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Anatomic considerations for arthroscopic glenoid reconstruction using iliac crest grafts: a radiologic study

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Background: Arthroscopic glenoid reconstruction using autografts is an advanced procedure that requires experience and preparation. Knowledge about anatomic pitfalls is therefore important to establish well-positioned portals and prevent neurovascular damage.

Methods: We included 43 computed tomography scans from 43 patients. The distance between the tip of the coracoid process and a perpendicular line representing the anteroinferior glenoid was measured. From these results an anteroinferior working portal was designed, and the angulation needed for screw insertion to fixate a hypothetical graft was measured. In a second step, 9 patients underwent magnetic resonance imaging scans 34 ± 10 months after glenoid reconstruction, and the distance between the screw approach path and the neurovascular bundle was measured.

Results: In the analyzed scans, average defect size was 23%, and the coracoid process to the anteroinferior glenoid distance was 32 ± 7 mm. We thus hypothesized that a corridor 20 to 30 mm inferior to the coracoid process would be the ideal position for a working portal. Through this portal, 85% of screws could be applied with 0° to 30° angulation. When the postoperative scans were analyzed, the distance from the neurovascular bundle showed an average of 26 ± 6 mm for the superior screw and 21 ± 5 mm for the inferior screw.

Conclusions: The ideal distance between the coracoid process and an anteroinferior working portal is 32 mm. Having established the portal, instruments should not be inserted pointing in a medial direction of the coracoid process due to the proximity of the neurovascular bundle.

Level of evidence: Anatomy study; Imaging

Keywords: Recurrent anterior shoulder instability; arthroscopy; glenoid reconstruction; arthroscopic portal; neurovascular bundle; coracoid process

No ethical approval was necessary for the retrospective part of our study as declared by §15 of the Code of Medical Ethics of the Medical Association of North Rhine, Germany. The Medical Association of North Rhine ethics committee approved the study protocol concerning the performance of magnetic resonance imaging scans (file number 2016324).

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Recurrent shoulder instability is a complex condition. In cases of large osseous deficits of the glenoid, soft tissue repair is often not sufficient to fully restore shoulder function.[1,10] For these patients, various authors have described options for coracoid or iliac crest bone grafting. Although open procedures were the clinical gold standard for a long time, arthroscopic techniques, such as iliac crest grafting or the arthroscopic Latarjet, as described by

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Lafosse, have gained relevance.[6,7,11-15,17] The superiority of all-arthroscopic procedures has not been demonstrated so far, however. What is more, the shape of glenoid deficits can vary between patients and require individual solutions.

To accurately remodel the shape of the glenoid cavity arthroscopically, surgeons need a straightforward and safe ventral approach to reach the defect and insert the screws into the graft. Previous works have recommended perpendicular screw insertion to achieve adequate compression of the graft to the glenoid,[19] and numerous complications can occur in case of portal misplacement. These include prolongation of procedure in cases of difficult portal placement, graft loosening due to inadequate compression, and even damage to the musculocutaneous nerve.[16]

In this study, we used the parasagittal plane of computed tomography (CT) scans to evaluate the average distance between the tip of the coracoid process and an anteroinferior portal placed with a cannula allowing vertical insertion of screws to fix a bone graft into the center of the anteroinferior glenoid. Surgeons can use this as a practical guideline for daily use in the operating theater. In a second step, we analyzed the axial distance between screws that were placed during surgery and the neurovascular bundle in 9 patients.

Materials and methods

This retrospective cohort study analyzed CT scans of previously treated patients.

Patient cohort

From 2009 to 2016, we treated 65 patients in our unit with recurrent anterior shoulder instability that was caused by a relevant bone loss of the glenoid. This bone loss was treated with all-arthroscopic glenoid reconstruction, as described before.[14] In this procedure, an iliac crest graft is harvested from the pelvis and applied to the anteroinferior glenoid using a tracking suture. This suture enters through the glenoid defect via an anteroinferior working portal and exits into the infraspinatus fossa. This anteroinferior portal is located inferior and lateral of the coracoid tip. This portal is established by placing a cannula into the joint at the inferior aspect or at least inferior third of the subscapularis tendon. Finding the right position often requires several attempts in a trial-and-error fashion. To prevent neurovascular damage, we follow a slalom-like technique as proposed by Resch et al,[16] inserting a blunt trocar perpendicularly to the frontal plane of the body while maintaining contact to the humeral head.

The graft is then connected to the anterior ending of the suture and secured with a stopper knot. After that, it is pulled through an enlarged standard anterior working portal and fixated at the glenoid using 2 titanium or bioresorbable screws.

