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Study on the anatomic relationship between the clavicle and the coracoid process using computed tomography scans of the shoulder

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Background: The current trend in the treatment of acromioclavicular dislocations is to reconstruct the coracoclavicular ligaments by using transosseous tunnels in the coracoid process or in the clavicle, yet there is no definition as to the location of these. To study the anatomic relationship between the coracoid process and the clavicle, we made measurements to find a convergence point (cP) between them that has intraoperative applicability for creating transosseous tunnels.
Methods: We analyzed 74 computed tomography scans (40 female and 34 male patients). Measurements were taken in the axial and sagittal planes and obtained from a cP, as determined by the intersection of the cortical surface of the clavicle and the coracoid process, with various relationships having been established.
Results: On average, the cP was determined to be about 2.9 cm and 2.5 cm distant from the coracoid process apex for male and female patients, respectively, whereas the width at this position was determined to be 2.1 cm and 1.9 cm. In the clavicle, this point is on average 2.9 cm and 2.5 cm distant from the acromioclavicular joint in male and female patients, respectively, and its anteroposterior width at this point is on average 1.9 cm and 1.6 cm.
Conclusion: The cP of the clavicle and the coracoid process was determined with the aim of preparing bone tunnels in operations for treating acromioclavicular dislocations.
Levels of evidence: Basic Science; Anatomy Study; Imaging

Keywords: Acromioclavicular joint/injuries; adult; anatomy; clavicle; multidetector computed tomography; shoulder

Treatment of acromioclavicular dislocations is surgical for types IV, V, and VI, and although there are >60 techniques described, none of them is considered standard.[5] The Weaver-Dunn[21] technique, which transfers the coracoacromial ligament to the clavicle, has been the most frequently used procedure in treating chronic dislocations.[14] However, biomechanical studies have proved that this ligament transfer maintains only 25% of the coracoclavicular fixation force and <50% of its resistance in comparison to the intact coracoclavicular ligaments, which postoperatively leads to subluxation or dislocation in as many as 30% of the cases.[8,11]

The study was submitted to the Research Ethics Committee of the institution and approved in accordance with the CAAE (Certificate of Application for Ethical Review): 41856315.0.0000.5479.

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New ligament reconstruction methods have emerged, using either autologous[9,10,14] or homologous[12,16] grafts or synthetic material, such as anchors, SutureTape (Arthrex, Naples, FL, USA),[11] or TightRope (Arthrex).[20] These options can be used by threading them beneath the coracoid process[11,16] or drilling transosseous tunnels in the coracoid process and in the clavicle, which has been the current trend.[2,3,5-7,13,15,20] However, there is no consensus on the definition of an exact point on which the drilling of the bone is to be conducted before the passage of biologic or synthetic implants through the tunnel thus created in the coracoid process or in the clavicle.

Several authors diverge with respect to the exact point where the transosseous tunnel should be drilled in the coracoid process. Mazzocca et al,[13] Costic et al,[5] and Grutter and Petersen[7] drilled the bone tunnel at its base, without specifying its exact placement; the diameter of the drilling ranged from 3.5 to 8 mm. Walz et al,[20] in turn, used two TightRope-type devices for reconstructing the conoid and trapezoid ligaments, both 3.5 mm in diameter. Coale et al[3] studied 3 possibilities for making transosseous tunnels, taking into account the midpoint from the origin of the coracoclavicular ligaments in the coracoid process, the clavicle, and an ideal point where the same bone distances could be obtained between the tunnel and the lateral and medial edges of the base of the coracoid process. They concluded that it is not possible to create transosseous tunnels capable of mimicking the anatomic position of the coracoclavicular ligaments without the risk of fracture of the coracoid process.[3]

With regard to creating transosseous tunnels in the clavicle, there is also a discussion in the literature about where, how many, and what diameter to drill.[4,19] Cook et al[4] stated that tunnels in the clavicle that are more medial stand a higher chance of early failure than do more lateral tunnels, whereas Voss et al[19] found that lateral holes 25 mm from the acromial end of the clavicle sustain early failure.

