss of a centred glenohumeral joint is seen in ± 60% of the cases (64 % eccentric glenoid B1, B2 , according to Habermeyer, CORR 2006) so this might be one of the challenges of the future study.
This study mainly uses the surgical guidelines that are advocated today to restore the normal glenoid plane of which is not known what is their different variation in a normal population. It is the is the first study which determines the normal glenoid plane using five different references points. These are not used in current surgical techniques were either all the systems are referring to an adjustment of the plane similar to that of the contralateral shoulder or to an adjustment to the level of the anterior plane of the glenoid.

b) Scan technique: Slices too thick without 3-D-reconstruction to evaluate rotation of the Glenoid surface to the scapula plane.
This study is using Dicom information obtained from CT-scan with slices of which we were told were taken every 2 mm. Of those slices a reconstruction is done of the whole scapula with the software program MIMICS. Due to this remark we went up looking how many slices we have available for every shoulder (in casu scapula) and we calculated at least 125 up to 180 slices per shoulder going up from the acromion down to the inferior angle of the scapula. This means between 1 to 2 mm thickness for one slice. We preferred to mention the maximum thickness of the slices as we considered that this would not affect the results of the determination of the scapular plane. For the same shoulder the glenoid plane is reconstructed using minimally 50 up to 70 slices. We hope that this explains the radiological technique better, the more that the 3-D reconstruction is used in this study to mimic as good as possible the surgical act of determining the glenoid plane. We determined the glenoid plane as we were doing open surgery!

Comparing to routine measurements which actually are performed by the majority of surgeons little new and useful information is provided.
We do not agree with this statement because the surgical technique used today to reconstruct the glenoid plane advises to use Saller's line going from the most superior point of the glenoid to the most inferior point. Another line is drawn between the most anterior point and the most posterior point. Those two lines are used to determine the centre of the glenoid which is approached by a guide to ream in a perpendicular way or if any correction is needed in with a correction calculated on one transversal slice from a 2-D Ct-scan. We think that this study clearly demonstrated that the surgeon best uses at least 3 bony references points (to construct a plane). Those bony reference points are best situated on the rim of the inferior glenoid in an effort to determine the glenoid

plane with the least variation. Because this variation is statistically different from all the other planes on a normal glenoid we think that this plane represents the most reliable glenoid plane. We believe this knowledge is new and useful information that can guide the surgeon. Indeed this study gives not the answer which reference point to use if the posteroinferior point is not available because we only studied a normal population. But apparently the superior point of the glenoid seems not the one to use…..

Reviewer #1: Title: What Is Your Glenoid Plane? Is It Accurate?

Manuscript Number: JSES-D-09-00274

General Comments:

This is a well-written interesting manuscript that would be of interest to reader of the Journal of Shoulder and Elbow Surgery, particularly those that perform shoulder arthroplasty. A few revisions and clarifications are in order as outline below. Page numbers need to be reformatted as they are missing from most pages of the manuscript on the printed copy.

Specific Sections Requiring Revision:

Page 1: The authors might want to consider changing the title to something more appropriate such as "Evaluation of Glenoid Morphology" or something similar. We agree that the title might be suboptimal reflecting the message of the study. We suggest to change in: Reliability of the glenoid plane.

Line 12: I believe "transverse" is more appropriate than "transversal." Corrected.

Line 13: I believe "transverse" is more appropriate than "transversal." Corrected.

Line 31: Omit "But" at the beginning of this sentence. Corrected.

Line 40: It would be appropriate to define "Saller's line" in the manuscript. Corrected.

Line 43: I believe "transverse" is more appropriate than "transversal." Corrected.

Line 56: How was pathology excluded in the shoulder (history, normal exam findings, normal CT scan, etc)? The pathology was excluded first by clinical examination and according to the patients history. Secondly every CT-scan with structural bony pathology (like cysts and visual bony deformations of clavicula, scapula or humerus as well as the SC, AC and GH-joint) was rejected. If soft tissue swellings or muscular fatty degeneration of the rotator cuff and/or deltoid were seen the casus was not included.

Line 83: Change "de" to "the." Corrected.

Line 92: I think [7] is the wrong reference for Churchill. Corrected into 5.

Line 96: I think [7] is the wrong reference for Churchill. Corrected into 5.

Line 132: This first paragraph belongs in the Methods section. Corrected.

Line 222: Change "woman" to "women." Corrected.

Line 223: Osteoarthritis is more common in females than males in European series. The converse is true in North American series. We did study a European population and according to the information of Jain N et. al. it a similar phenomenon is seen among the population of the US. (female 66.3% versus male 33.7% ; Nitin Jain, Ricardo Pietrobon, Shawn Hocker, Ulrich Guller, Anoop Shankar, and Laurence D. Higgins The Relationship Between Surgeon and Hospital Volume and Outcomes for Shoulder Arthroplasty J. Bone Joint Surg. Am., Mar 2004; 86: 496 – 505). This information is added to the discussion.

Figure 5: A better figure would be helpful at demonstrating the neutral glenoid plane. Corrected

Table 1: This is actually a Figure, not a Table. Corrected.

Table 2: The table should be reformatted to "English style" replacing the commas with decimal points.
Corrected.

Table 3: The table should be reformatted to "English style" replacing the commas with decimal points.
Corrected.

Table 4: The table should be reformatted to "English style" replacing the commas with decimal points.
Corrected.

Reviewer #2: P 2 line 7
You are not looking for the true glenoid plane but for the more reliable glenoid plane. This is true and we thank the reviewer of this constructive criticism. We changed this in the manuscript and title.

P 2 Line 18
You mentioned in the Method paragraph that you calculated the scapula plane orientation; however no results are reported in the abstract. This is true and we can add this information in the abstract but then it becomes difficult to respect the 200 words limit. We add more information in the resultchapter and in the discussion on the findings of the scapular plane.

P 4 line 54
The patients have a wide range of age (18 to 80), which increase the risk of degenerative osteophytes altering glenoid morphology.
The pathology was excluded first by clinical examination and according to the patients history. Secondly every CT-scan with structural bony pathology (like cysts and visual bony deformations of clavicula, scapula or humerus as well as the SC, AC and GH-joint) was rejected. If soft tissue swellings or muscular fatty degeneration of the rotator cuff and/or deltoid were seen the casus was not included.

Furthermore, you CT acquisition slices thickness is large (2mm) (low resolution CT), leading to obscuring the accurate visualisation of potential degenerative osteophytes in patient inclusion. 0.625mm slice allows a far better resolution.
This limitation has to be add in the discussion
Technique : This study is using Dicom information obtained from CT-scan with slices of which we were told were taken every 2 mm. Of those slices a reconstruction is done of the whole scapula with the software program MIMICS. Due to this remark we went up looking how many slices we have available for every shoulder (in casu scapula) and we calculated at least 125 up to 180 slices per shoulder going up from the acromion down to the inferior angle of the scapula. This means between 1 to 2 mm thickness for one slice. We preferred to mention the maximum thickness of the slices as we considered that this would not affect the results of the determination of the scapular plane. For the same shoulder the glenoid plane is reconstructed using minimally 50 up to 70 slices. We hope that this explains the radiological technique better, the more that the 3-D reconstruction is used in this study to mimic as good as possible the surgical act of determining the glenoid plane. We determined the glenoid plane as we were doing open surgery!

P 4 line 62
Please had much more details of the CT-scan setting (CT model used, Slices pixel, kW, mA, field of view..)

Type of scanner : Somatom Volume Zoom - Siemens.
Matrix: 512/ kV:140/ eff. mAs: 350
Field Of View: adapted to the individual patient: max. 500 for both shoulders and minimally for one shoulder 150. The scan field of view (SFOV) is always 500.