Of the patients treated, 20 did not receive a CT scan and were excluded from our study. One CT was not available for technical reasons, and the slices in another case were saved in pixels with undefined size, which made it impossible to measure distances. The final data analysis included 43 shoulders of 43 patients.

Radiologic analysis

Once all scans were identified, the data were analyzed at a digital radiologic working station using JiveX Review Client 4.4.5 software (VISUS Technology Transfer GmbH, Bochum, Germany). The scans were performed with a 128-slice CT scanner in head-first position, creating 3-mm slices. The scanned region reached from 1 cm superior to the shoulder to 1 cm inferior to the scapula. During data processing at the day of scan, correction of the parasagittal plane was performed to ensure an en face position independent of glenoid version. Analysis of scans was performed by 1 orthopedic surgeon (B.B.) and then verified by 2 fellowship-level senior surgeons (A.J.V. and W.N.).

The following parameters were measured:

- *Defect size:* The defect size was measured in the parasagittal plane using the surface area method as described before (Figs. 1, *a*, and 2, *a*).[9] The slice with the largest osseous deficit was selected for measurement.
- *Coracoid-to-glenoid distance:* For this parameter, the most posterior point of the glenoid cavity was identified in the parasagittal plane as described by de Wilde et al[5] ("B", Fig. 1, *a*). A line ("d", Fig. 1, *a*) was drawn from B to the opposite of the perfect circle ("A", Fig. 1, *a*), through the center of this circle and the defect. Line d was elongated. Another line was drawn perpendicular to d (Figs. 1, *a*, and 2, *b*). The distance between d and the anterior tip of the coracoid process was called coracoid-to-glenoid (CG) distance. If the tip of the coracoid process was depicted on a more posterior slice than the defect, the tip was marked on this posterior slice manually, and the measurement was then continued on the initial slice depicting the defect.
- *Angulation:* After the CG distance was evaluated, 2 guidelines were drawn parallel to and on each side of line d (Figs. 1, *a* and *b*, and 2, *c*). These guidelines simulate screws inserted perpendicularly to the surface of the graft and were both drawn with a 5-mm distance to line d. Afterwards, we analyzed whether these screws could be inserted through an anteroinferior working portal that was reproduced with 2-cm to 3-cm distance to the coracoid process, based on the results of the CG distance analysis. In a final step, we measured the angulation necessary to insert these screws (Fig. 1, *b*). Angulations were then subgrouped in 0° to 15°, 15° to 30°, 30° to 45°, and more than 45°.

In a next step, the 42 patients who had been treated with this procedure between 2009 and 2015 were invited to a magnetic resonance imaging (MRI) examination. Patients treated between 2015 and 2016 were not invited to MRI scans because exact measurements can be impeded by hematoma and scarring during the first 12 months after surgery. The first 9 patients who agreed to be examined were included and received an MRI scan at our unit. All patients gave written informed consent before MRI scanning.

The MRI scans were performed after a mean follow-up of 34 ± 10 months (range, 19-50 months) after the procedure. A standard 1.5-Tesla MRI scanner was used (Vantage Titan; Toshiba Medical Systems GmbH, Neuss, Germany). The scanned shoulder was positioned in

