

# A guideline for screw fixation of coracoid process base fracture by 3D technology

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## Research article

**Keywords:** Coracoid process base, Axial perspective, Digital measurement, Screw fixation

**Posted Date:** December 23rd, 2020

**DOI:** <https://doi.org/10.21203/rs.3.rs-132352/v1>

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**Version of Record:** A version of this preprint was published on January 14th, 2021. See the published version at <https://doi.org/10.1186/s13018-021-02203-0>.

# Abstract

## Background

Fractures of the base of the coracoid process are relatively rare, but an increasing number of studies have reported using screws to fix basal coracoid process fractures. This study was performed to simulate the surgical procedure and obtain the ideal diameter, length, insertion point and angle of the screw through the method of 3-D axial perspective in Chinese patients.

## Methods

We randomly collected the right scapula computed tomography (CT) scans of 100 adults. DICOM-formatted CT-scan images were imported into Mimics software. The 3D digital model of the right scapula was established. Two virtual cylinders representing two screws were placed from the top of the coracoid process to the neck of the scapula and across the base of the coracoid process to fix the basal coracoid process. The largest secure diameters and lengths of the virtual screws were measured. The positions of the insertion points and the directions of the screws were also researched.

## Results

The screw insertion safe zone can exhibit an irregular fusiform shape from the reconstructed scapula model. The mean maximum diameters of the medial and lateral screws were  $7.08 \pm 1.19$  mm and  $7.34 \pm 1.11$  mm, respectively. The mean maximum lengths of the medial and lateral screws were  $43.11 \pm 6.31$  mm and  $48.16 \pm 6.94$  mm, respectively. The screw insertion corridor with a diameter of at least 4.5 mm was found in anyone. We found gender-dependent differences for the mean maximum diameters and the maximum lengths of the two screws. The positions of the two insertion points were statistically significant in different genders.

## Conclusions

The study provides a valuable guideline for the largest secure corridor of two screws that fixed the fracture at the base of the coracoid process. For the ideal screw placement, we suggest an individual preoperative 3D reconstruction simulation. Further biomechanical studies are needed to verify the function of the screws.

## Background

Fractures of the coracoid process base are rare, and current treatment guidelines remain unclear[1]. Ogawa et al have proposed a classification system for coracoid fractures based on the relationship between the fracture site and the coracoclavicular ligament. Type I fractures are located behind the CC ligaments, whereas type II fractures are anterior to it. They considered that Type-I fractures indeed need operation whenever the scapuloclavicular connection have been destroyed[2]. This is consistent with many reports in the literature[1–12, 22]. Within these injuries, a fracture of the coracoid process base

represents a severe form of the injury, and a variety of classifications have stressed the importance of recognition of this subtype. The definitive fixation for the fracture of the coracoid process base is done with 1 to 2 bicortical solid screws  $\pm$  washers[2, 4–9, 11, 12, 19]. W. Hill et al believed that the second screw may be used to supplement the single screw and has the benefit of controlling rotation of the fracture thus enhancing fixation against traction and rotational forces of the upper extremity. The coracoid process is in close proximity to major neurovascular structures, consisting of the brachial plexus and the axillary artery and vein[13]. A knowledge of the correct location of the insertion point and screw direction is essential to avoid penetrating into joint and injury to neurovascular structures. In addition, the complex anatomy of the coracoid process and the ligaments and muscles attached to it make screw placement more difficult. Bhatia et al described percutaneous coracoid base fixation using orthogonal biplanar fluoroscopic guidance techniques. Nevertheless, they noted that theoretical complications such as articular perforation, neurovascular injury and damage to coracoclavicular ligaments may emerge even when performed by an experienced shoulder surgeon[12]. Yoshiteru Kawasaki reported a new screw fixation technique for coracoid base fracture under fluoroscopic guidance and counted anatomic information on the cross-sectional size of the coracoid base obtained in a computed tomography (CT) study[7].