P5 line87
How did you create the planes and calculate the angles (with Mimics software, with another software, by direct measurement on the screen)? Please had further information, because it is crucial for validating and reproducing your method
see technique

P5 lines 92 and 96
The reference does not match with the table of references.
This is corrected (one mistake ic Churchill ref 7 →5)

There are also major other problem in the references (missing references..)
We had to blind our own references

Further more, Churchill calculated the glenoid version on cadaver scapula with very basic tools. In his series, the scapula were fixed in the scapular plane and the version and inclinaison calculated in basic 2D planes perpendicular to the scapula plane. The rotation of the glenoid was not taken into account. We would have expected that the glenoid rotation would have been taken into account with the use of CT 3-D reconstruction, but unfortunately this article failed to do it. This is the major shortcoming of this article and it probably explains why the conclusion of this huge work is so poor.
We can only agree partially with this statement. The method of Churchill is indeed concentrating on the retroversion of the glenoid and this is described as an angle between two lines the line of the scapula and the line of the glenoid at its most anterior an posterior point. This study does much more, it calculates an angle between two planes and not between two lines. And thanks to this we were able to identify a highly statistical significant difference between variation of the inferior plane and the scapular plane compared to the other planes used in this study. This study did not study 2-D information but exclusively 3-D information which we thought would be totally different from the information one can get from a transverse slice of the 2-D CT-scan. We need to admit that this seems not to be the case so one can wonder about the extra value a 3-D reconstruction gives for the orthopaedic surgeon in preoperative planning. But unfortunately this was not the aim of the study.

P5 lines 107-8
I do not understand what this sentence means. Do you mean that the glenoid plane and the transversal plane of the body are parallel?
As mentioned above we studied angles between planes and for comparison reason also for the glenoid inclination and the glenoid retroversion between lines. Because angles between planes never are measured or publisched in the literature we are trying to compare those angles with similar angles (between the lines) in that are known in the literature. Because in normal osteology the angle between the lines and the planes are similar (with exception for the anterior and posterior plane) we did not discuss this topic. We clarified this more in the methods and comment this difference in the discussion.

P7-8 lines 160-74
Could you please give further details of the scapula plane angles (Mean, SD,max, min)
We included this information. We extended the discussion with this information.

P9 lines187-90
Please clarify your stance
As mentioned above we tried to do so.

Reliability of the glenoid plane.

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Financial Renumeration:

Lieven De Wilde: The author, their immediate family, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Tom Verstraeten: The co-author, their immediate family, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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Anne Karelse: The co-author, their immediate family, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Ethical approval

Ethical approval was cleared from the ethics committee University Hospital Ghent - Chairman Prof. dr. R. Rubens (EC/2009-099/Svdm : The normal glenohumeral relationships : a 3-Dimensional CT-scan stduy of the humeral and glenoid planes in one hundred and fifty normal shoulders).

Figures to be published in colour

Figure 2, 3, 4, 5, 6, 7, 8, 9, and 10 a-b-c

*Manuscript

Reliability of the glenoid plane.

Abstract

Hypothesis: The purpose of this study was to investigate the three dimensional orientation of the glenoid plane and the scapular plane. Different definitions of the glenoid plane were used and different planes were measured and we hypothesed that the 3-D plane with the least variation would be best to define the most reliable glenoid plane.

Methods: We studied 150 CT scans from non-pathological shoulders from patients between 18 and 80. The scapular plane and five different glenoid planes were determined: an inferior, anterior, posterior, superior and neutral glenoid plane. Of all planes version and inclination angles were measured. Because all examinations were done in a standardized position to the coronal, sagittal and transverse plane of the body the scapular plane could be defined versus the coronal, sagittal and transverse planes of the body.

Results: The version (mean: 3.76) of the inferior glenoid plane showed a significantly lower standard deviation than the version of the anterior ($p<0.001$), posterior ($p=0.001$) and superior ($p=0.001$) glenoid plane (ANOVA). For inclination all planes have a similar variance. The scapular plane was different between gender ($P=0.022$) and correlated with age.

Conclusion: This study showed that the retroversion of the inferior glenoid is reasonably constant. The osseous anthropometry of the inferior glenoid can offer a reproducible point of reference to be used in prosthetic surgery of the shoulder.

Keywords: glenoid cavity; anthropometry; plane of reference; variability; retroversion; prosthetic surgery; inferior glenoid circle; scapular plane.

Prognostic Study, Level II of Evidence.

Introduction

Restoration of the glenoid plane is essential in total shoulder arthroplasty. Failing to restore the inclination and the version of the glenoid is associated with prosthetic instability and jeopardizes the longevity of the prosthesis [25]. Correct restoration of the glenoid plane balances the forces across the glenoid and prosthetic components thereby improving stability, and functional outcomes [14, 19, 30, 33]. The definition of the glenoid plane itself is not clear. This can be explained by the fact that the morphology of the glenoid is extremely diverse [8]. Also the angulation of the glenoid has a wide range of variety in healthy individuals with a version ranging from 14 degrees of retroversion to 12 degrees of anteversion [3, 5, 10, 22, 24], and an inclination ranging from –8° to 15.8° [5, 12].

At the inferior glenoid a constant shape of a true circle can be distinguished [8, 13, 16]. The plane of this inferior glenoid circle is less variable and can be used as an anatomic guide [17, 21] in prosthetic glenoid surgery. However the orthopaedic surgeon tends to use the plane with the centre defined as the crossing line between the most superior and inferior point of the glenoid (Saller's line) and the largest antero-posterior distance [1, 26]. Recently a standardized 3-dimensional (3-D) glenoid vault model mimicking the contralateral shoulder was introduced to assist in restoring the plane of the glenoid in the coronal and transversal plane of the body [6, 27, 28]. It is assumed that this plane represents the normal plane of the body for that individual person [16] . The normal anatomy of the 3-D positioning of the glenoid plane in a population is still unknown. The purpose of this study is to investigate the normal three dimensional relationship of the glenoid plane and scapular plane, and we try to define the most reliable glenoid plane, which should be most suitable for prosthetic surgery. Different definitions of the glenoid plane were used and different planes were measured and we hypothesed that the 3-D plane with the least variation would be best to define the 'true' glenoid plane.

Material and Methods

We examined 150 Computed tomography (CT) scans of non pathologic shoulders of patients who were examined with an arthro-ct scan for pathology of the contra lateral shoulder. The patients were between 18 and 80 years old (mean: 41.75). There were 68 females and 82 males. The age distribution is found in figure 1.

Ethical approval was cleared from the ethics committee (EC/2009-099/Svdm). The patients received no extra irradiation because it is difficult to impossible to positioning one shoulder more central in the CT-scan tunnel to be able to narrow the window resulting in less irradiation.

The patients that were included had a CT scan examination of the contralateral (pathologic) shoulder for instability (30), AC-joint arthritis (33), Rotator Cuff tears (33), (partial (5), Full thickness (28)), calcifying tendinitis (12), frozen shoulder (8), subacromial impingement (17), tendinitis of the long head of biceps brachii (12), fractures of the proximal humerus (5).

The shoulder was included if any pathology was excluded first by clinical examination and according to the patients history. If any structural bony pathology (like cysts and visual bony deformations of clavicula, scapula or humerus as well as the SC, AC and GH-joint) or soft tissue pathology (like swellings or muscular fatty degeneration of the rotator cuff and/or deltoid) were seen the casus was not included.

