The Effect of Scapula Tilt and Best-Fit Circle Placement When Measuring Glenoid Bone Loss in Shoulder Instability Patients

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Purpose: To analyze the effect of lack of standardization on the reliability of current measurement techniques for glenoid bone loss in clinical practice. **Methods:** Ten consecutive patients with anterior glenoid bone loss due to recurrent anterior shoulder instability and available computed tomographic (CT) scans of the affected shoulder were included in this study. One hundred seventy 3-dimensional en-face view images of the 10 glenoids with up to 20° degrees of tilt in the anterior, posterior, superior, and inferior direction were rendered. Three independent observers first identified the en-face view images and subsequently performed measurements of the defect surface and diameter as well as the glenoid surface and diameter on all 170 images. Measurements were completed based on the conventional best-fit circle technique using the edge of the visible glenoid bone as reference and additionally based on the so-called spoon technique, which places the best-fit circle on the edge of the visible glenoid concavity. **Results:** The overall agreement regarding en-face view image selection between the observers was 30% (K-alpha = 0.10, 95% confidence interval 0.02-0.22). Tilt of the en-face view in any direction resulted in significant alterations of all 4 measurement parameters as well as the relative defect area and diameter ($P < .05$). The conventional and the spoon techniques rendered significantly different results regarding all 4 measurement parameters as well as the relative defect area ($P < .05$). **Conclusion:** Impreciseness of scapula positioning for creation of an en-face view of the glenoid as well as varying best-fit circle placement significantly alter glenoid defect size measurement results. **Clinical Relevance:** Because the glenoid defect size plays an important role in the choice of treatment for anterior shoulder instability, measurement techniques need to be as precise as possible.

Biomechanical studies have shown the negative effect of increasing degrees of glenoid bone loss on shoulder stability.[1,2] Furthermore, glenoid bone loss is associated with an increased failure rate after soft-tissue stabilization procedures in patients with recurrent anterior shoulder instability.[3,4] However, the threshold value for the critical glenoid defect size is still under debate.[2,5]

To adequately analyze the effect of glenoid bone loss on shoulder stability, it is necessary to accurately and reliably measure the size of the defects. Several different measurement techniques for glenoid bone loss in anterior shoulder instability patients have been proposed.[6-13] Generally, computed tomographic (CT) imaging shows advantages in the evaluation of bony glenoid defects over magnetic resonance (MR) imaging.[14] Although originally only 2-dimensional (2D) CT was available, current measurement techniques use 3-dimensional (3D) reconstructions of the glenoid articular surface to evaluate defects more precisely. A comparison of different measurement techniques showed that 2DCT-based methods render less accurate measurements than 3DCT-based techniques and that surface measurements of the defect prevail over linear measurements in terms of reliability.[15] The Pico Method[9] has been described as the most reliable

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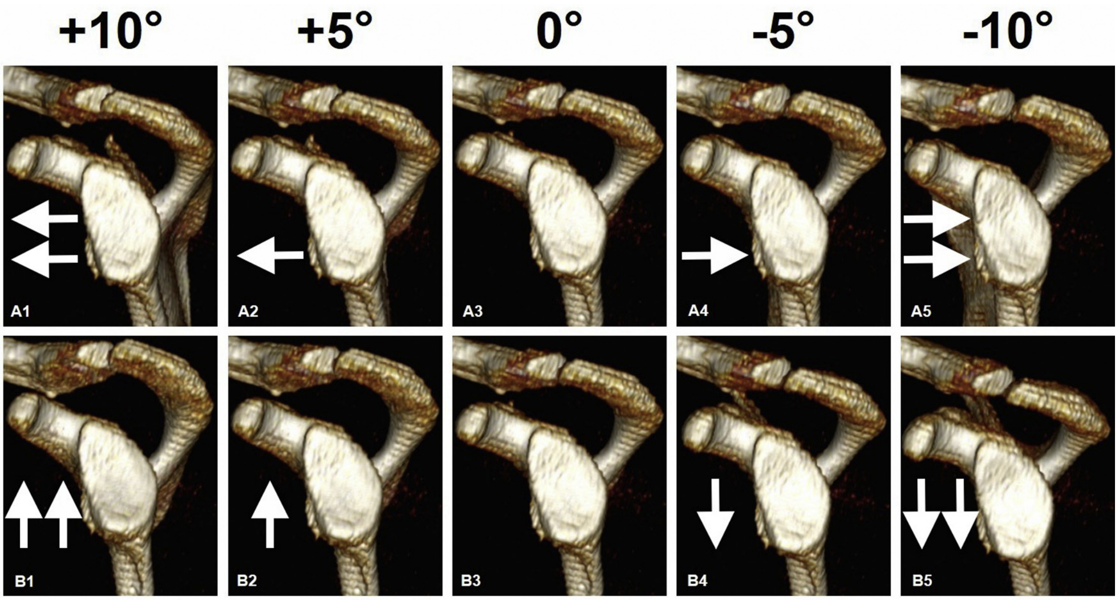