W. Hill et al described that if the fracture is not comminuted and occurs through the base, then a 3.5-mm lag screw is often needed for adequate stability. They used a screw length between 30 and 45 mm with 15 medial angulation and 30–40 posterior angulation to ensure that the screw remains enclosed in the bone[6]. Many reports also show their fixation and good postoperative outcomes. Although some methods of open, mini-open, and percutaneous techniques under fluoroscopic guidance have been reported previously [2, 4–9, 11, 12, 21], screw insertion into the neck of the scapula across the fracture of coracoid base is difficult due to the complex shape of the scapula [14, 15].

At present, there are many studies on the application of CT data into various software for the fixation of screws in treatment of different fractures [16, 17, 18]. In previous studies, only Length of the long and short axes at the thinnest part of the coracoid base in the axial CT plane was measured[7]. The purpose of the study is to specify the ideal insertion points, the largest secure diameters and lengths, and the accurate angles of the two screws through the method of axial perspective.

## Materials And Methods

We retrospectively collected the right scapula CT scans of 100 adults who had undergone continuous slice CT scanning at the imaging research center of our hospital between August 2018 and July 2020. Patients were excluded if they had scapula fractures, tumors or severe deformities. This study was approved by the Institutional Review Board of our hospital, and patients' informed consent was obtained. The mean age of the patients on whom the models were based was  $47.96 \pm 16.12$  years (range 18–85 years).

DICOM-formatted CT-scan images of each patient were imported into Mimics software (21.0; Materialise, Leuven, Belgium). We removed the soft tissue by the function of image segmentation, region growth and multiple slice editing, respectively. A total of 100 right virtual scapula models were created.

We reduced the transparency of the right scapula models and turned it to the axial perspective view, which was parallel to the cross section of the base of the coracoid process from top to bottom (Fig. 1A). We observed and adjusted the position of the model to find the largest translucent area through the perspective view. Then, a translucent area like an irregular fusiform shape was seen clearly and divided into two basically equal parts to implant two screws (Fig. 1B). The red outline represents the top boundary of the horizontal part of the coracoid process, and the blue outline represents the boundary of the cross section of the base of the coracoid process. The green and orange areas represented the two screw paths, respectively. Two virtual cylinders representing the screws were placed into the translucent area. The diameter was increased progressively and the maximum diameter was defined when the cylinder did not penetrate the border of the area (Fig. 1C). We observed and adjusted the length of the screw to make sure that the screw just penetrated the posterior cortical bone (Fig. 2A-C). The diameters and lengths of the virtual screws were measured. In order to confirm the position of screw, the distances from the insertion point to the closest point of coracoid and the posterior border line of the horizontal part of coracoid were measured, respectively. They were recorded as Distance L1, L2 for medial screw (MS) and L3, L4 for the lateral screw (LS) (Fig. 3). The slope of the upper edge of the posterior coracoid process was selected as the reference plane called plane1. The anterior inclination angle between the screw and plane1 was measured and recorded as angle  $\alpha$  (Fig. 4A). In addition, we defined another reference plane perpendicular to plane1 called plane2. The medial inclination angle between the screw and plane2 was also measured and recorded as angle  $\beta$  (Fig. 4B).

The collected data were analyzed by SPSS 25.0 statistical software. The experimental data are represented as the mean  $\pm$  SD. T tests were used to compare the data. Statistical significance was accepted at  $p < 0.05$ .

## Results

The study subjects included 50 males and 50 females aged between 18 and 85 years old, with a mean age of  $47.96 \pm 16.12$  years. As shown in Fig. 1-B, the screw insertion safe zone can exhibit an irregular fusiform shape from the reconstructed scapula model.