The CT-scan settings are : type of scanner : Somatom Volume Zoom – Siemens (Siemens Business Park, Marie Curiesquare 30 - Square Marie Curie 30; 1070 Brussel – Bruxelles). Matrix: 512/ kV:140/ eff. mAs: 350. The scan field of view (SFOV) is always 500. Field of view (FOV): adapted to the individual patient: max. 500 for both shoulders and minimally for one shoulder 150.

In an effort to minimize the influence of the individual positioning all CT scans were made with the patient positioned as described by the senior author [17] in dorsal recumbency and with a thoracobrachial orthosis to keep the arm adducted in the coronal plane and the forearm flexed in the sagittal plane of the body. The glenohumeral joint was scanned with 2-mm interval slices. Three independent investigators imported CT-images (dicom) into a medical imaging computer software (Mimics® 11.02 for Intel X86 Platform V11.2.2.1 1992-2007 Materialise n.v., Haasrode Belgium) to create 3D images of the shoulder joint. Both bones of the joint could be separated digitally and virtually manipulated to determine the bony reference points for purposes of measurement.

The five different glenoid planes were created as follows:

Four points were indicated at the glenoid rim: A superior point (S) and a inferior point (I) at the greatest length of the glenoid (=identical to the points used to determine Saller's line), an anterior point (A) and a posterior point (P) at the greatest width of the glenoid.

The *inferior glenoid plane* was determined by three points : the anterior point (A), the posterior point (P) and the inferior point (I) (figure 2).

The *anterior glenoid plane* was determined by three points: the superior (S), the inferior (I) and the anterior (A) (figure 3).

The *posterior glenoid plane* was determined by three points : the superior (S), the inferior (I) and the posterior (P) (figure 4).

The *superior glenoid plane* was determined by three points : the superior (S), the anterior (A) and the posterior (P) (figure 5).

The *neutral glenoid plane* was determined by only two points : the superior (S) and the inferior (I), and is perpendicular to the scapular plane (figure 6).

The *scapular plane* is the plane determined by three points : a lateral scapular point in the surgical centre of the glenoid (this is the crosspoint (C) between the line between de most anterior point (A) and the most posterior point (P) and the line between the most superior point (S) and the most inferior point (I)), a medial scapular point (MS) at the most medial point of the spina scapula and the inferior scapular point (IS) at the most inferior point of the scapula (figure 7).

From these planes different angles were measured:

A. Angles measured within the scapula.

A. a. angles between lines:

2-D Glenoid version (GV): the angle between the line from the most anterior point (A) to the most posterior point (P) and the line of the scapular plane, calculated conform the method of Churchill [5] (figure 8).

2-D Glenoid inclination (GI): the angle between the line from the most superior point (S) to the most inferior point (P) and the line between the most medial scapular point (MS) and the middle of the glenoid (crosspoint (C), measured conform the method of Churchill [5] (figure 9)

A. b. angles between planes:

3-D Glenoid retroversion: the angle between the scapular plane and the plane of different glenoid planes (superior, inferior, anterior, posterior and the neutral plane).

3-D Glenoid inclination: the angle between the perpedicular to scapular plane including point C and point MS and the plane of different glenoid planes (superior, inferior, anterior, posterior and the neutral plane).

B. Angles of the different glenoid planes (neutral, superior, anterior, posterior and inferior) and the scapular plane versus the coronal, sagittal and transversal plane of the body (Spatial parameters).

Because all measurements are related to the *scapular plane* all patients were positioned similar to minimize error due to a different scapular orientation. This allowed us to measure the scapular plane and different scapular angles. We defined the angle of the scapular plane and the coronal plane as the *Coronal Scapular Angle (CSA)* (figure 10-a), the angle of the scapular plane and the sagittal plane as the *Sagittal Scapular Angle (SSA)* (figure 10-b) and the angle of the scapular plane and the transversal plane as the *Transversal Scapular Angle (TSA)* (figure 10-c). This means that CSA is comparable to the angle measured in the transversal plane of the body in a normal CT-setting. For the SSA this means that this angle is comparable to the angle of the glenoid plane (AG) [9].

Statistical analysis

Statistical testing was performed (ANOVA) to detect significant differences in the measured angles.

a. Comparative man/women

A Mann-Whitney U test (MWU) was used to detect the distribution of angle measurements between males and females

b. Correlation

Spearman correlations were used to explore the correlation with age.

Regression models for each of the angle measurements were used to verify the interaction between age and gender and to obtain (potentially) age- and gender specific normal distributions of the angle. P-values smaller than 0.05 were considered significant. Terms with $p < 0.10$ were kept in the regression model. No corrections for multiple testing were performed, since the aim is to detect any indication that the construction of normal values for the angle measurements should be done gender and/or age-specific.

c. Accuracy, reliability and repeatability

Twenty different glenoids were analysed by two independent investigators in order to determine the inter-observer variability. To measure the intra-observer variability, 20 specimens were analysed twice by the same person. To determine these variabilities, the interclass and intraclass correlation coefficient were used [29] (ICC, Wilcox on Signed Ranks test).

Results

A. Angles measured within the scapula

A. a. angles between lines:

2-D Glenoid version (GV): the descriptive statistics are mean=-3.78° ; Min=-13.74° ; Max=4.89° ; SD=3.50°.

2-D Glenoid inclination (GI): the descriptive statistics for the method of Churchill [5] are mean=10.89° ; Min=1.02° ; Max=24.91° ; SD=4.46°.

A. b. angles between planes

a. Descriptive statistics

3-D Glenoid retroversion: the descriptive statistics of the different glenoid planes (superior, inferior, anterior, and posterior) to the scapular plane can be find in (table 1). The angle between the neutral plane is of course always 90°.

3-D Glenoid inclination: the descriptive statistics of the different glenoid planes (superior, inferior, anterior, and posterior) to the scapular plane can be find in (table 2).

B. Angles of the different glenoid planes (neutral, superior, anterior, posterior and inferior) and the scapular plane versus the coronal, sagittal and transversal plane of the body (Spatial parameters).

3-D angle of the different glenoid planes: the descriptive statistics of the different glenoid planes (neutral, superior, inferior, anterior, and posterior) versus can be find in (table 3).

3-D angle of the scapular plane : the descriptive statistics of the different glenoid planes CSA, SSA and TSA can be find in (table 4).

b. Comparative statistics

The 3-D retroversion of the inferior glenoid plane showed a significantly lower standard deviation than the version of the anterior ($p<0.001$), posterior ($p=0.001$) and superior ($p=0.001$) glenoid plane (ANOVA). Figure 11-a shows a normal distribution of the inferior glenoid version and figure 11-b shows its Q-Q plot.

For the 3-D retroversion of the posterior glenoid plane ($p=0.036$) significantly different values were found between men (mean : -13,2507) and woman (mean : -14,9748) (MWU test) implying that a less retroverted posterior glenoid plane is found in men.

No significant difference between all calculated inclination angles was found (ANOVA).

A significant difference between men (mean : 20,3009) and woman (mean : 22,3078) was found (MWU) for the 3-D inclination (p = 0,035) of the inferior glenoid plane: in men less inclination is found.

A significant difference between the defined different glenoid planes is found p < 0.001(MWU).

c. Correlation statistics

A correlation with age was found for 3-D retroversion of the anterior glenoid plane (r = -0.162, correlation at the 0.05 level) and superior glenoid plane (0,186, correlation at the 0,05 level) implying that both planes are more retroverted in the elderly (Spearman correlation).

No significant correlation could be calculated between the 3-D inclination angles and age or gender (Spearman correlation).