Fig 1. Three-dimensional computed tomographic en-face view images of the same left glenoid with horizontal (A) and vertical (B) variation of the orientation of the scapula (each white arrow indicates a tilt in the according direction by 5°).

measurement technique.[15] It measures the glenoid defect area on the so-called en-face view of a 3DCT scan and relates the defect area to the surface area of a best-fit circle placed on the inferior aspect of the remainder of the articular surface of the glenoid as described by Sugaya.[16] Although this measurement method has been proven reliable in a standardized in vitro setting,[15] there are no data on the performance of the measurement technique in a less-standardized clinical setting. Currently, there is neither a clear definition for the exact positioning of the scapula in the 3DCT images to create an en-face view (Fig 1) nor a guideline whether to place the best-fit circle on the edge of the visible glenoid or on the edge of the visible glenoid concavity (Fig 2). There is reasonable concern that this lack of standardization of currently employed measurement techniques might jeopardize their reliability in determining the exact glenoid defect size, which plays an important role in the choice of treatment for anterior shoulder instability.

The purpose of this study was to analyze the effect of lack of standardization on the reliability of current measurement techniques for glenoid bone loss in clinical practice. The hypothesis of this study was that impreciseness of en-face view orientation and best-fit circle placement have a significant influence on the results obtained using the current gold standard measurement techniques for glenoid bone loss.

Methods

Prior to the beginning of this study, approval of the local ethical committee was obtained. Ten consecutive patients with glenoid bone loss due to recurrent anterior shoulder instability and available CT scans of the affected shoulder collected from February till April 2016 were included in the study. Excluded were all patients with prior surgical intervention (n = 3) or osteoarthritis (n = 1). The selection process was completed by the first author of the study. All CT scans were obtained using a 64-slice CT scanner (Somatom Sensation 64; Siemens, Erlangen, Germany) and were exported to DICOM files with a slice thickness of 1.0 mm using the image-viewing software Impax EE R20 VIII (Agfa HealthCare, Mortsel, Belgium). The exported CT data sets were used to render 3D models of the bony morphology of the scapula using the image processing software OsiriX (Pixmeo, Geneva, Switzerland).

Image Selection

The 3D models of the scapulae were oriented to render a typical en-face view of the glenoid as used in clinical practice for measurement of glenoid defects. This supposed en-face view image was exported along with further images of stepwise increased horizontal rotation by 5°. Three shoulder surgeons with experience in en-face view measurements evaluated the 72 created images and independently chose the image best resembling an en-face view of the glenoid in their opinion as they are used from clinical practice. In the case of diverging individual choices, a consensus was found after a joint discussion. The collectively chosen en-face image was used as a starting point to render further images of stepwise increased vertical rotation by 5°. The 72 rendered images were again evaluated by expert shoulder surgeons who independently picked the image best resembling an en-face view of the