As shown in Tables 1 and 2, the mean maximum diameters of the medial and lateral screws were  $7.08 \pm 1.19$  mm and  $7.34 \pm 1.11$  mm, respectively. The mean maximum lengths of the medial and lateral screws were  $43.11 \pm 6.31$  mm and  $48.16 \pm 6.94$  mm, respectively. The mean distance L1 was  $11.63 \pm 2.87$  mm, L2 was  $7.50 \pm 1.72$  mm, L3 was  $19.87 \pm 2.76$  mm, and L4 was  $4.88 \pm 0.86$  mm, respectively. For the data captured above, the intersex difference was significant ( $P < 0.05$ ).

Table 1

Comparison between different genders: Diameters of medial screws, Lengths of medial screws, L1 and L2.

Group	Diameter <sup>#</sup> (mm)	Length <sup>#</sup> (mm)	L1 <sup>#</sup> (mm)	L2 <sup>#</sup> (mm)
All(n = 100)	7.08 ± 1.19	43.11 ± 6.31	11.63 ± 2.87	7.50 ± 1.72
Male(n = 50)	7.89 ± 0.98	47.62 ± 4.29	12.36 ± 2.70	8.21 ± 1.68
Female(n = 50)	6.27 ± 0.76	38.60 ± 4.54	10.89 ± 2.87	6.80 ± 1.45
t value*	9.237	10.207	2.629	4.475
P value*	0.00	0.00	0.01	0.00
Note:* t and P are the results of gender comparisons. <sup>#</sup> For the Diameter, Length,the distance of L1 and L2, intersex difference was significant (P < 0.05).				

Table 2

Comparison between different genders: Diameters of lateral screws, Lengths of lateral screws, L3 and L4.

Group	Diameter <sup>#</sup> (mm)	Length <sup>#</sup> (mm)	L3 <sup>#</sup> (mm)	L4 <sup>#</sup> (mm)
All(n = 100)	7.34 ± 1.11	48.16 ± 6.94	19.87 ± 2.76	4.88 ± 0.86
Male(n = 50)	8.06 ± 0.81	52.81 ± 5.40	21.08 ± 2.51	5.06 ± 0.70
Female(n = 50)	6.61 ± 0.87	43.52 ± 4.91	18.66 ± 2.47	4.69 ± 0.96
t value*	8.655	8.997	4.856	2.181
P value*	0.00	0.00	0.00	0.03
Note:* t and P are the results of gender comparisons. <sup>#</sup> For the Diameter, Length,the distance of L3 and L4, intersex difference was significant (P < 0.05).				

The mean angle  $\alpha$  and  $\beta$  of different genders were also recorded in Table 3. The former was  $16.40^\circ \pm 6.03^\circ$  and the latter was  $10.33^\circ \pm 7.39^\circ$ . The results of the angle  $\beta$  were statistically significant between males and females ( $P < 0.05$ ). However, the angle  $\alpha$  were not statistically significant ( $P > 0.05$ ).

Table 3  
Comparison between different genders: Angle  $\alpha$  and  $\beta$ .

Group	$\alpha$ (°)	$\beta$ (°)#
All(n = 100)	16.40 ± 6.03	10.33 ± 7.39
male(n = 50)	16.58 ± 5.78	8.39 ± 6.65
female(n = 50)	16.21 ± 6.33	12.26 ± 7.64
t value*	0.304	-2.696
P value*	0.762	.008
Note:* t and P are the results of gender comparisons. #For the angle $\beta$ , intersex difference was significant (P < 0.05)		

The screw insertion corridor with a diameter of at least 4.5 mm was found in everyone in our research.

## Discussion

In 1996, Ogawa et al believes that a type 1 coracoid fracture would be more unstable and require an open reduction and internal fixation. They fixed unstable fractures of the coracoid base with a malleolar screw and washer[2]. W. Hill et al described in detail the technique and clinical experience of screw fixation for fracture of coracoid base. The difference with Ogawa is that another screw may be used to supplement the single screw and has the benefit of offering rotational control of the fracture thus enhancing fixation against traction and rotational forces of the upper extremity[6]. We share this view that the common fixation methods for coracoid base fractures are to pass two parallel screws vertically through the fracture line. He provided detailed surgical approaches and nail placement angles, but the exact point of entry is not given. The Angle and diameter and length of the screw will change with different entry points.