Accordingly, to date, there is no consensus in the literature on where and how to drill a transosseous tunnel either in the coracoid process or in the clavicle. With the loss of vertical stabilization of the acromioclavicular joint, which occurs in complete lesions of the coracoclavicular ligaments, ligament reconstruction surgery must interconnect the coracoid process to the clavicle in such a way as to prevent its superior dislocation. Thus, a bone tunnel in the central region of the coracoid process positioned at its base, just beneath where the reduced clavicle would be, allows the biologic or synthetic material used to pull the clavicle in the inferior direction, thereby preventing its superior dislocation. Bone tunnels drilled in unsuitable sites may lead to poor reduction of the acromioclavicular joint, causing fixed anterior subluxation[15] or contributing to fractures.[2,6,12] The correct location for creating a transosseous tunnel in the coracoid process is known to be at its base; still, its precise numerical definition has not yet been determined. The objective of this work was to study the anatomic relationship between the coracoid process and the clavicle and to make measurements by using computed tomography (CT) imaging for determining the convergence point (cP) between them. Our hypothesis was that the cP between the coracoid process and the clavicle must be located in the central region of the base of the coracoid process, and in the clavicle, it must be located in the central region and above the coracoid process.

Methods

A total of 74 CT scans of the shoulders of patients, whose test results were stored in the database of the Diagnostic Imaging Service System at the hospital at which the test was conducted between 2011 and 2013, were analyzed. Of these, 40 patients were female and 34 were male. We have used the IMPAX Results Viewer 1.0 software (Agfa HealthCare NV, Mortsel, Belgium) for viewing the images. As inclusion criteria, only the scans of patients who had no changes in the scapula or clavicle, regardless of whether there were any changes in the humerus, were analyzed. All those shoulder CT scans showing changes in the scapula or clavicle were excluded. Whether the shoulder examined was the dominant one or not was not taken into consideration.

For conducting the tomographic study of the relationship between the clavicle and the coracoid process, we have used the helical technique coupled to a 6- and 64-channel multidetector CT scanner (Philips Healthcare, Eindhoven, The Netherlands), with axial slices of 1 mm in thickness, additional reformatting in the sagittal planes, and image overlapping with the aid of a workstation (Philips).

Initially, scans for showing the relationship between the clavicle and the coracoid process were performed in the axial plane using the overlapping technique. Images in the axial plane were selected, including the image with the portion of the clavicle with a larger anteroposterior diameter at the level of the coracoid process (Fig. 1, *A*) and another running through the base of the coracoid process (defined as the greatest distance in the laterolateral direction) that contained the apex of this structure (Fig. 1, *B*). For the assessment of measurements, the acromioclavicular joint and the distal end of the coracoid process had necessarily to be included.

In this plane, the relationships between the clavicle and the coracoid process were obtained from a cP, which is the midpoint of a line AB, where A was determined at the intersection of the anterior cortical surface of the clavicle and the lateral cortical surface of the coracoid process and B was determined at the intersection of the posterior cortical surface of the clavicle and the medial cortical surface of the coracoid process (Fig. 1, *C*). From the cP, many relationships have been established. In the clavicle, they were measured from the cP to the articular surface of the acromial end of the clavicle (cP-ac) (Fig. 2, *A*); the anteroposterior distance of the clavicle, running through the coracoid process (Ap-clav) (Fig. 2, *B*); from the cP to the most distal apex of the coracoid process (cP-cor) (Fig. 2, *C*); and the lateral distance from the coracoid process running through the cP (Lat lat-cor) (Fig. 2, *D*).

Subsequently, measurements were taken of the relationship between the clavicle and the coracoid process in the sagittal plane, with the sagittal image necessarily having to pass through the cP (Fig. 3) as well. The relationships assessed and measured were the craniocaudal distance between the upper and lower cortical surfaces of the clavicle (cc-clav) (Fig. 4, *A*) and the craniocaudal distance between the upper and lower cortical surfaces of the coracoid process (cc-cor) (Fig. 4, *B*).