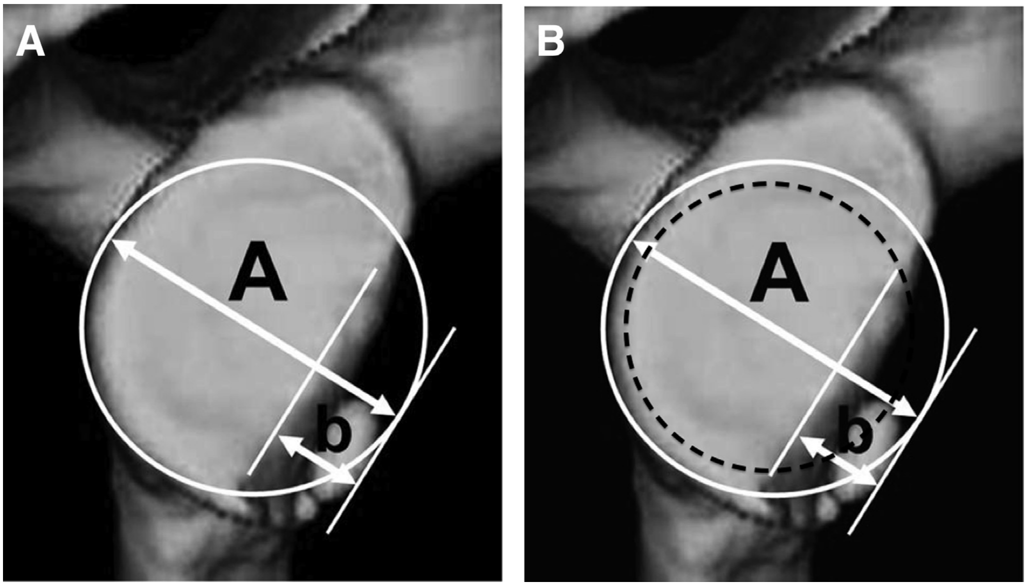

Fig 2. Conventional method (A) and "spoon technique" (B) of best-fit circle placement on a right glenoid according to Sugaya et al.[10] Image reproduced from the *Journal of Bone and Joint Surgery*, with permission from Wolters Kluwer Health.

glenoid. In the case of divergent choices, a consensus was obtained after a joint discussion, and the selected image was defined as the actual en-face view image. Subsequently all 16 images up to 20° of anterior, posterior, superior, or inferior tilt in relation to the defined en-face view image were selected. This selection process was repeated for all 10 patients, resulting in a total of 170 images for further measurement analysis.

Measurement Method

All measurements were independently completed by the 3 observers using the image-processing software OsiriX (Pixmeo, Geneva, Switzerland). On all 170 images, a best-fit circle was placed on the remainder of the intact glenoid as described by Sugaya et al.[16] We called this method the "conventional technique" (Fig 2A). Performed measurements included the surface area of the best-fit circle and the glenoid defect as described by Baudi et al.[9] as well as the diameter of the best-fit circle and the glenoid defect as described by Sugaya et al.[10] The relative glenoid bone loss area was calculated as the ratio between the surface area of the bone defect and the best-fit circle. The relative glenoid bone loss diameter was calculated as the diameter of the defect relative to the diameter of the best-fit circle. All measurements were repeated using the so-called "spoon technique" with a best-fit circle placed on the rim forming the highest points of the glenoid concavity rather than on the outer edge of the glenoid (Fig 2B). A total of 1,360 different measurements were performed by each observer independently.

Statistics

Patient characteristics are presented using descriptive statistics. The categorical agreement between the 3 observers when choosing the en-face view of the glenoid was assessed using the overall percentage agreement (p_o) and the Krippendorff alpha (K-alpha) along with a 95% confidence interval (CI). Normally, K-alpha ranges from 0.0 to 1.0, with 1.0 equating to perfect agreement and 0.0 equating to no agreement. Regarding a recommendation by Landis and Koch,[17] a K-alpha <0.20 resembles slight agreement, 0.21 to 0.40 fair agreement, 0.41 to 0.60 moderate agreement, 0.61 to 0.80 substantial agreement, and >0.81 almost perfect agreement. The intraclass correlation coefficient (ICC) along with a 95% CI was calculated to determine the interobserver reliability. The ICC was calculated for 4 radiologic measurements (best-fit circle area, best-fit circle diameter, glenoid defect area, glenoid defect diameter) for both the conventional technique and the spoon technique. Interobserver reliability results were interpreted using the Landis and Koch recommendations. Next, all values were averaged across the 3 observers and visualized graphically. Data were tested for normal distribution using the Kolmogorov-Smirnov test. All values measured with the conventional technique and with the spoon technique were then compared with either the paired *t* test or the Wilcoxon test. The repeated measures analysis of variance was used to detect differences within both the conventional and the spoon technique. The alpha level was set to 0.05.