Many anatomic and radiographic measurements of the coracoid process have been reported[14,15,20,23]. Yoshiteru Kawasaki et al reported the cross-sectional size at the level of the coracoid base by the study on CT axial measurement of the coracoid base[7]. The measurement data on the coracoid base may be useful for safety screw fixation of coracoid base fracture.

The coracoid process is complex in structure and varies from person to person[14,15]. Previous reports did not give a large number of patients whose coracoid base fracture requires screw fixation with their own entry points and angles, as well as screw lengths and diameters statistics. There are few digital anatomical studies on its properties.

Mimics software has been widely used in 3D reconstruction for the development of digital orthopedics technology. In our study, we applied the 3D method of axial perspective as described in previous studies [16,17,18]. We observed and adjusted the position of the model to find the largest translucent area through the perspective view. Then, the translucent area like an irregular fusiform shape was divided into

two basically equal parts to implant two screws. We increased the diameters of two virtual screws progressively and monitored the virtual screws in the views of coronal plane, sagittal plane and horizontal plane, without violating the cortices and articular surface. The method used in our study not only saves manpower, materials and financial resources, but also can be repeated and verified by test results with high reliability.

In our research, we recorded the exact points of entry. And the distances from two screw insertion points to the closest point of coracoid and the vertical distances from two screw insertion points to the posterior border line of the horizontal part of coracoid were all observed in this study. There are significant gender differences. For the data captured above, this is due to the obvious anatomic differences in scapula bones between female and male.

Many screws with a diameter of 3.5mm or 4.5mm have been reported for fixation of coracoid process base fractures[2,4-9,11,12]. According to the information in our study, the maximum diameter to avoid cortical breaches is  $7.89\pm 0.98$  mm(MS),  $8.06\pm 0.81$  mm(LS) in male and  $6.27\pm 0.76$  mm(MS),  $6.61\pm 0.87$  mm(LS) in female. Anyone possessed a corridor with diameter of at least 4.5mm. Nevertheless, due to individual and sex differences, the use of preoperative measurements and calculations by digital tools is recommended.

W. Hill et al described the screws he used to fix the base fracture of the coracoid process as 30-45cm[6]. In our study We measured the maximum length of the screws just passing through the posterior cortex of the scapula. The length of medial screw is  $47.62\pm 4.29$ mm in male, and  $38.60\pm 4.54$ mm in female. The length of lateral screw is  $52.81\pm 5.40$ mm in male, and  $43.52\pm 4.91$ mm in female. It turns out that we can actually choose a slightly longer screw.

On the basis of mastering the diameter and length of screw, the insertion point and direction are two important factors affecting the safe placement of screws. Previous reports have not given the exact points of entry. Different from previous studies, we found that the optimized insertion points are  $12.36\pm 2.70$  mm(MS),  $21.08\pm 2.51$ mm(LS) away from the closest point in males and  $10.89\pm 2.87$  mm(MS),  $18.66\pm 2.47$ mm(LS) in females; simultaneously are  $8.21\pm 1.68$ mm(MS),  $5.06\pm 0.70$ mm(LS) away from the posterior line in males and  $6.80\pm 1.45$  mm(MS),  $4.69\pm 0.96$ mm(LS) in females. The anatomic landmark of the closest point and the posterior line of coracoid process can be well palpable and identified, so they can be used as effective references intraoperatively.