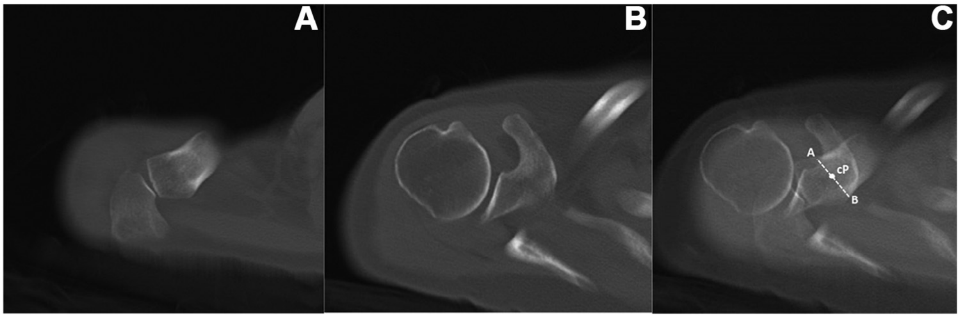

Figure 1 Method used for superimposing the images to the axial plane. (**A**) Right shoulder, axial plane, with slicing of the largest anteroposterior diameter of the clavicle at the level of the coracoid process including the acromioclavicular joint (case 1, female patient). (**B**) Right shoulder, axial plane, with slicing containing both the base and the apex of the coracoid process. (**C**) Determination of the convergence point (*cP*). *A*, Anterior cortical surface of the clavicle and lateral aspect of the coracoid process. *B*, Posterior cortical surface of the clavicle and medial aspect of the coracoid process.

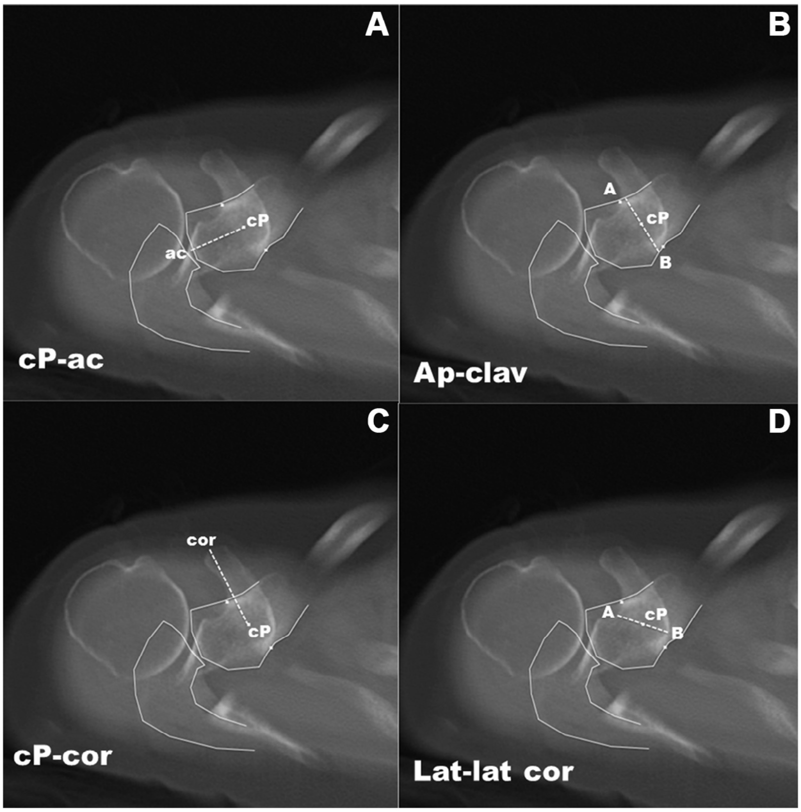

Figure 2 Measurements made in the axial plane, having the convergence point (*cP*) as a reference. (**A**) Determination of the cP-ac segment. (**B**) Determination of the anteroposterior segment of the clavicle (Ap-clav). (*A*, Anterior cortical surface of the clavicle; *B*, posterior cortical surface of the clavicle.) (**C**) Determination of the cP-cor segment. (**D**) Determination of the laterolateral segment of the coracoid process (Lat lat-cor). (*A*, lateral aspect of the coracoid process; *B*, medial aspect of the coracoid process.) *cP-ac*, Measurement from the convergence point to the articular surface of the acromial end of the clavicle, at the acromioclavicular joint; *cP-cor*, measurement from the convergence point to the distal cortical apex of the coracoid process; *Ap-clav*, anteroposterior distance of the clavicle, running through the coracoid process; *Lat lat-cor*, lateral distance from the coracoid process, running through the convergence point.

