Assessment of glenoid inclination on routine clinical radiographs and computed tomography examinations of the shoulder

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Abstract: BACKGROUND: Accurate assessment of glenoid inclination is of interest for a variety of conditions and procedures. The purpose of this study was to develop an accurate and reproducible measurement for glenoid inclination on standardized anterior-posterior (AP) radiographs and on computed tomography (CT) images. MATERIALS AND METHODS: Three consistently identifiable angles were defined: Angle by line AB connecting the superior and inferior glenoid tubercle (glenoid fossa) and the line identifying the scapular spine; angle by line AB and the floor of the supraspinatus fossa; angle by line AB and the lateral margin of the scapula. Experimental study: these 3 angles were measured in function of the scapular position to test their resistance to rotation. Conventional AP radiographs and CT scans were acquired in extension/flexion and internal/external rotation in a range up to ±40°. Clinical study: the inter-rater reliability of all angles was assessed on AP radiographs and CT scans of 60 patients (30 with proximal humeral fractures, 30 with osteoarthritis) by 2 independent observers. RESULTS: The experimental study showed that angle and have a resistance to rotation of up to ±20°. The deviation from neutral position was not more than ±10°. The results for the inter-rater reliability analyzed by Bland-Altman plots for the angle fracture group were (mean ± standard deviation) -0.1 ± 4.2 for radiographs and -0.3 ± 3.3 for CT scans; and for the osteoarthritis group were -1.2 ± 3.8 for radiographs and -3.0 ± 3.6 for CT scans. CONCLUSION: Angle is the most reproducible measurement for glenoid inclination on conventional AP radiographs, providing a resistance to positional variability of the scapula and a good inter-rater reliability.

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ABSTRACT

Background

Accurate assessment of glenoid inclination is of interest for a variety of conditions and procedures. The purpose was to develop an accurate and reproducible measurement for glenoid inclination on standardized radiographs and on computed tomography (CT).

Methods

Three consistently identifiable angles were defined: Angle α is defined by a line AB connecting the superior and inferior glenoid tubercle (glenoid fossa) and the line identifying the scapular spine. Angle β is defined by line AB and the floor of the supraspinatus fossa and angle γ is defined by line AB and the lateral margin of the scapula. In the experimental part these angles were measured in function of the scapular position. Conventional radiographs and CT-scans of two dry scapulae were acquired in extension/flexion and internal/external rotation in a range up to ±40°. In the clinical part, the interrater reliability of all angles was assessed on a-p radiographs and CT-scans of 60 patients by two independent observers (30 proximal humeral fractures, 30 cases with osteoarthritis).

Results

The experimental part showed that angle α and β have a good resistance to rotation of the scapula up to ±20°. In the clinical study, interrater reliability analysed by Bland & Altman plots was best for angle β (Values of angle β fracture group: radiographs: mean/SD 74.5°/4.2°; osteoarthritis group: radiographs: 75.5°/3.8°). For the angles α and γ the interrater reliability was unsatisfactory.

Discussion

In conclusion, angle β is a robust and reproducible measurement for the glenoid inclination on conventional radiographs.

Level of Evidence: Basic Science Study

Keywords: glenohumeral joint; measurement glenoid inclination; conventional radiographs, CT-scans; rotator cuff tears; superior humeral head migration; shoulder arthroplasty

INTRODUCTION

The orientation of the glenoid is important for the biomechanics of the glenohumeral joint. The knowledge of the exact orientation of the glenoid is essential for the understanding of various shoulder conditions. An abnormal inclination of the glenoid may be associated with rotator cuff tears[7-9] and superior humeral head migration[5; 15]. Some studies analyze the influence of the glenoid component inclination in shoulder arthroplasty[1; 13; 14]. A valid and reproducible technique for measuring the inclination of the glenoid using routine clinical imaging is, however, not available to our knowledge. There are anatomic studies measuring the inclination of the glenoid directly on the scapular bone[4] or on radiographs[11]. These studies provide exact information on the orientation of the glenoid. These methods for the assessment of the inclination of the glenoid are not routinely applicable in clinical practice because the anatomical references are usually not available on routine imaging.