W. Hill et al used a screw with 15 medial angulation and 30–40 posterior angulation to ensure that the screw remains enclosed in the bone [6]. Because of the difference in the reference plane, the results cannot be compared. We believe that the exact coordinates of the measurement angle are not given in the previous research report, which leads to the imprecision of the measured angle. The angle of measurement will vary depending on the position of the scapula. In our study we measured a significant gender difference in Angle $\beta$ . The parameters of the two screws may provide the surgeon appropriate information of safe screw placement for the treatment of coracoid base fracture. The large standard deviation of our results indicates great differences among individuals. As a result, preoperative planning

should be implemented detailedly for each patient. 3D reconstruction and simulated screw placement technique with digital software before operation are valuable.

There are some limitations to this study. We only analyzed the data according to the gender, not according to different age groups. In addition, we only studied the scapula of Chinese people, who have different skeletal shapes than European and American populations. What is more, more biomechanical studies and related clinical research should be performed .

## **Conclusion**

We indicate a valuable guideline for the safe zone of two screws that fixed the coracoid process base fractures. The ideal screw position and the size of the screws can be determined in 3D-models by digital software. Further biomechanical studies are needed to verify the strength and effect of the screw.

## **Abbreviations**

3-D: Three-dimensional; CT: Computed tomography; DICOM: Digital Imaging and Communication in Medicine; Mimics: Materialise's Interactive Medical Image Control System; SPSS: Statistical Package for the Social Sciences; SD: Standard deviation; CC :the coracoclavicular; MS:the medial screw; LS:the lateral screw.

## **Declarations**

### **Acknowledgements**

Not applicable.

### **Authors' contributions**

ZYS, HL performed the study, analyzed the data, and drafted the manuscript. BW, LRH and SZH contributed to discussion of data, writing, and editing of the article. XFY and BZ contributed to conception and study design, and editing of the article. All authors read and approved the final manuscript. All authors have read the journal policies and have no issues relating to journal policies. All authors have seen the manuscript and approved to submit to your journal. The work described has not been submitted elsewhere for publication, in whole or in part.

### **Funding**

No funding.

### **Availability of data and materials**

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

### **Ethics approval and consent to participate**

This study has obtained ethics approval and consent of the ethics committee in our hospital.

### **Consent for publication**

Not applicable.

### **Competing interests**

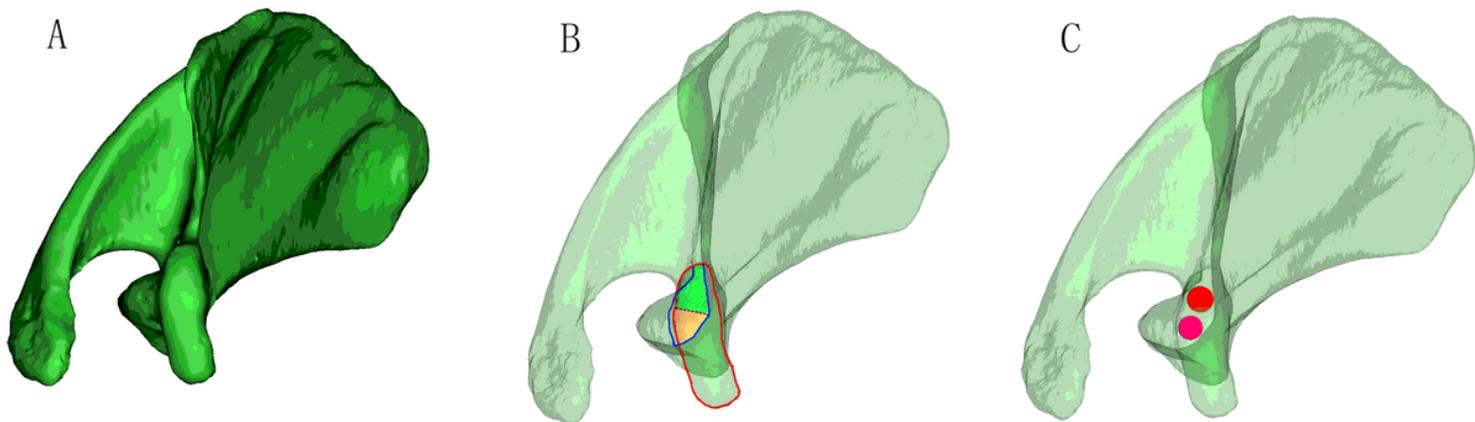
The authors declare that they have no conflict of interest.