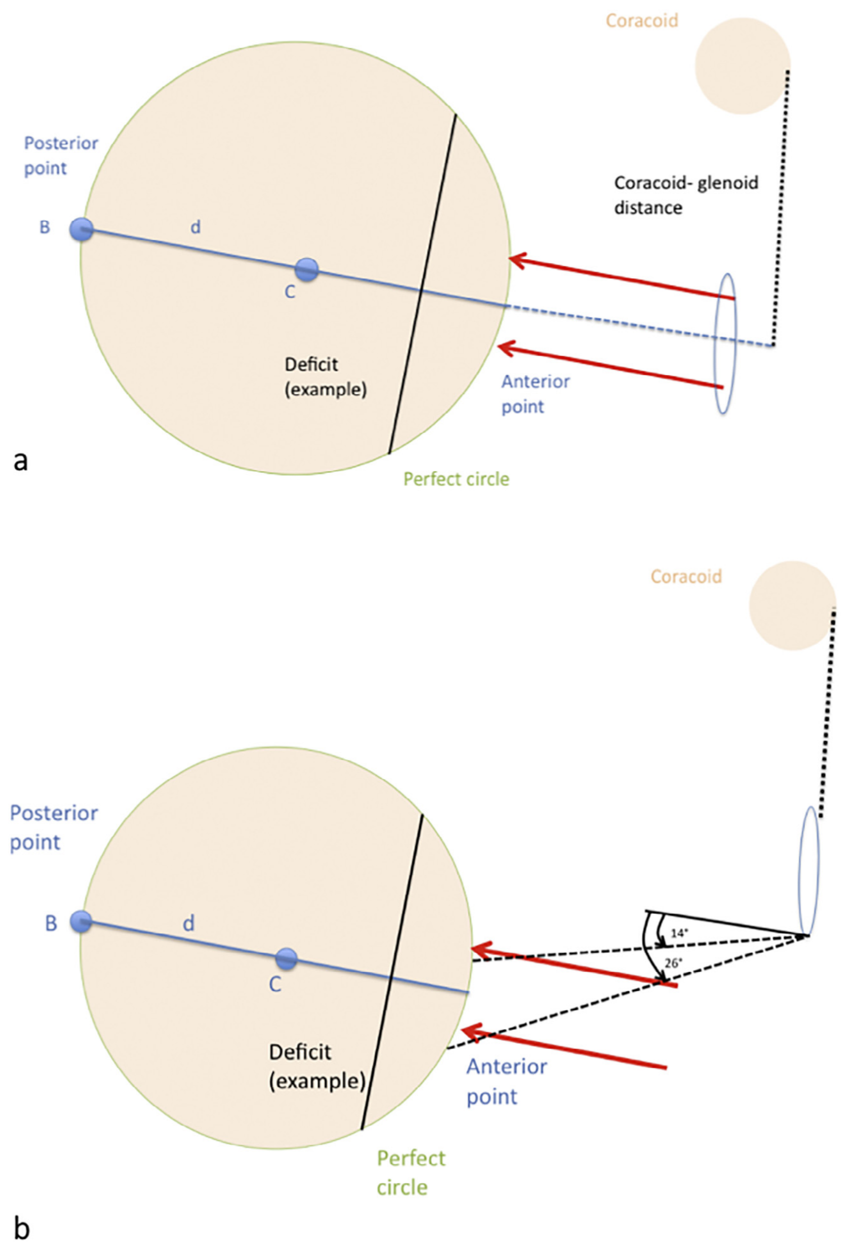

Figure 1 (**a**) Illustration of measurement protocol, including defect size, the coracoid-glenoid distance, and angulation. Two guidelines (*arrows*) were drawn parallel to and on each side of line *d*. These guidelines simulate screws inserted perpendicularly to the surface of the graft, and were both drawn with 5 mm distance to line *d*. (**b**) If 1 or even both screws laid outside the designated portal, the angulation to reach this screw was measured by drawing a line at the inferior edge of the portal parallel to the virtual screws. In a next step, the angle between this line and the entrance point of the respective screw was measured (in this case, 14° and 26°).

neutral rotation in a standard shoulder array coil as recommended by the manufacturer. Fat-saturated T2 sequences were used for the examinations (image size, 210 × 300 mm; slice thickness, 1.5 mm; repetition time, 2016.0 ms; echo time, 30.0 ms). In a final step, coronal, axial, and parasagittal reformats were built.

To evaluate the distance between the superior and inferior screw on the one hand and the neurovascular bundle on the other, we identified both implants in the axial scans, and a straight line was drawn through the screw body, as described by Taverna et al.[18] In a next step, the neurovascular bundle was identified in the same slice as the screw. Then, a perpendicular line was drawn between the line and the neurovascular bundle. This distance was recorded and regarded as the space between the screw insertion corridor and the neurovascular bundle.

Statistics

For data analysis, we used IBM SPSS 22 software (IBM, Armonk, NY, USA). Normal distribution was tested with the Kolmogorov-Smirnov test. Analysis of variance was used to detect differences between the superior and inferior screw distance. A Pearson

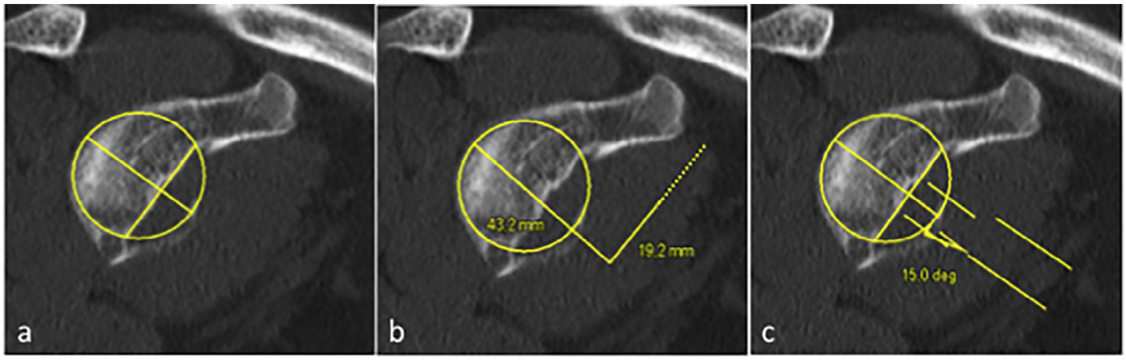

Figure 2 Measurement of (**a**) defect size, (**b**) coracoid-glenoid distance, and (**c**) working portal feasibility on parasagittal computed tomography scans of a right shoulder in a male patient.

correlation analysis was performed to examine the correlation between CG distance and screw distance to the neurovascular bundle.