It was therefore the purpose of this study to develop a robust and reproducible measurement method for glenoid inclination, which can be used on routine images such as standard conventional radiographs, and CT examinations of the shoulder.

MATERIAL AND METHODS

Definition of Anatomic Landmarks and Angles

To assess which parts of the scapula and which anatomic landmarks are consistently available for analysis, 30 radiographs and 30 CT scans of shoulders were reviewed. The following landmarks were consistently detectable on all anterior-posterior (a-p) radiographs and CT-scans of the shoulder and were therefore considered suitable for angle definition: The articular surface of the glenoid fossa, the scapular spine, the floor of the supraspinatus fossa and lateral margin of the scapula. On conventional radiographs, the scapula is visible for a mean distance m_1 of 73mm (SD 20.3 mm; range 39.4 to 104.7 mm) medial to the glenoid (Figure 1). On CT scans the scapula is visible for a mean distance m_2 of 63mm (SD 22.3 mm; range 31.9 to 145.1 mm) medial to the glenoid (Figure 2A).

Figures 1 and 2 show the definition of the angles for glenoid inclination measurement on conventional radiographs and on CT images. The glenoid fossa line is the base line for all angles tested. On conventional radiographs (Figure 1) the glenoid fossa line (AB) is defined as a line connecting the uppermost point (A) and the lowermost point (B) of the glenoid. On CT images (Figure 2A) the glenoid fossa line is defined on the coronal oblique image through the centre of the glenoid connecting the uppermost point (A) and the lowermost point (B) of the glenoid.

Angle α: Angle between the spine of the scapula (a) and glenoid fossa line (AB): On conventional radiographs, line (a) is placed in the upper cortical margin of the spine. Only the part of the spine medial to the glenoid is used, lateral to the glenoid the spine is usually curved (Figure 1). On CT images, the coronal image displaying the largest portion of the spine is selected. Corresponding to conventional radiographs, line (a) is defined by a tangent on the upper cortical margin of the spine, medial to the glenoid (Figure 2B).

Angle β: Angle between the floor of the supraspinatus fossa (b) and the glenoid fossa (AB): On conventional radiographs the floor of the supraspinatus fossa is visible as a sclerotic line (Figure 1, line b). On CT images, the coronal section to the deepest point (Figure 2A) of the supraspinatus fossa is used. Line b is placed along the cortical margin of the floor of the supraspinatus fossa.

Angle γ: Angle between the lateral margin of the scapula (c) and the glenoid fossa (AB). On conventional radiographs line c is placed on the cortical border of the lateral margin of the scapula medial to the neck of the glenoid (Figure 1). On CT images, the coronal sections optimally displaying the lateral margin of the scapula (Figure 2A) are used. Corresponding to the conventional radiographs line c is placed on the cortical border of the lateral margin of the scapula medial to the neck of the glenoid.

Experimental study: Behaviour of the angles in function of the position of the scapula

Two human, left, dry, adult scapulae were used to test the influence of different positioning on the three glenoid inclination angles. A device for fixation of a scapula which allows incremental rotation and flexion and extension of the scapula was built (Figure 3). With this device a human, dry scapula could be rotated in steps of 10° in extension/flexion and in internal/external rotation and in combination. Extension is defined as a rotation in direction of the scapular spine. Flexion refers to a rotation in the direction of the coracoid process. While external rotation or extension is indicated with positive degrees, internal rotation or flexion is marked with negative degrees. The neutral position (0°/0°) was defined as follows (Figure 3): The scapula was fixed in the middle of the margo medialis of the scapula. The scapula was rotated in -10° flexion. The angle (φ) between the scapular spine and the vertical axis is 100° (Figure 1, 3). In neutral position the rotation axis for internal/external rotation goes through the deepest point L of the angulus inferior scapulae.