Results

This study included 10 patients (1 female, 9 men) with a mean age of 34 ± 17 years (range 16-61 years). There were 4 right shoulders and 6 left shoulders.

The overall percentage agreement regarding en-face image selection between the 3 observers was 30%

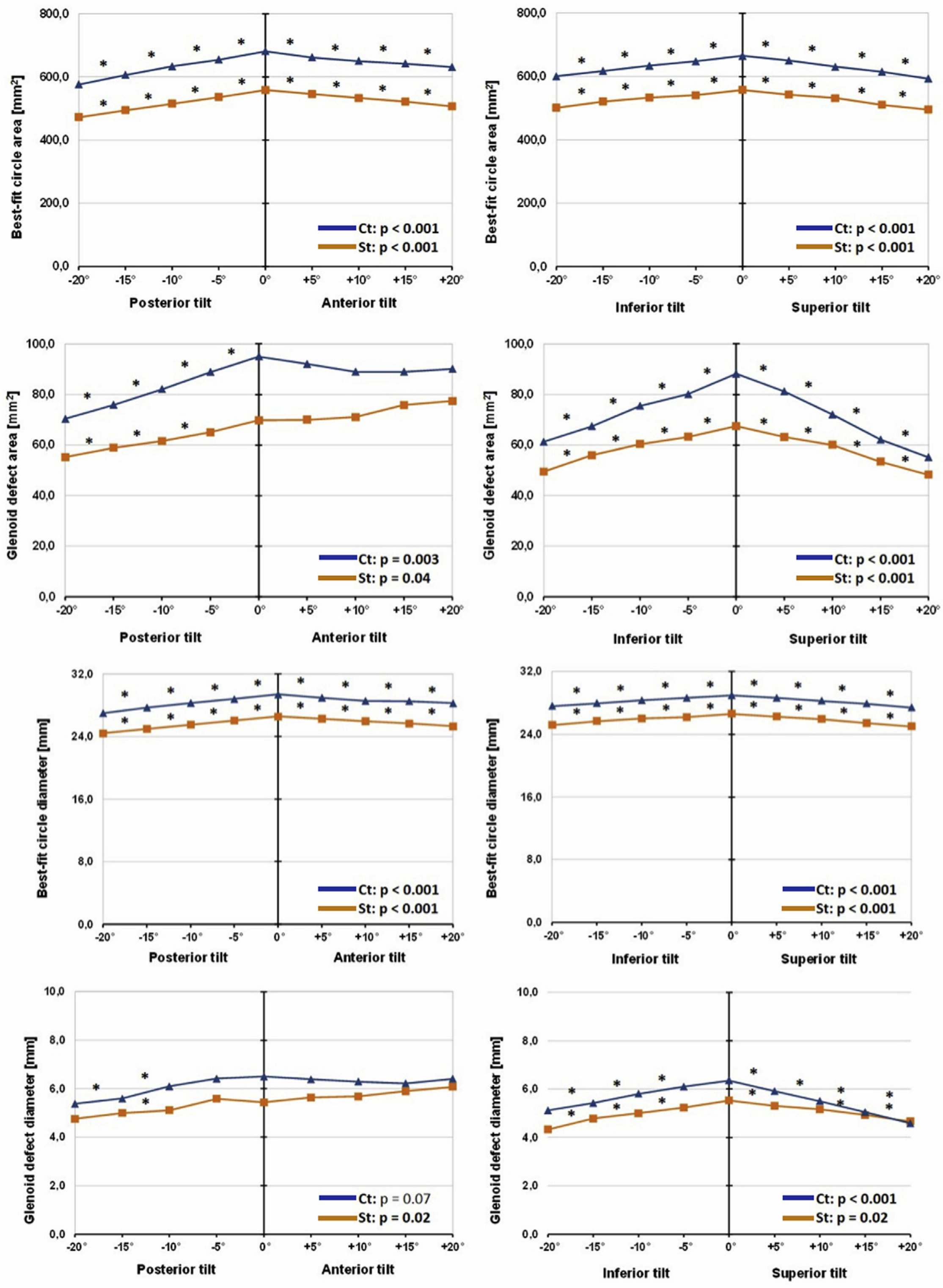

Fig 3. Comparison of the effect of en-face view tilt on the different glenoid bone loss measurement parameters using the conventional best-fit circle technique (blue line and triangles) and the spoon technique (orange line and squares). *Significant difference compared with the en-face view measurement. (Ct, conventional technique; St, spoon technique.)