Results

Of the 43 patients included for CT analysis, 9 (21%) were women and 34 (79%) were men. The average age was 33 ± 11 years. The left shoulder was injured in 17 patients (40%), and the right shoulder was affected in 26 (60%). The averages were 23% (range, 11%-42%) for defect size and 32 mm (range, 22-46 mm) for CG distance. The screw angulations ranged from 0° to 52°. Through our proposed working portal, 61 of the necessary 86 screws (71%) could be applied with an angulation of 0° to 15° (Table I). Including an angulation of 0° to 30°, 85% of screws could be inserted feasibly. Accessibility of the inferior screw was poor in the 2 patients with the highest angulation (50° and 52°). This was caused by a large CG distance (40 mm and 46 mm, respectively), which led to a relatively cranial placement of the working portal.

We performed MRI scans in 6 women and 3 men with an average age of 31 ± 9 years. To fixate the iliac crest graft, titanium screws had been used in 1 patient (3- to 4-mm screws), and all other patients had received bioresorbable screws (3- × 26-mm Bio-Compression screws; Arthrex, Naples, FL, USA). Intraoperative findings included 2 superior labrum anteroposterior lesions, 4 Hill-Sachs lesions (3 on-track, 1 off-track), and 1 patient with loose bodies.

The superior screw showed an average distance to the neurovascular bundle of 26 ± 6 mm, whereas the inferior screw laid 21 ± 5 mm away (Fig. 3). This difference was not statistically significant ($P = .127$). The distance ranged from 16 to 34 mm for the superior screws and 14 to 30 mm for the inferior screws. An increased CG distance correlated with a higher distance to the neurovascular bundle (superior screw: $r = 0.586$, $P = .222$; inferior screw: $r = 0.778$, $P = .069$).

Table I Results for portal feasibility: number of screws that were applied through the working portal with different angulation angles

Angulation needed to insert screw	Number of screws	Percentage of all screws
0°-15°	61	71
15°-30°	12	14
30°-45°	11	13
>45°	2	2

Discussion

Our study was aimed at measuring the ideal distance from the coracoid process to an anteroinferior working portal, which can be used for screw placement in iliac crest bone grafting. Such a portal is often created under needle localization with direct visualization. This method of trial and error could be sped up with the data provided by our study. Because the distance between the coracoid process and anteroinferior glenoid was 32 mm, we concluded that a corridor 2 to 3 cm straight inferior to the coracoid process is the ideal position. The necessary angulation was categorized into 4 different groups with increasing angle. In daily clinical use, angulation of up to 30° is easy to accomplish; in some arthroscopic procedures, far higher degrees of angulation are accepted. Especially anchors used for arthroscopic Bankart repair maintain good mechanical stability when inserted in steep angles, whereas screws for fixation of bone grafts to the glenoid should be applied perpendicularly to achieve good compression.[8,19]

Resch et al[16] examined the average distance from the coracoid process to the intersection of the musculocutaneous nerve with the medial margin of the coracobrachial muscle and found it was more than 5 cm, leading to the conclusion that this nerve is seldom at risk when establishing an anterior portal for Bankart repair. In 4 patients, however, the distance was less than 3 cm, which should be considered critical regarding the abovementioned results of this work.

In a second work, De Simoni et al[4] described the technique of establishing a 5:30 o'clock portal for Bankart repair measuring 8 cm to 10 cm distance from the tip of the coracoid portal. The distance to the axillary nerve measured 1.5 cm to 5 cm, whereas the anterior humeral circumflex artery ran 0.5 cm to 2.5 cm afar, showing a higher risk for damage than the nerve. A blunt rod was recommended to establish the working portal. Other works confirmed these results.[2,20]