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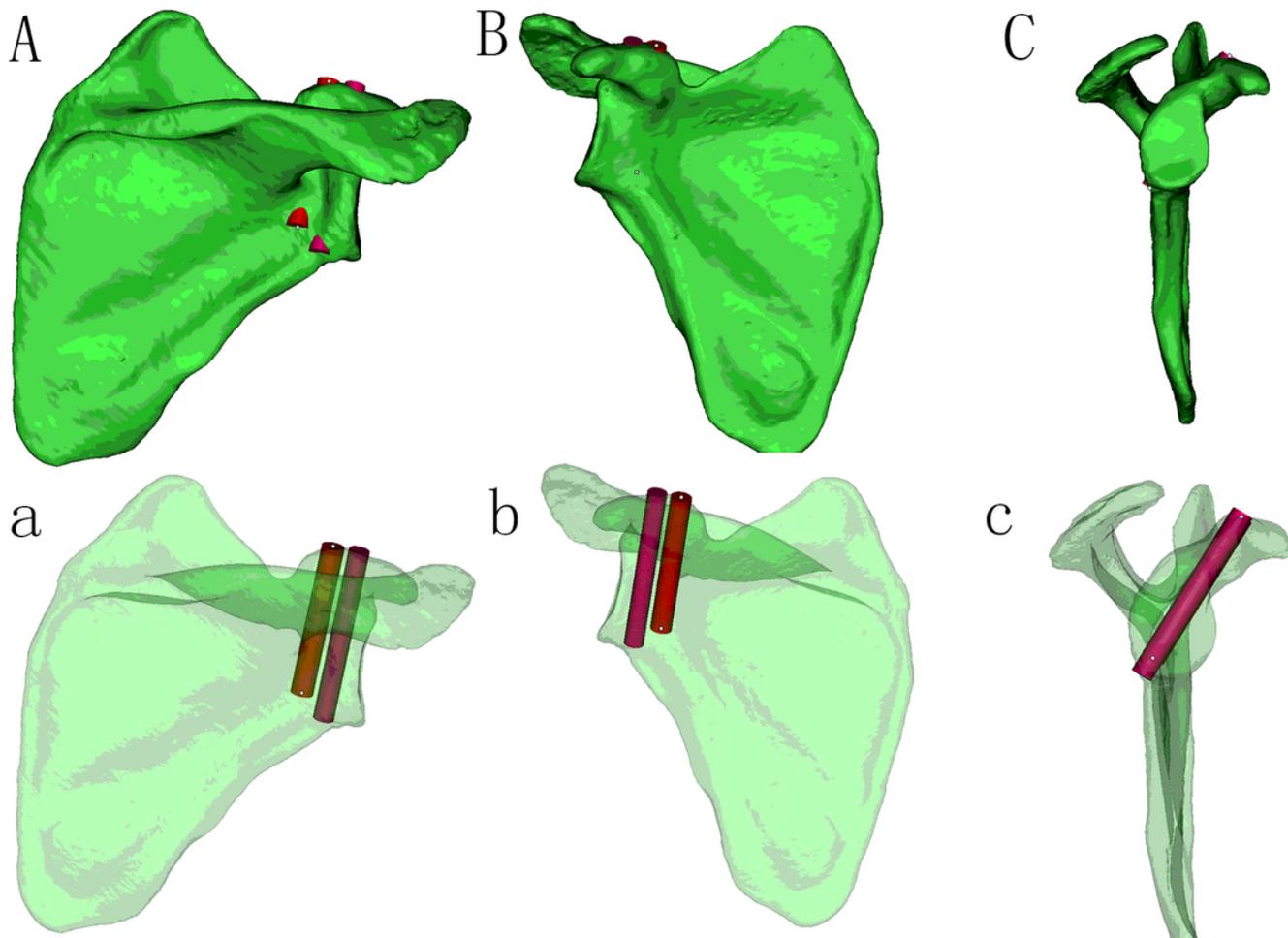
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## Figures