The scapula position was changed in steps of ±10°, ±20°, ±30°, ±40° extension/flexion or internal/external rotation. The extension/flexion or internal/external rotation was also combined in the positions ±10°/±10°, ±20°/±20°, ±30°/±30°, ±40°/±40°. In each position a conventional radiograph was taken.

CT scans of both dry scapulae were obtained. The dataset of the CT scans were rotated by means of simulation on the workstation. Corresponding to the conventional radiographs the dataset was rotated in steps of 0°, ±5°, ±10°, ±15°, ±20°, ±30°, ±40° extension/flexion and internal/external rotation and standard reconstruction in axial, coronal and sagittal oblique plain. In each position the three angles were measured on the conventional radiographs and on the CT scans.

The calculation of the deviation from the neutral position in percent was used to describe the changes of the glenoid inclination angles in relation to different positions of the scapula during imaging. The mean values were calculated for summarizing the percentage deviation of the two scapulae in each corresponding position. Histograms were used to assess which glenoid inclination angle has the best resistance to rotation: the number of measured angles having a deviation of less than ±10% from the neutral position in a rotation range up to ±20° (extension/flexion or internal/external rotation) were analyzed. 16 different scapula positions from each of the three angles were used for calculating the histograms.

Clinical study: Interrater reliability

In the clinical part of the study the interrater reliability of all three angles was tested. For this purpose conventional radiographs and the corresponding CT examinations of the shoulders in 60 patients were retrospectively evaluated. 30 consecutive patients with osteoarthritis of the glenohumeral joint and 30 patients with proximal humeral fracture were retrospectively collected from our PACS database. Inclusion criteria were standardized conventional radiographs and CT examination in our institution within two years. The patients' age at examination was between 20 and 80 years. Exclusion criteria were previous shoulder surgery, and/or fracture of the glenoid. There were 29 male and 31 female patients with a mean age of 60 years. There were 33 right and 27 left shoulders.

Standardized a-p radiographs of the shoulder which are part of the routine radiographic assessment in patients with shoulder problems were used. The patient was positioned 30 to 45° obliquely in order to obtain radiographs tangential to the articular surface of the glenoid. The beam was angled 20° cranio-caudally and the arm was in zero degrees of abduction and neutrally rotated.

CT examination was performed with the patient supine and the arm in neutral rotation, using a 40 slice multi detector CT (Philips Brilliance 40, Philips Medical Systems, Best, NL). Continuous slices of 0.9mm with a field of view of 150x150mm were obtained. Coronal oblique images perpendicular to the glenoid plane and sagittal oblique images parallel to the glenoid plane were reconstructed.

The analysis was done by two independent shoulder surgeons. The cases with osteoarthritis and proximal humeral fractures were mixed for the analysis. Conventional radiographs and CT scans were examined separately on two different occasions within an interval of four weeks.

Statistical methods

For analyzing the interrater reliability in the clinical part of the investigation Bland & Altman plots[2] were calculated. The differences between the angles pairs are plotted against the mean of the angle pairs measured by the two observers, which allows a graphical analysis of the interrater reliability. The mean of differences and the double standard deviation (SD) of differences are displayed in the same chart. This alludes to the fact that 95% of the differences are less than two SD. The double SD of differences between measurements is defined as the coefficient of repeatability (CR)[2]. It enables to compare different Bland & Altman plots. The comparison of CR makes only sense if the mean of differences is about zero. That means a calculation of the CR is not always useful. Analyzing the distribution of the differences and the range of the average of each angle pair, a statement about the interrater reliability is feasible. The larger the range of the angle, the smaller the SD of difference, combined with a mean of differences about zero, the better is the interrater reliability of the angle.

RESULTS

Experimental study: Behaviour of the angles in function of the position of the scapula

Changes of the glenoid inclination angles on conventional radiographs and CT examinations in relation to the rotational position of the scapula are displayed in Figures 4a and 4b. For angle α and β the deviation from the neutral position does usually not exceed ±10% for both the conventional radiographs and the CT examinations. In both cases angle γ is more susceptible to rotational changes than α and β.