B. Angles of the scapular plane versus the coronal, sagittal and transversal plane of the body (Spatial parameters).

a. Comparative

The mean SSA in women is 53,3119°, in men : 55,4463°. The difference is significant (p=0.022) (MWU) and implies that the scapular plane is more protracted in women.

b. Correlation

For the SSA (r = 0.171, correlation at the 0.05 level) and the TSA (r=-0.224, correlation at the 0.01 level) a significant correlation with age was found: in the elderly the protraction and the anteflexion of the scapular plane increases. (Spearman correlation).

Accuracy, reliability and repeatability.

Inter- and intra-observer variability was very high with an intraclass correlation coefficient of 0.98 and an intraclass coefficient of 0.99 (ICC,Wilcoxon Signed Rank Tests).

Discussion

We used a three dimensional reconstruction soft ware program (Mimics®) that enabled us to define the orientation of the scapular plane and glenoid plane versus the coronal, sagittal and transversal plane of the body in a patient positioned in dorsal recumbency. According to the literature this is the first study which defines the three dimensional orientation of the scapular and glenoid plane in vivo. The knowledge of this orientation can be important in future studies of the range of motion of the shoulder [4], instability [24] and rotator cuff tears [1, 23, 31, 32].

The osseous measurements of this 3-D CT-scan reconstruction are consistent with the literature. The 2-D retroversion of the superior and inferior plane are comparable with the known osteology [3, 5, 11, 17, 20, 21, 22, 26]. The reason why the version of the anterior and posterior plane are not comparable with the literature is that the maximum anteroposterior diameter of the glenoid is not taken into account. The same phenomenon is seen comparing the 2-D inclination with the known literature [1, 11, 12, 17, 20]. A different absolute value is found regarding the inclination of the inferior or superior plane, a comparable value is found with the neutral, the anterior and posterior plane.

Standardizing the positioning of the patient in the scanner minimizes the error of positioning both scapulae in a different coronal plane. The thoracobrachial orthosis forces the elbow (and the shoulder) to be positioned at the same transversal level and brings the upper arms (and caput humeri) in the same rotation. In a previous study [9] we could demonstrate that this positioning reduces the variability of the in vivo measurements to the variability of the osseous anthropometric results. Unfortunately neither the length, the weight and the body mass of the patients are taken into account, nor are the length and the orientation of the clavicula. These shortcomings can be considered as the major weakness of this study which can thereby not pretend to analyse the impact of the morphology of the clavicle and thoracic cage on the positioning of the scapula.

Although this study has a very high intra- en interobserver accuracy a similar variation is found between our measurements and the literature confirming the known variation of these measurements [3, 5, 11, 17, 20, 21, 22, 26]. Only one exception is found for this statement : this study defines the inferior glenoid plane as the plane with the least variability regarding the retroversion of the glenoid (p≤0.001). Conform with the literature this plane is the plane of the inferior glenoid circle [8, 13, 16, 21], which seems to be a constant finding of the in the normal glenoid morphology. The variability of the inclination of this plane is similar to the variability of the other planes. The inferior plane is situated more distally so a greater influence of variables as morphology of the clavicle and the thoracic cage can be expected.

Because this study calculates a statistically significant difference between all the different planes of the glenoid it seems important to define the most reliable one if the surgeon wants to reconstruct normal anatomy. This might be difficult when normal anatomy is distorted as is the case in about two third of the rotator cuff sufficient omarthrosis which shows a posteroinferior defect of the glenoid [12]. Probably new parameters need to be defined [6] or computer aided surgery will be indicated to mimic as close as possible normal glenoid anatomy.

The results show that the scapular plane is more protracted in women than in men, and that protraction and anteflexion of the scapular plane increase in the elderly. This might be explained by the degree of thoracic kyphosis which increases with age and effects the thoracic morphology and so scapular orientation [7, 18].

The scapular positioning influences the glenoid plane as well [9, 18]. Nevertheless this study could not find particular relationships between the scapula and the glenoid. We demonstrated a less inclinated inferior glenoid plane in men than in woman and maybe this can be seen as a causal factor in the higher incidence of rotator cuff tears in men [1, 34].

This study found less retroversion of the posterior glenoid plane in men than in woman and this can be probably an explanation why degenerative osteoarthritis of the shoulder is less frequently found in men than in women [2, 15]. The anterior and superior glenoid plane are more retroverted in the elderly, but aging cannot explain this since none of the scans showed degenerative articular signs. Maybe it is a consequence of aging of the rotator cuff [34]. These statements need to be confirmed by studies comparing inclination and version in non-pathologic shoulders to the values in shoulders with rotator cuff tears and degenerative osteoarthritic lesions.

Conclusion

This study shows that the inferior plane of the glenoid formed by the most anterior, posterior and inferior point of the rim of the glenoid has a constant degree of retroversion. This finding supports the use of this plane as the most appropriate plane to restore normal anatomy. This is important in prosthetic surgery where the restoration of the glenoid anatomy is crucial for the longevity of the prosthesis and the functional outcomes.

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Figures

Figure 1 : Age distribution of the patients

Figure 2: Inferior Glenoid Plane: was determined by setting 3 points on the rim of the inferior quadrants of the glenoid. An inferior (I), anterior (A) and posterior (P) glenoid point.

Figure 3: Anterior Glenoid Plane: was determined by setting 3 points on the rim of the anterior quadrants of the glenoid. An inferior (I), superior (S) and anterior (A) glenoid point.

Figure 4: Posterior Glenoid Plane: was determined by setting 3 points on the rim of the posterior quadrants of the glenoid. An inferior (I), superior (S) and posterior (P) glenoid point.

Figure 5: Superior Glenoid Plane: was determined by setting 3 points on the rim of the posterior quadrants of the glenoid. A superior (S), anterior (A) and posterior (P) glenoid point.

Figure 6: Neutral Glenoid Plane: was determined by setting two points on the rim of the superior and inferior quadrant of the glenoid. An inferior (I)and superior (S) glenoid point. This plane is perpendicular to the scapular plane.

Figure 7: Scapular Plane: was determined by selecting three points on the scapula. A lateral scapular point in the center of the glenoid (C) which is the cross point of the line between the most superior (S) and inferior (I) glenoid point (Sallers line) and the line between the most anterior (A) and most posterior (P) point of the glenoid, a medial scapular point (MS) at the most medial point of the spina scapula and the inferior scapular point (IS) at the most inferior point of the scapula.

Figure 8 : 2-D Glenoid version : angle between the line from the most anterior point (A) to the most posterior point (P) and the scapular plane (formed by the most medial scapular point (MS) and the center of the glenoid (C)).

Figure 9: 2-D Glenoid inclination (GI) :

according to the method of Churchill: angle between the line from superior point (S) tot inferior point (P) and the line between the line from the most medial scapular point (MS) and the middle of the glenoid (crosspoint (C)) -90°.

Figure 10 : 3-D angles :

Figure 10-a: the *Coronal Scapular Angle (CSA)* = the angle of the scapular plane and the coronal plane.

Figure 10-b: the *Sagittal Scapular Angle (SSA)* the angle of the scapular plane and the sagittal plane as and the angle

Figure 10-c: the *Transversal Scapular Angle (TSA)* = the angle of the scapular plane and the transversal plane

Figure 11 : distribution of the version of the inferior glenoid plane

Figure 11-a: Normal distribution of the Inferior Glenoid Version.

Figure 11-b: Q-Q Plot to demonstrate the normal distribution of the Inferior Glenoid Version.

Content of Tables

Table 1: Descriptive statistics of the version angles of the different glenoid planes. Negative values are retroversion, positive values are anteversion.

Table 2: Descriptive statistics of the inclination of the glenoid planes. Negative values have a caudal directed angle (downslope) and positive values have a cranial directed angle (upslope).