All measurements of the lines were taken in millimeters and the values were rounded to whole numbers (decimal places were excluded), taking into account their future surgical applicability. They were grouped according to gender (male and female) and the tomographic plane assessed (axial and sagittal).

The measurements were made by 2 radiologists specializing in the musculoskeletal system with 10 and 12 years of experience in the field, henceforth referred to as observers. These observers would take measurements at different times, without knowing the values previously measured by the other colleague.

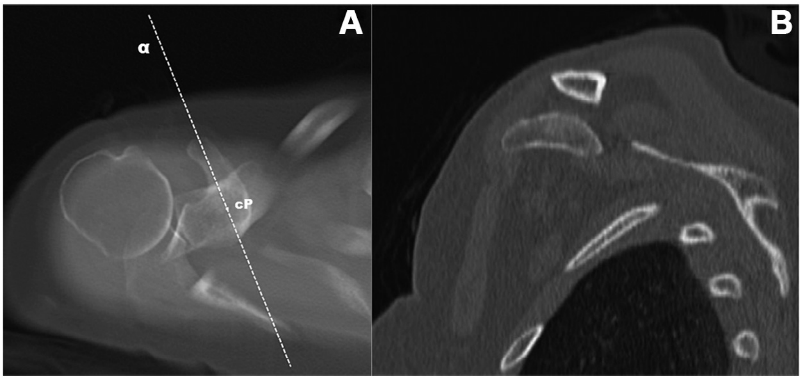

Figure 3 Method used for the sagittal plane in measuring the relationship between the clavicle and coracoid process. (**A**) Axial plane, right shoulder, with slices containing the distal end of the coracoid process; the straight line α is the cutting plane for determining the points in the sagittal plane. (**B**) Sagittal plane, right shoulder, necessarily passing through the convergence point (*cP*, same plane as the straight line α).

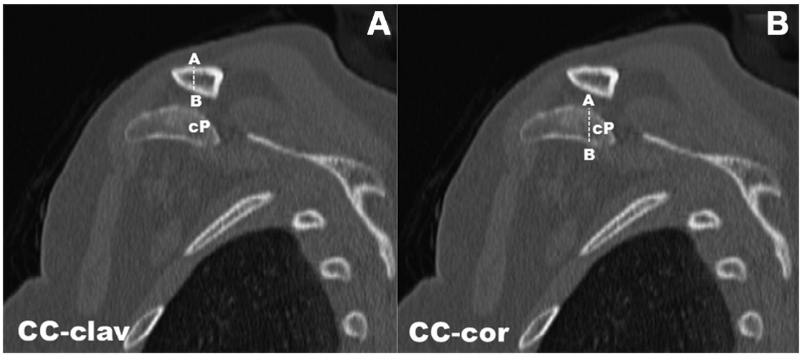

Figure 4 Measurements taken in the sagittal plane. (**A**) Determination of the craniocaudal segment of the clavicle (cc-clav). (**B**) Determination of the craniocaudal segment of the coracoid process (cc-cor). *cP*, Convergence point; *A*, upper cortical surface of the coracoid process; *B*, lower cortical surface of the coracoid process.

The Anderson-Darling, Ryan-Joiner, and Kolmogorov-Smirnov statistical tests were used for determining adherence to the normal distribution of each measurement made by each of the observers. In addition, Fisher *F*-test was used to determine the equality of variances in each set of measurements.

All hypothesis tests were carried out by adopting a 5% significance level, and their respective descriptive levels (*P* value) are given. Hypotheses with P value < .05 were rejected. Data were analyzed with the help of statistical software Minitab 16 (Minitab, State College, PA, USA).