Figure 5 represents the percentage number of glenoid inclination angles with a maximum deviation of ±10% from the neutral position in relation to a rotation of the scapula of up to ±20°. Angle α and β stand out against angle γ. On CT-scans, over 90% of angles α and β are within the range of ±10% of deviation from the neutral position. On radiographs 100% are within that range. On CT scans only 40% of angles γ are within a range of ±10% of deviation from the neutral position and thus, angle γ is most susceptible to rotation.

Clinical study: Interrater reliability

For the interrater reliability, graphical and statistical values are presented: Table 1 shows the mean of interrater differences, SD of differences and, if possible, the coefficient of repeatability (CR) of the Bland & Altman plots. Table 2 gives an overview of the measured angles with mean, SD and maximal/minimal values. In Figure 6 the interrater reliability of chosen angles are graphically presented in Bland & Altman plots: The x-axis shows the average of each angle pair the two surgeons measured. The y-axis shows the differences between each angle pair the two surgeons measured. The mean value of all measured differences and its SD are also shown in the diagram.

In comparison to the other angles, the mean of interrater differences and SD of differences of **angle α** in the fracture group and the osteoarthritis group is high (Table 1).

Therefore, angle α is unsuitable to measure glenoid inclination despite a good resistance to rotation.

Angle γ has a high mean of interrater differences on both conventional radiographs and on CT images with a relatively high SD. However, the angle γ performs slightly better than angle α. Further, the poor interrater reliability of angle α and γ is confirmed through the confidence intervals of the mean value of differences of angle α and γ not including zero (Table 1).

Angle β: On conventional radiographs in the fracture group shows a low mean of interrater differences (-0.1) and a quite low SD (4.2). In the osteoarthritis group, angle β shows a low mean of differences (-1.2) and a low SD of differences (3.8) (Table 1). The Bland & Altman plots of angle β on routine radiographs show that many calculated differences of the measured angels are 5° or less (Figures 6a and 6b). This indicates that angle β in the fracture and osteoarthritis group on radiographs has the best interrater reliability of all tested angles. Angle β in the fracture group on CT scans shows a good result with a mean of differences of -0.3 and a SD of differences of 3.3 (Table 1, Figure 6c). But the small range (19.0) of this angle weakens the good values (Table 2). Angle β on CT-scans in the osteoarthritis group shows an unsatisfactory mean of differences of -3.0 (Table 1). Analyzing the interrater variability on these aspects, angle β on conventional radiographs perform better than CT images. The characteristics of angle β on conventional radiographs in the fracture group calculated on 29 angles show a mean of 74.5 and a 2SD of 15.0 and in osteoarthritis group calculated on 25 angles show a mean of 75.5 and a 2SD of 15.4.

DISCUSSION

Glenoid inclination seems to play an important role in shoulder biomechanics. It is currently assessed radiographically without guidelines for an optimal measurement technique. For clinical purposes, it is not clearly known whether the inclination of the glenoid with respect to the vertical or to the most important muscle vectors or to the rotator cuff and thereby to the rotator cuff is most important. It is certainly a limit of this study that it identifies a measurement option for the inclination of the glenoid with respect to the scapula. This, however, is the currently most utilized method and it appears to be a very reasonable first step to establish a reliable measurement method for assessing at least the inclination of the glenoid with respect to the scapular body and thereby the vectors of the rotator cuff muscles.

Glenoid inclination should be defined by consistently identifiable landmarks. The scapula has a complex geometry which makes the definition of appropriate landmarks challenging. Anatomical structures with high variability such as the acromion cannot be used as references. Several structures such as the medial boarder of the scapula or the inferior scapular angle are often not visible on routine radiographs of the shoulder and can therefore not be used as landmarks to define the glenoid inclination angle. Moreover, the measurement of the glenoid inclination should still be feasible and reproducible in abnormal scapulae. In this study, the angle between the glenoid and the supraspinatus fossa (angle β) satisfactorily fulfilled all requested criteria. The floor of the supraspinatus fossa as a reference line is usually easily identifiable. The advantage of the angle β is demonstrated by its superior resistance to different scapular positioning compared with other angles. The interrater reliability of angle β on conventional radiographs was good and even slightly superior to that on CT scans.