Table 3: Descriptive statistics of the different glenoid plane (superior, anterior, posterior, inferior and neutral) versus the coronal, sagittal and transversal plane of the body.

Table 4: Descriptive statistics of the scapular plane versus the coronal, sagittal and transversal plane of the body.

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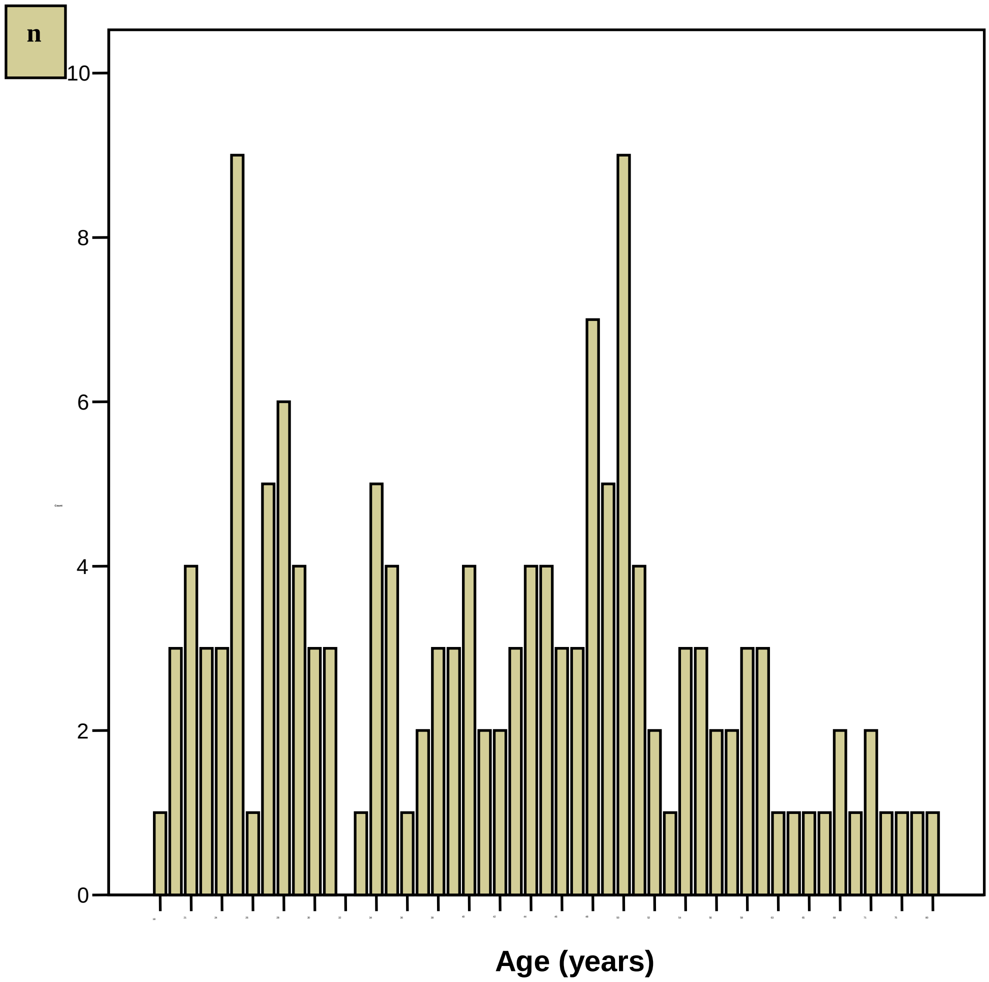

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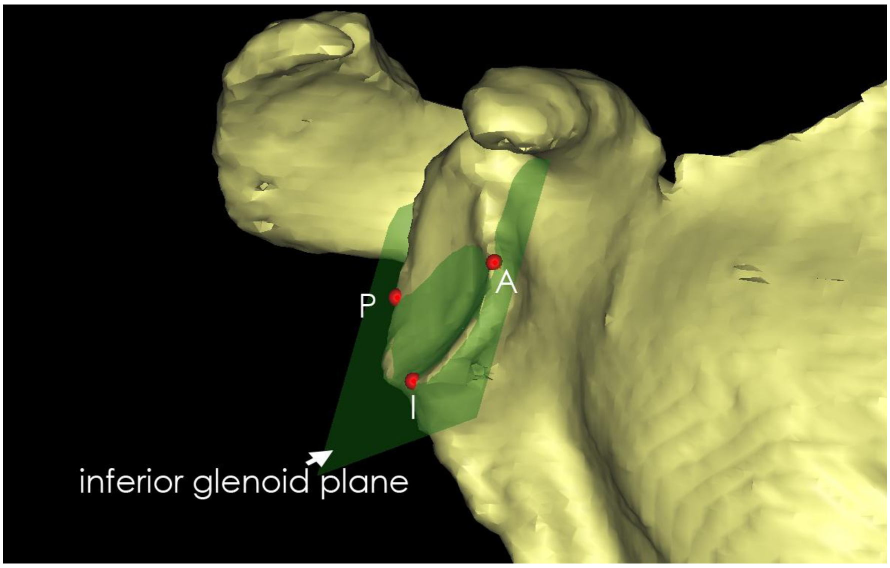

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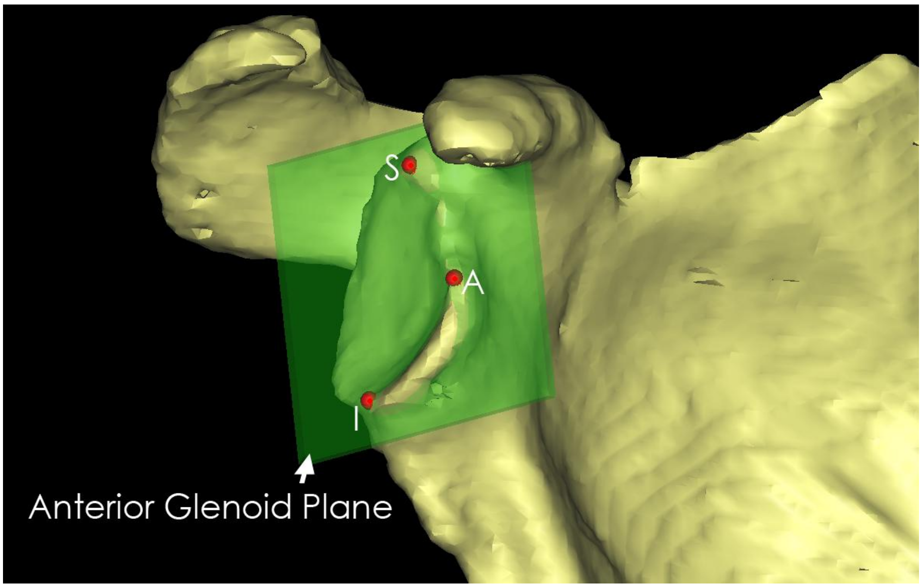