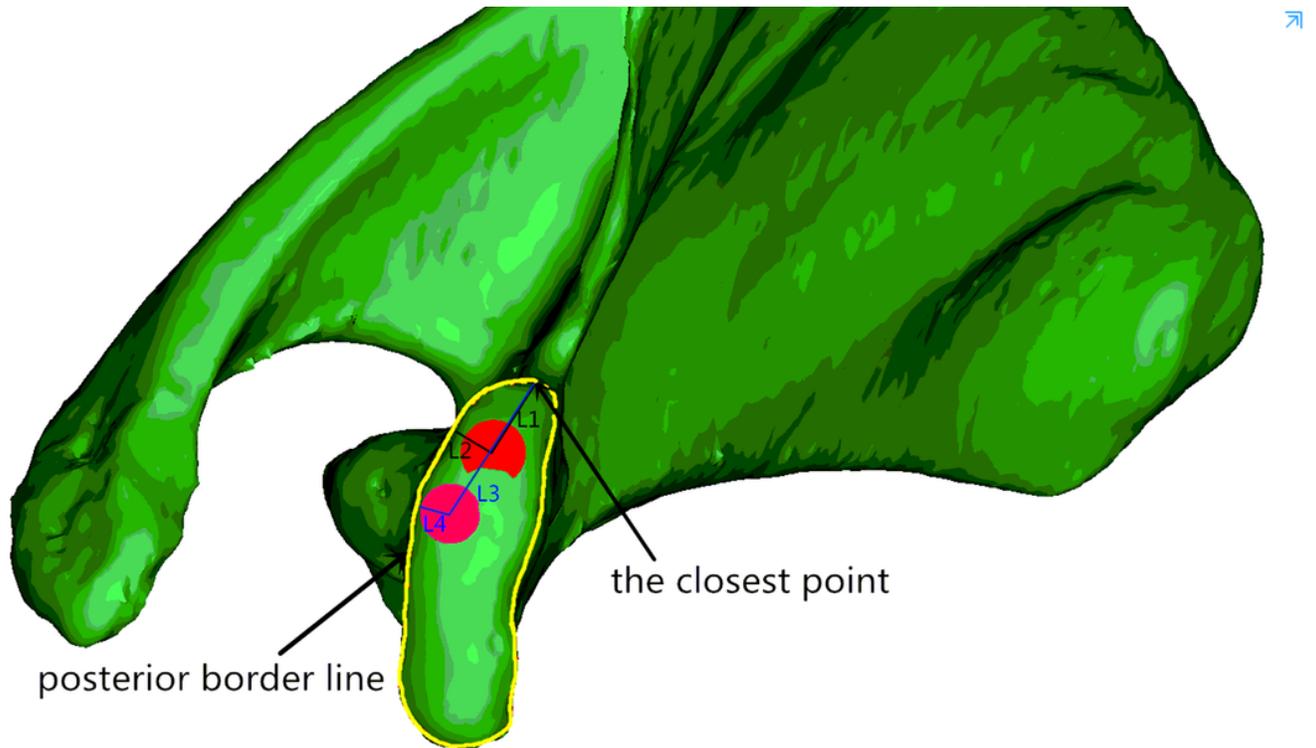
**Figure 1**

Find the largest screw path. A: The 3D model was turned to the axial perspective to find the largest translucent area. B: The red outline represents the top boundary of the horizontal part of the coracoid process, and the blue outline represents the boundary of the cross section of the base of the coracoid process. The green and orange areas represented the two screw paths, respectively. C: Two virtual screws were inserted into the green and orange areas, respectively. Then, the diameters were increased progressively until they reached the borderline of the area (the red circle of the cylinder represents the largest medial screw, and the purple one represents the largest lateral screw).