Two studies have demonstrated that an upward-facing glenoid favours superior migration of the humeral head[5; 15]. Superior humeral head migration and upward-facing glenoid is associated with the development of rotator cuff tears[7; 9]. A study based on fresh-frozen full upper extremities examined in a dynamic shoulder testing apparatus found that the downward facing of the glenoid component with irreparable rotator cuff initiates a significant reduction of humeral head migration and the doubling of the abduction angle[9]. On the other hand, in the field of joint replacement angle β may be helpful: The glenoid inclination and the positioning of glenoid components in joint replacement surgery may have an important role for clinical outcome. Studies with biomechanical models and computer simulation showed that a downward facing of the glenoid component in shoulder arthroplasty reduces superior humeral head migration[9], glenoid component tilting[13] and humeral head subluxation[13] and balances supraspinatus deficiency[14]. A downward facing of the glenoid component seems to improve the stability of the glenohumeral joint. With the increasing use of reverse shoulder prosthesis the importance of the positing of the glenoid base has been recognized. In case of erroneous inclination a notching can occur.

This study developed a robust and reproducible measurement for the inclination angle of the glenoid for application on routine clinical radiographs. Preferably it should be possible to assess the inclination of glenoid on routine radiographs without the necessity to use specialized imaging to avoid unnecessary costs and radiation. According to our data, a reliable assessment of the glenoid inclination using angle β on standard radiographs is possible. This is in contrast to the assessment of the glenoid version[3; 6; 10]. The glenoid version cannot be determined accurately on standard axial radiographs[12]. CT is usually necessary. Since it is possible to measure the glenoid inclination angle on standard radiographs, it is also possible to use this measurement during surgery using fluoroscopy or intraoperative radiographs.

CONCLUSION

The purpose of this study was to develop a robust and reproducible measurement method for glenoid inclination, which can be used on routine images such as standard conventional radiographs, and CT examinations of the shoulder. In conclusion, the angle β between the glenoid and the floor of the supraspinatus fossa is the most reproducible measurement for glenoid inclination on conventional radiographs, providing a resistance to positional variability of the scapula and a good interrater reliability.

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FIGURE LEGENDS

Figure 1: Definition of angles on conventional radiographs. The glenoid fossa line (AB) is defined as a line connecting the uppermost point (A) and the lowermost point (B) of the glenoid. **Angle Alpha:** Angle between the spine of the scapula (a) and glenoid fossa line (AB). **Angle Beta:** Angle between the floor of the supraspinatus fossa (b) and the glenoid fossa line (AB). **Angle Gamma:** Angle between the lateral margin of the scapula (c) and the glenoid fossa line (AB). The distance from the medial boarder of the radiograph and the centre of the glenoid fossa line (AB) is m_1. The angle between the scapular spine (a) and the medial border of the radiograph is φ .

Figure 2: Definition of angles and other artificial lines on CT-scans. The glenoid fossa line AB is defined on the coronal oblique image through the centre of the glenoid connecting the uppermost point (A) and the lowermost point (B) of the glenoid. **Angle α:** Angle between the spine of the scapula (a) and glenoid fossa line (AB). The coronal image displaying the largest portion of the spine is selected. Line a is defined by a tangent on the upper cortical margin of the spine, medial to the glenoid (Figure 2B). **Angle β:** Angle between the floor of the supraspinatus fossa (b) and the glenoid fossa line (AB). The coronal section to the deepest point of the supraspinatus fossa is used. Line b is placed along the cortical margin of the floor of the supraspinatus fossa (Figure 2A). **Angle γ:** Angle between the lateral margin of the scapula (c) and the glenoid fossa (AB). The coronal sections which optimally display the lateral margin of the scapula are used (Figure 2B). The distance between the medial boarder of the radiograph and the centre of the glenoid fossa line (AB) is m_2 (Figure 2A).