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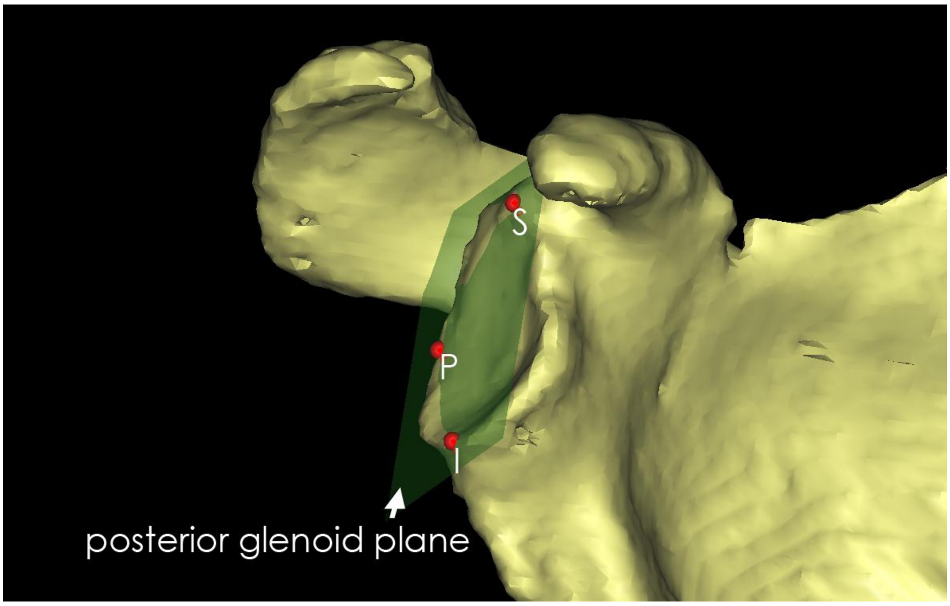

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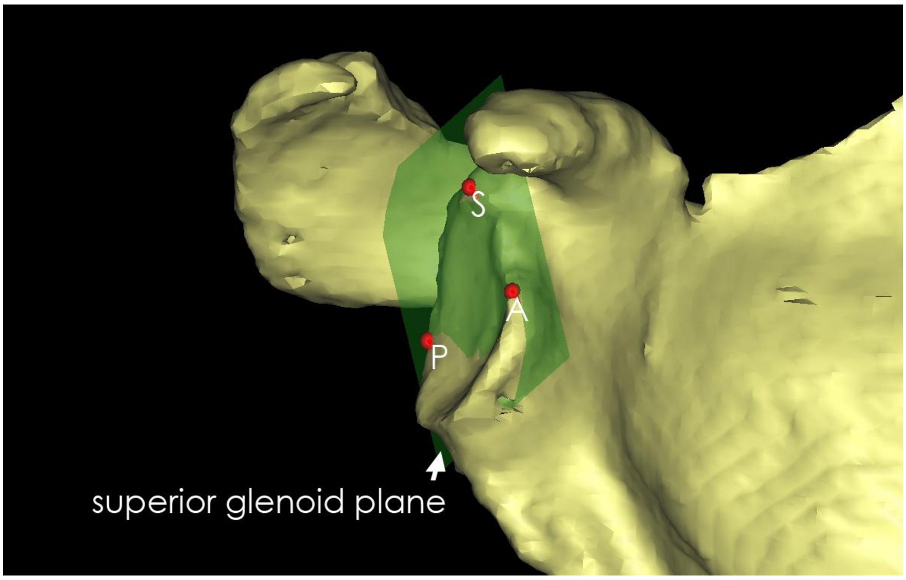

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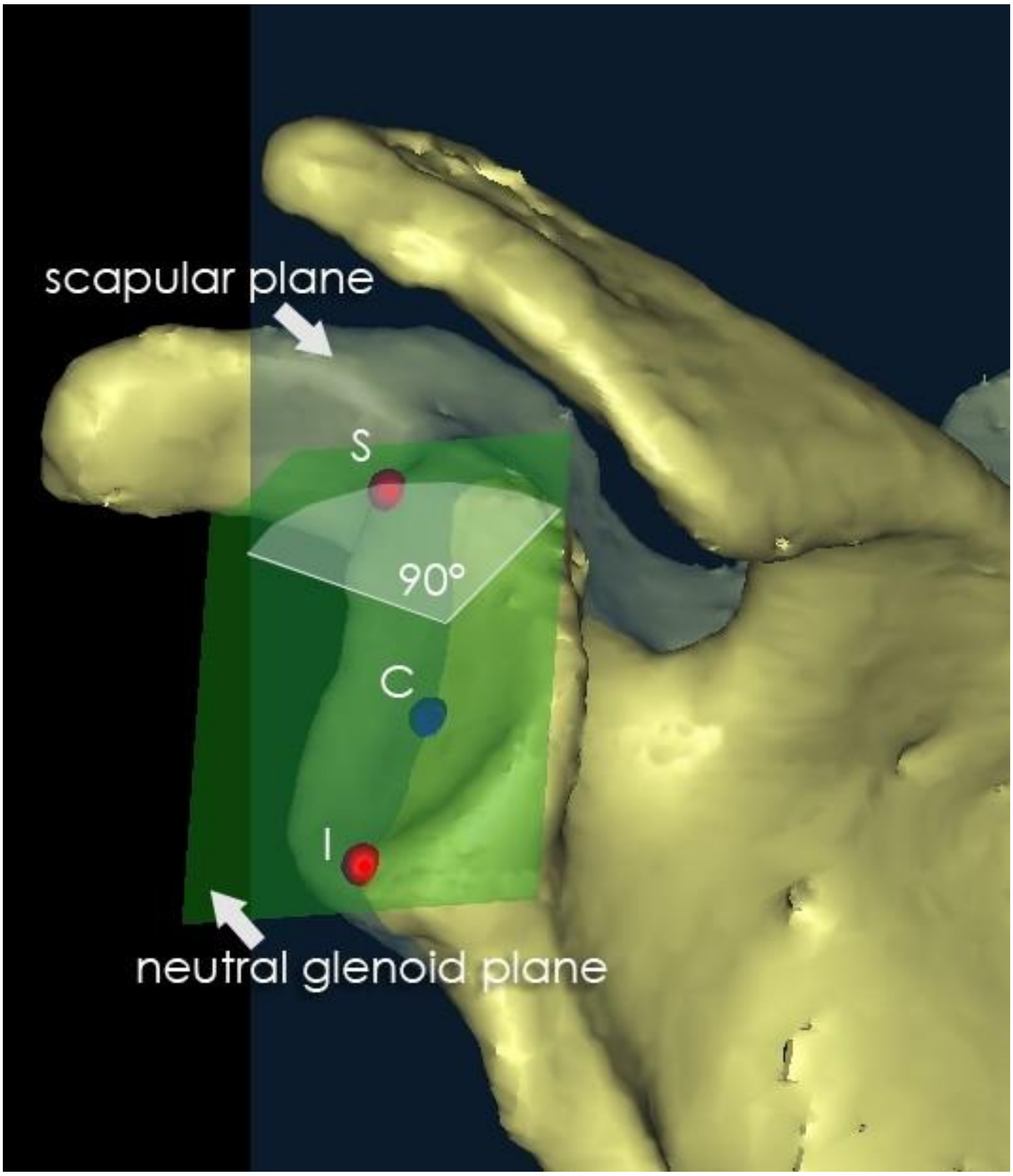

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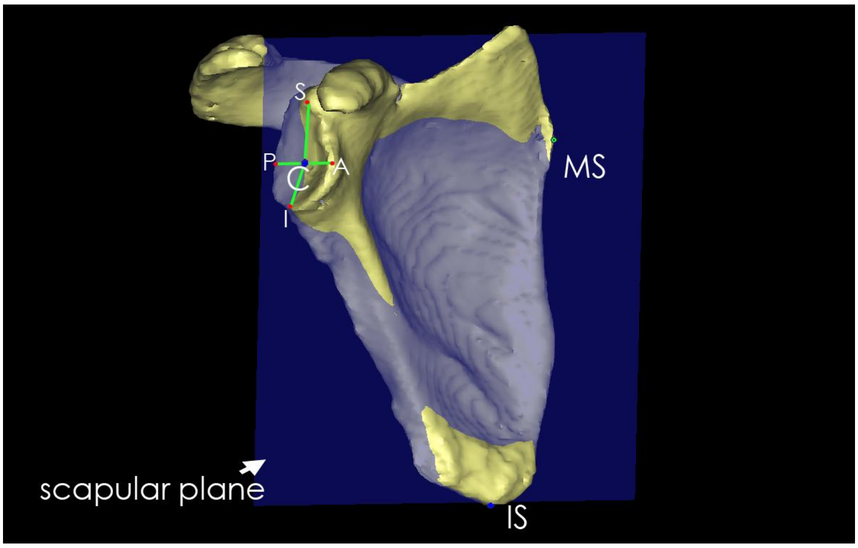