(6 of 20). The agreement was slightly better within the vertically rotated images (40%; 4 of 10) than within the horizontally rotated images (20%; 2 of 10). Overall, the 3 observers had only slight agreement (K-alpha = 0.10, 95% CI 0.02-0.22). Eleven of the 14 disagreements differed by 1 image being equivalent to 5° of scapula rotation and 3 disagreements by 2 images (10° of rotation).

There was very good interobserver reliability for all radiologic measurements (best-fit circle area, best-fit circle diameter, glenoid defect area, and glenoid defect diameter) with use of the spoon technique (R = 0.86, 95% CI 0.76-0.91; R = 0.86, 95% CI 0.77-0.91; R = 0.84, 95% CI 0.79-0.88; R = 0.91, 95% CI 0.88-0.93). Analysis of measurements using the conventional technique revealed that the interobserver reliability was good for glenoid defect area (R = 0.75, 95% CI 0.64-0.83) and very good for best-fit circle area (R = 0.86, 95% CI 0.81-0.90), best-fit circle diameter (R = 0.85, 95% CI 0.80-0.89), and glenoid defect diameter (R = 0.88, 95% CI 0.80-0.92).

Tilt of the en-face view in any direction resulted in significant alterations of each of the 4 measurement parameters, except for anterior tilt regarding measurements of the glenoid defect (Fig 3). Similarly, the relative defect area and diameter were significantly affected by tilt changes of the en-face view ($P < .001$), especially in the vertical direction (Table 1).

The mean relative glenoid bone loss area measured on the collectively chosen en-face image was 12.7% ± 5.9% (range 7.2%-28.0%) using the spoon technique and 13.9% ± 5.9% (range 7.9%-26.6%) using the conventional technique. The mean relative defect diameter was 20.9% ± 9.4% (range 13.2%-46.8%) using the spoon technique and 22.3% ± 9.3% (range 13.5%-47.6%) using the conventional technique. There was a significant difference between both techniques for the area-based method ($P = .01$) as well as the diameter-based method ($P = .01$) (Table 2).

Discussion

Any tilt from the en-face view tends to result in diminished measured surface area and diameter of the best-fit circle. Although superior, inferior, and posterior tilt similarly tend to decrease the measured surface area and diameter of the defect, anterior tilt does not show this trend apparently because it even further exposes the anteriorly located defect. As a result, superior, inferior, and posterior tilts of the scapula during measurement tend to lead to underestimated defect sizes, whereas anterior tilt can lead to overestimation of defects. Vertical tilt, in particular, seems to have a significant altering effect, even if only as little as 5° of malrotation is present. Even though small amounts of tilt can have a statistically significant effect, they do not necessarily result in large, clinically relevant changes of the different measurement results. The higher the degrees of tilt, the higher the measurement error tends to

Table 1. Effect of En-Face View Tilt on the Relative Defect Area and Diameter Measurement

	−20°	−15°	−10°	−5°	0°	+5°	+10°	+15°	+20°	Overall *P* Value
Relative defect area, %										
Spoon technique										
Horizontal tilt										<.001
Mean	11.7	11.9	12.2	12.5	12.9	13.2	13.7	14.7	15.3	
P value	.17	.17	.31	.48		.22	.09	.02	.03	
Vertical tilt										
Mean	10.2	11.1	11.6	12.1	12.9	12.1	11.7	10.9	10.1	
P value	.01	.03	.07	.07		.04	.01	.01	.01	
Conventional technique										
Horizontal tilt										.001
Mean	12.2	12.6	13.2	13.8	14.1	14.1	13.8	14.0	14.4	
P value	.07	.08	.15	.34		.72	.44	.72	.61	
Vertical tilt										
Mean	10.4	11.1	12.1	12.5	13.5	12.7	11.6	10.3	9.5	
P value	.01	.01	.01	.02		.04	.01	.01	.01	
Relative defect diameter, %										
Spoon technique										
Horizontal tilt										.020
Mean	19.5	20.0	20.2	21.8	20.7	21.8	22.1	23.1	24.0	
P value	.20	.44	.50	.72		.02	.09	.01	.03	
Vertical tilt										
Mean	17.5	19.0	19.5	20.4	21.2	20.6	20.3	19.8	19.1	
P value	.01	.01	.09	.11		.26	.07	.01	.01	
Conventional technique										
Horizontal tilt										.010
Mean	20.0	20.3	21.8	22.5	22.4	22.3	22.2	22.0	22.9	
P value	.14	.06	.77	.68		.84	.88	.80	.44	
Vertical tilt										
Mean	18.9	19.7	20.8	21.6	22.3	21.0	19.8	18.4	17.1	
P value	.01	.01	.07	.28		.01	.01	.01	.01	