## Figure 2

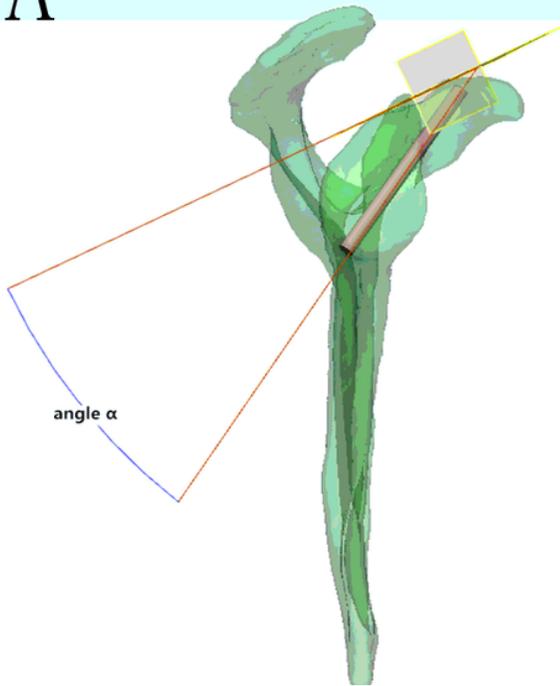
The position of the virtual screws were verified in the 3D model. A, B,C: Observed from the posterior , anterior and lateral of the opaque 3D model, respectively. The screws had the largest lengths and diameters just penetrating the cortical bone. a,b,c: Observed from the posterior , anterior and lateral of the translucent 3D model, respectively. Adjusted to the optimal lengths and diameters of the screws from the translucent 3D model.



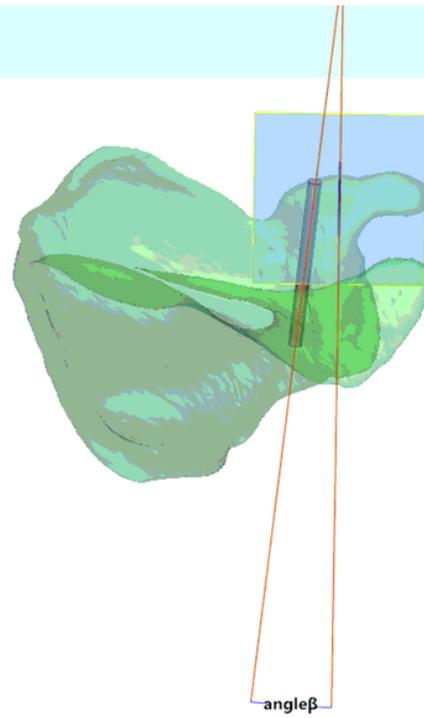
## Figure 3

The measurement of Distance L1, L2 ,L3 andL4. The yellow outline represents the boundary of the horizontal part of the coracoid process.The distances from the medial and lateral screw insertion points to the closest point of coracoid were recorded as Distance L1 and L3 ,respectively.The vertical distances from the medial and lateral screw insertion points to the posterior border line of the horizontal part of coracoid were recorded as Distance L2 and L4 ,respectively.

A



B



**Figure 4**

The measurement of Angle  $\alpha$  and  $\beta$ . A: The slope of the upper edge of the posterior coracoid process was selected as the reference plane called plane1 (yellow plane). The anterior inclination angle between the screw and plane1 was measured and recorded as angle  $\alpha$ . B: The other reference plane perpendicular to plane1 was called plane2 (blue plane). The medial inclination angle between the screw and plane2 was measured and recorded as angle  $\beta$ .