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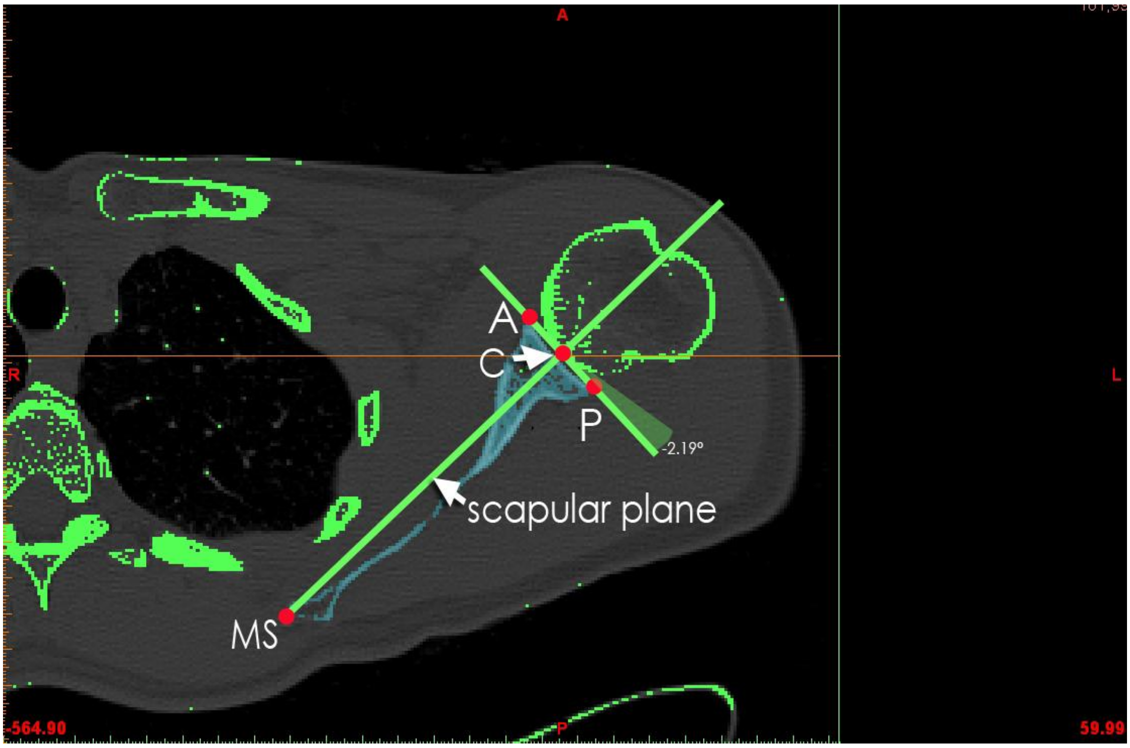

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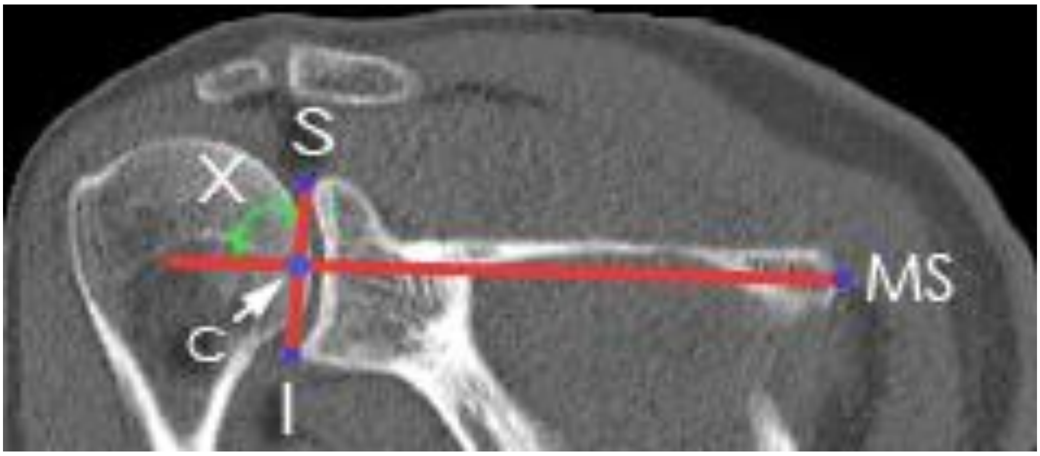

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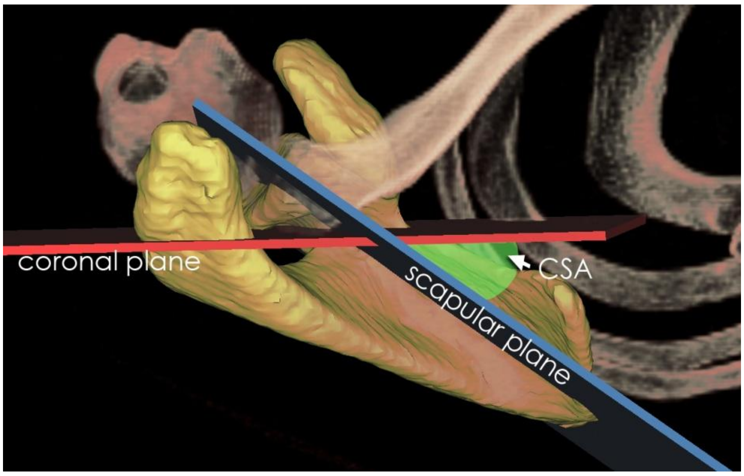
Figure 10 a :



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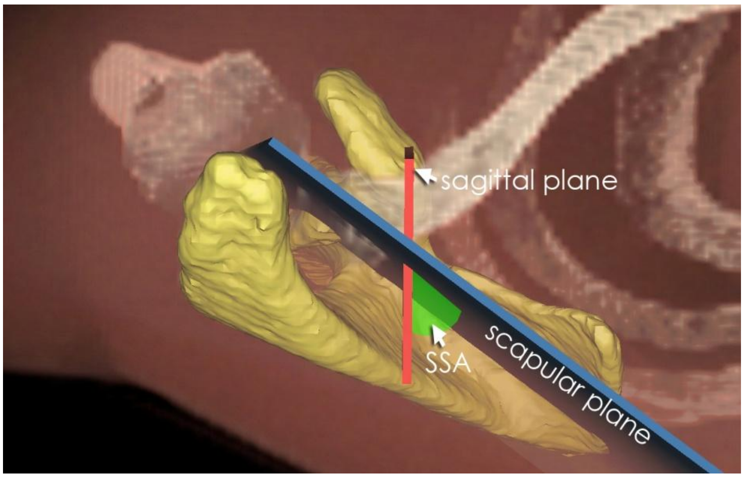