Table 2. Comparison Between Both Techniques on the Selected En-Face View

	Conventional Technique	Spoon Technique	*P* Value
Glenoid defect area, mm^2, M ± SD	91.6 ± 28.4	68.6 ± 25.0	<.001
Best-fit circle area, mm^2, M ± SD	673.5 ± 88.9	558.3 ± 73.8	<.001
Relative defect area, %, M ± SD	13.9 ± 5.3	12.7 ± 5.9	.010
Glenoid defect diameter, mm^2, M ± SD	6.4 ± 2.3	5.5 ± 2.1	<.001
Best-fit circle diameter, mm^2, M ± SD	29.2 ± 2.0	26.6 ± 1.8	<.001
Relative defect diameter, %, M ± SD	22.3 ± 9.3	20.9 ± 9.4	.010

M, mean; SD, standard deviation.

be. Therefore, careful selection of the en-face view image is mandatory to ensure measurement validity.

As shown by the agreement analysis, the choice of the correct en-face image differs interindividually even among surgeons experienced in the matter. Moreover, the 3D reconstruction of the CT data is often not performed by the treating surgeon but rather someone else, who makes the 3D reconstruction available as a small selection of 2D image extractions with varying positioning of the 3D scapula model. Thus, the person performing the defect measurements does not necessarily have access to the exact en-face view orientation desired.

Generally, it is very difficult to exactly define the correct en-face view based on anatomic landmarks of the scapula because of interindividual anatomic differences and variations in glenoid version and inclination. Based on the observations made in this study, we recommend defining the correct en-face view as the image that displays the glenoid articular surface with its largest surface extension in the horizontal and vertical planes, because any variation in scapula tilt away from the correct en-face view will result in reduced surface extension. In clinical practice, repeat measurements of the glenoid articular surface size (e.g., width and length) can help to determine the scapula position rendering the largest glenoid articular surface extent and thus the correct en-face view.

Regardless of en-face view tilt, best-fit circle placement can significantly affect the various measurement parameters required to determine glenoid bone loss. On average, the conventional measurement technique rendered 9% higher relative values for the defect area measurement and 7% higher values for the defect diameter measurements than the spoon technique. Because the edge of the concavity is the actual border of the stability-creating part of the glenoid,[2,12] the spoon technique might be the more accurate method to determine biomechanically significant glenoid bone loss. However, this concept is yet to be proven. Nonetheless, our data suggest that a more precise description and standardization of the best-fit circle placement is needed to ensure interstudy comparability and improve measurement reliability in clinical practice in the future.

Limitations

A limitation of this study is that only horizontal and vertical tilt variations of the en-face view were analyzed and not combinations thereof (e.g., 5° superior tilt plus 5° posterior tilt). Although these combined measurements would certainly have been of interest, the number of necessary measurements would have been unbearable for the observers. However, the available data clearly show that the subjective choice of en-face view represents a source of error that needs to be considered. A further matter of discussion is that the average defect size measurement differences are rather small if less than 10° of scapula tilt is present. However, these differences were of high statistical significance and increased with rising degrees of tilt. This clearly indicates that the current measurement techniques are subject to the risk of a systematical error.

Conclusion

Impreciseness of scapula positioning for creation of an en-face view of the glenoid as well as varying best-fit circle placement significantly alter glenoid defect size measurement results.

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