Figure 3: The rotation device allows movements in flexion/extension, internal/external rotation and combination in steps of 10°. The neutral position of the scapula was determined with radiological examinations of standard a-p radiographs of the shoulder. The angle

between the lengthening of the spina scapula (a) and the vertical axis of the rotation device is Angle φ (100°). The scapula was also tilt about -10° in flexion. The scapula was fixed in the middle of the margo medialis. In neutral position the rotation axis for internal/external rotation goes through the deepest point L of the angulus inferior scapulae.

Figure 4: Percentage of deviation from the neutral position during scapulae rotation in a range up to ±40° of angle α, β, and γ on radiographs and on CT-scans. The x-axis shows the dimensions of rotation in extension or internal rotation in negative degrees and flexion or external rotation in positive degrees. The y-axis shows the average deviation from the neutral position in percent. **Figure 4a**: Percentage deviation for angles on conventional radiographs. **Figure 4b:** Percentage deviation for angles on CT-scans.

Figure 5: The diagram shows the number of angles in percentage having a maximal deviation of ±10% from the neutral position in CT scans as well as on radiographs. 16 angles (=100%) were analysed for each angle α, β, and γ during the rotation process. This resistance analysis of angles α, β,and γ was done in a rotation range up to ±20°. No differentiation between flexion/extension, internal/external rotation or combination was done in the analysis.

Figure 6: The three diagrams show the interrater analysis of angle beta with the help of Bland & Altman plots. The x-axis shows the average of each angle pair the two surgeons measured. The y-axis shows the differences between each angle pair the two surgeons measured. The mean value of all measured differences (Mean) and its SD are also shown in the diagram. **Figure 6a:** Interrater reliability analysis of angle beta in the fracture group on radiographs. **Figure 6b:** Interrater reliability analysis of angle beta in the osteoarthritis group on radiographs. **Figure 6c:** Interrater reliability analysis of angle beta in the fracture group on CT-scans.

Table 1

Interrater reliability analysis by means of Bland&Altman plots

Angles [°]	Fracture group				Osteoarthritis group			
	Mean of differences	SD	CR* ≙ 2SD	N	Mean of differences	SD	CR* ≙ 2SD	N
Alpha X-ray	-6.6 [CI_{95} -9.2 to -4.0]	6.9	-	30	-6.1 [CI_{95} -8.6 to -3.7]	6.3	-	27
Alpha CT	-8.0 [CI_{95} -11.0 to -4.9]	8.1	-	30	-5.2 [CI_{95} -8.9 to -1.5]	9.3	-	27
Beta X-ray	-0.1 [CI_{95} -1.7 to 1.5]	4.2	8.5	29	-1.2 [CI_{95} -2.7 to -0.4]	3.8	7.5	25
Beta CT	-0.3 [CI_{95} -1.6 to 1.0]	3.3	6.7	29	-3.0 [CI_{95} -4.4 to -1.5]	3.6	-	27
Gamma X-ray	-2.0 [CI_{95} -3.8 to -0.2]	4.7	-	30	-0.01 [CI_{95} -3.7 to -3.5]	9.1	18.2	27
Gamma CT	-4.4 [CI_{95} -6.6 to -2.3]	5.7	-	30	-1.0 [CI_{95} -2.9 to -0.9]	4.8	9.6	27

* coefficient of repeatability

Table 2

Mean, SD and range of angles alpha, beta and gamma

Angles [°]	Fracture group						Osteoarthritis group					
	Mean	SD	Max	Min	Max - Min	N	Mean	SD	Max	Min	Max - Min	N
Alpha X-ray	81.0	3.8	86.9	71.0	16.0	30	79.3	6.5	86.2	56.3	29.9	27
Alpha CT	81.6	4.0	88.6	69.7	18.9	30	79.1	6.4	87.4	54.6	32.8	27
Beta X-ray	74.5	7.5	87.9	54.6	33.3	29	75.5	7.7	89.4	59.5	29.9	25
Beta CT	75.9	5.5	84.7	65.7	19.0	29	75.4	7.6	88.9	59.4	29.5	27
Gamma X-ray	44.9	6.8	58.6	23.7	34.9	30	45.7	10.3	65.8	10.0	55.8	27
Gamma CT	55.1	6.7	69.3	41.5	27.8	30	55.0	10.9	73.5	24.9	48.6	27