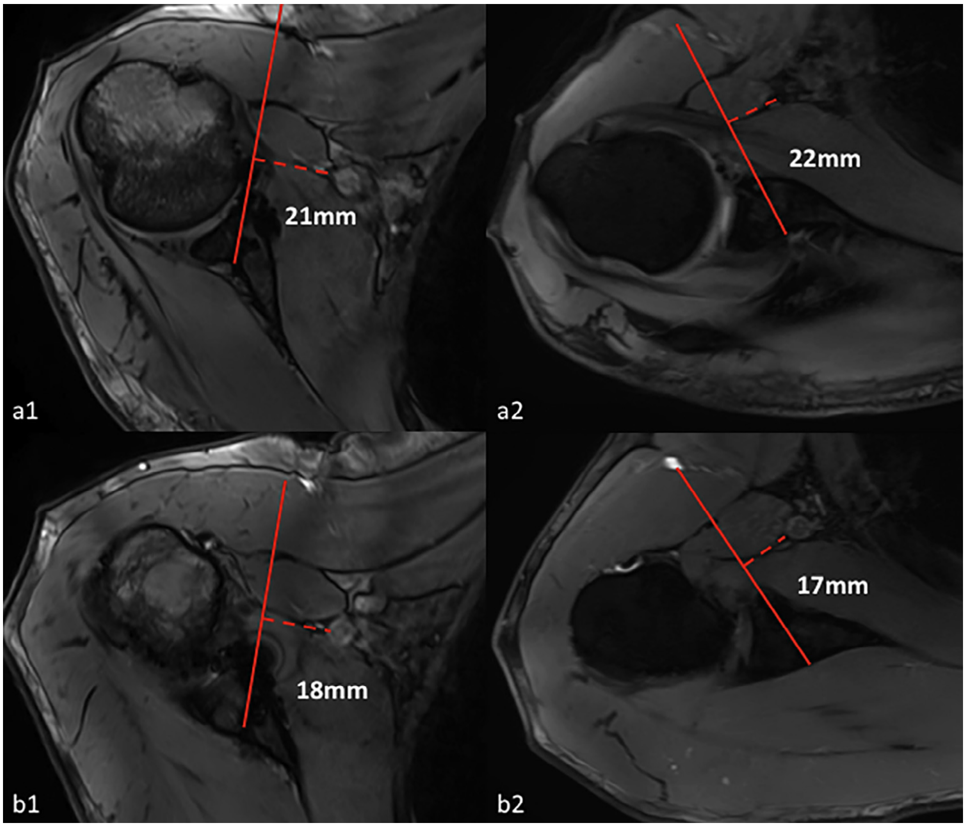

Figure 3 Distance to the neurovascular bundle in right shoulder of a 29-year-old man for the (**a1**) superior and (**b1**) inferior screw. Similar relationships can be found in the right shoulder of a 26-year-old woman (**a2**: superior, **b2**: inferior).

In our unit, glenoid reconstruction is performed with an iliac crest graft via the rotator interval using an anterior and an anteroinferior portal, as described above. So far, no effects on the axillary or musculocutaneous nerve have been observed. Taking the above-mentioned results into consideration, the latter one should be placed 1 to 2 cm lateral and 2 to 3 cm inferior of the coracoid process. When instruments are inserted through this portal, special attention should be given to the close anatomic relationships with the neurovascular bundle, as shown by our MRI scans. In cases of increased CG distance, a larger gap to the neurovascular bundle can be expected; however, this might simply be caused by a generally increased body size of the patients.

We were able to reproduce these findings in situ and find it a helpful tool. When doing so, the variability of the anatomy of the coracoid process should be taken into account, which has been described in previous studies.[3,21] Moreover, skin elasticity allows correction of the entrance point with less angulation.

This study has some limitations. First, the CG distance was measured using a line from the posterior aspect of the glenoid. In some of the scans, this posterior aspect cannot be identified as a single spot, but rather as a corridor. This creates a relevant bias in the retest reliability.

Second, a higher number of patients would have increased the accuracy of our data. A group of 9 patients allows only limited conclusions concerning the safe area in the axial plane.

Third, the shape of the coracoid tip differs significantly between patients. This leads to different measurement results for the CG distance. When using our results in daily clinical life, this should be kept in mind.

Finally, all measurements were performed on 2-dimensional images. Three-dimensional imaging would have been more precise, especially when analyzing the distance between the entry path of the screw and the neurovascular bundle.

In summary, our analysis provides valuable insight on how to measure the approximate distance between the coracoid process and an anteroinferior portal as well as on how to evaluate the distance to the neurovascular bundle during arthroscopic glenoid reconstruction.

Conclusion

The ideal distance between the coracoid process and an anteroinferior working portal is 32 mm. After having established the portal, instruments should never be inserted pointing in the medial direction of the coracoid process due to the close relationship to the neurovascular bundle.

Disclaimer

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