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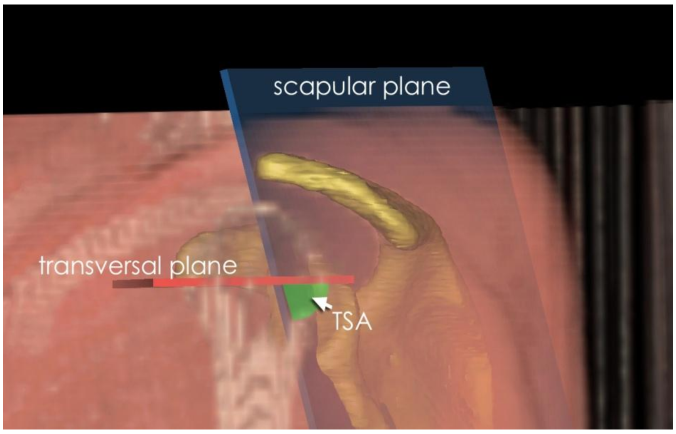

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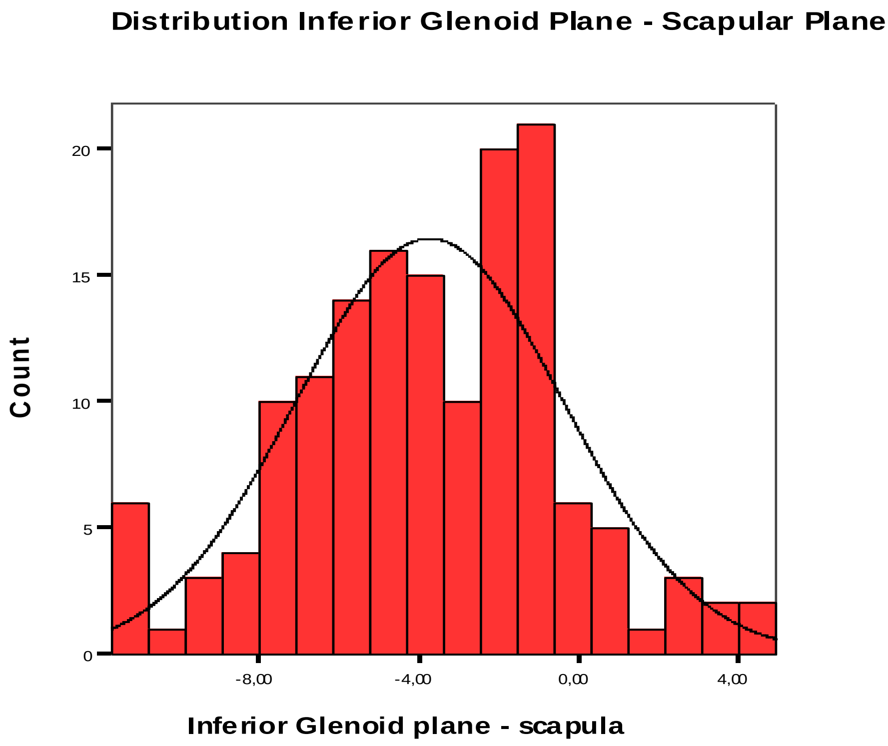

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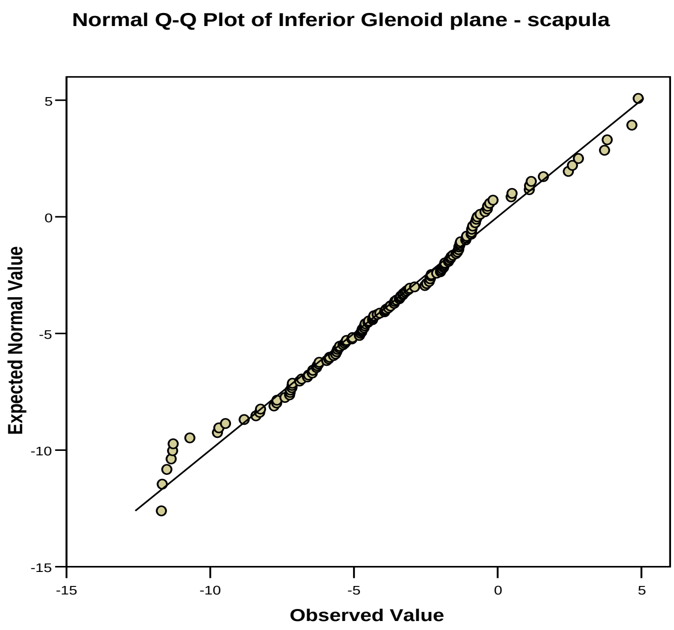

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Table 1 :

Glenoid plane versus scapular plane	N	3-D Version (Degrees) Range	Minimum	Maximum	Mean	Std. Deviation
Anterior	150	28.26	.03	28.29	11.7135	5.88238
Inferior	150	16.59	-11.70	4.89	-3.7641	3.35027
Posterior	150	22.91	-25.38	-2.47	-14.0438	4.60318
Superior	150	24.27	-12.02	12.25	-2.0078	4.41418

Table 2 :

Glenoid plane versus ⊥ scapular plane	N	3-D Inclination (Degrees) Range	Minimum	Maximum	Mean	Std. Deviation
Neutral	150	23.89	1.02	24.91	10.8941	4.45579
Anterior	150	25.59	.00	25.59	9.7711	4.90862
Posterior	150	26.42	.01	26.43	12.1466	4.66731
Inferior	150	31.36	5.97	37.33	21.2241	5.22018
Superior	150	25.36	-8.76	16.60	3.2625	4.80235

Table 3 :

a. Glenoid planes - Transversal plane

	N	Minimum	Maximum	Mean	Std. Deviation
Anterior glenoid vlak - transversaal vlak	150	65,6	90,0	83,054	5,0179
Inferior Glenoid vlak - transversaal vlak	150	50,3	89,7	69,202	7,1800
Posterior glenoid vlak - transversaal vlak	150	55,01	88,97	73,5167	6,90878
Superior glenoid vlak - transversaal vlak	150	69,3	90,0	83,634	4,3615
Gemiddeld glenoid vlak - transversaal	150	63,38	89,94	79,5105	6,20665
Valid N (listwise)	150				

b. Glenoid planes - Sagittal plane

	N	Minimum	Maximum	Mean	Std. Deviation
Anterior glenoid vlak - sagittaal vlak	150	31,44	78,36	54,0653	7,71738
Inferior Glenoid vlak - sagittaal vlak	150	31,7	67,3	48,254	5,8391
Posterior glenoid vlak - sagittaal vlak	150	16,75	62,14	35,3538	6,09866
Superior glenoid vlak - sagittaal vlak	150	23,27	57,88	39,0705	5,70850
Gemiddeld glenoid vlak - sagittaal	150	30,7	61,7	44,904	4,8934
Valid N (listwise)	150				

c . Glenoid planes - Coronal plane

	N	Minimum	Maximum	Mean	Std. Deviation
Anterior glenoid vlak - coronaal vlak	150	13,37	63,72	37,2932	8,00143
Inferior Glenoid vlak - coronaal vlak	150	35,79	64,83	49,8086	5,31474
Posterior glenoid vlak - coronaal vlak	150	28,28	78,97	60,6745	6,52316
Superior glenoid vlak - coronaal vlak	150	32,79	67,46	52,0086	5,84530
Gemiddeld glenoid vlak - coronaal	150	34,75	59,85	47,6495	4,66447
Valid N (listwise)	150				

Table 4 :

Angle of the Scapular plane and the coronal, sagital and transverse plane	N	Range	Minimum	Maximum	Mean	Std. Deviation
CSA	150	21.0	35.4	56.4	44.876	3.9937
SSA	150	40.33	37.72	78.05	54.4645	6.72804
TSA	150	37.97	46.59	84.56	67.6457	7.11497