Figure 1: Definition of angles on conventional radiographs. The glenoid fossa line (AB) is defined as a line connecting the uppermost point (A) and the lowermost point (B) of the glenoid. **Angle Alpha:** Angle between the spine of the scapula (a) and glenoid fossa line (AB). **Angle Beta:** Angle between the floor of the supraspinatus fossa (b) and the glenoid fossa line (AB). **Angle Gamma:** Angle between the lateral margin of the scapula (c) and the glenoid fossa line (AB). The distance from the medial boarder of the radiograph and the centre of the glenoid fossa line (AB) is m_1. The angle between the scapular spine (a) and the medial border of the radiograph is φ .

Figure 2: Definition of angles and other artificial lines on CT-scans. The glenoid fossa line AB is defined on the coronal oblique image through the centre of the glenoid connecting the uppermost point (A) and the lowermost point (B) of the glenoid. **Angle α:** Angle between the spine of the scapula (a) and glenoid fossa line (AB). The coronal image displaying the largest portion of the spine is selected. Line a is defined by a tangent on the upper cortical margin of the spine, medial to the glenoid (Figure 2B). **Angle β:** Angle between the floor of the supraspinatus fossa (b) and the glenoid fossa line (AB). The coronal section to the deepest point of the supraspinatus fossa is used. Line b is placed along the cortical margin of the floor of the supraspinatus fossa (Figure 2A). **Angle γ:** Angle between the lateral margin of the scapula (c) and the glenoid fossa (AB). The coronal sections which optimally display the lateral margin of the scapula are used (Figure 2B). The distance between the medial boarder of the radiograph and the centre of the glenoid fossa line (AB) is m_2 (Figure 2A).

Figure 3: The rotation device allows movements in flexion/extension, internal/external rotation and combination in steps of 10°. The neutral position of the scapula was determined with radiological examinations of standard a-p radiographs of the shoulder. The angle between the lengthening of the spina scapula (a) and the vertical axis of the rotation device is

Angle φ (100°). The scapula was also tilt about -10° in flexion. The scapula was fixed in the middle of the margo medialis. In neutral position the rotation axis for internal/external rotation goes through the deepest point L of the angulus inferior scapulae.

Figure 4: Percentage of deviation from the neutral position during scapulae rotation in a range up to ±40° of angle α, β, and γ on radiographs and on CT-scans. The x-axis shows the dimensions of rotation in extension or internal rotation in negative degrees and flexion or external rotation in positive degrees. The y-axis shows the average deviation from the neutral position in percent. **Figure 4a**: Percentage deviation for angles on conventional radiographs. **Figure 4b:** Percentage deviation for angles on CT-scans.

Figure 5: The diagram shows the number of angles in percentage having a maximal deviation of ±10% from the neutral position in CT scans as well as on radiographs. 16 angles (=100%) were analysed for each angle α, β, and γ during the rotation process. This resistance analysis of angles α, β,and γ was done in a rotation range up to ±20°. No differentiation between flexion/extension, internal/external rotation or combination was done in the analysis.

Figure 6: The three diagrams show the interrater analysis of angle beta with the help of Bland & Altman plots. The x-axis shows the average of each angle pair the two surgeons measured. The y-axis shows the differences between each angle pair the two surgeons measured. The mean value of all measured differences (Mean) and its SD are also shown in the diagram. **Figure 6a:** Interrater reliability analysis of angle beta in the fracture group on radiographs. **Figure 6b:** Interrater reliability analysis of angle beta in the osteoarthritis group on radiographs. **Figure 6c:** Interrater reliability analysis of angle beta in the fracture group on CT-scans.