Results

The Anderson-Darling, Ryan-Joiner, and Kolmogorov-Smirnov statistical tests showed that the measurements of both observers followed a normal distribution. Fisher *F*-test was used for testing the equality of variances in each set of measurements, and it was found that the observers made measurements compatible with each other.

Table I (male patients, 34 cases) and Table II (female patients, 40 cases) show the average difference between measurements made by the observers for each variable, statistically comparing and analyzing them. With respect to male patients, the values were considered statistically significant for the variables cP-cor and cc-clav; whereas with respect to female patients, only Ap-clav was considered statistically significant. The absolute values of the average of these differences, for both genders, fall within tenths of a millimeter and were hence considered negligible.

Tables III and IV show the average results for each variable in male and female patients, respectively, obtained by the 2 observers, including standard deviation and the confidence interval for the measurements. The results for male and female patients were, respectively, as follows: cP-cor, 29.3 mm and 24.9 mm; Lat lat-cor, 21.5 mm and 19.1 mm; cc-cor, 16.6 mm and 13.1 mm; cP-ac, 29.3 mm and 25.6 mm; Ap-clav, 19.2 mm and 16.5 mm; and cc-clav, 10.5 mm and 9.6 mm.

Discussion

Aiming to find the cP between the coracoid process and the clavicle to be used in drilling bone tunnels, we went on to acquire tomographic images of these structures and to derive measurements from them, as described. Tomography was

Table I Results for the differences between observers in the measurements made in male patients

Variable	No. of cases	Average	Standard deviation	Minimum-maximum	*P* value
Diff cP-ac	34	−0.265	1.421	−0.760 to 0.231	.285
Diff cP-cor	34	−0.529	0.992	−0.876 to −0.183	**.004**
Diff Ap-clav	34	0.147	1.105	−0.238 to 0.532	.443
Diff Lat lat-cor	34	−0.176	1.336	−0.643 to 0.290	.447
Diff cc-clav	34	−0.265	0.710	−0.512 to −0.017	**.037**
Diff cc-cor	34	0.176	0.758	−0.088 to 0.441	.184

The values in **boldface** are statistically significant.
Diff, difference; *cP-ac*, measurement from the convergence point to the articular surface of the acromial end of the clavicle, at the acromioclavicular joint; *cP-cor*, measurement from the convergence point to the distal cortical apex of the coracoid process; *Ap-clav*, anteroposterior distance of the clavicle, running through the coracoid process; *Lat lat-cor*, lateral distance from the coracoid process, running through the convergence point; *cc-clav*, the craniocaudal distance between the upper and lower cortical surfaces of the clavicle; *cc-cor*, the craniocaudal distance between the upper and lower cortical surfaces of the coracoid process.

Table II Results for the differences between observers in the measurements made in female patients

Variable	No. of cases	Average	Standard deviation	Minimum-maximum	*P* value
Diff cP-ac	40	−0.075	1.071	−0.418 to 0.268	.660
Diff cP-cor	40	−0.150	1.145	−0.516 to 0.216	.412
Diff Ap-clav	40	0.550	0.876	0.270 to 0.830	**.000**
Diff Lat lat-cor	40	0.150	1.145	−0.216 to 0.516	.412
Diff cc-clav	40	−0.050	0.904	−0.339 to 0.239	.738
Diff cc-cor	40	0.025	1.000	−0.295 to 0.345	.875

The value in **boldface** is statistically significant.
Diff, difference; *cP-ac*, measurement from the convergence point to the articular surface of the acromial end of the clavicle, at the acromioclavicular joint; *cP-cor*, measurement from the convergence point to the distal cortical apex of the coracoid process; *Ap-clav*, anteroposterior distance of the clavicle, running through the coracoid process; *Lat lat-cor*, lateral distance from the coracoid process, running through the convergence point; *cc-clav*, the craniocaudal distance between the upper and lower cortical surfaces of the clavicle; *cc-cor*, the craniocaudal distance between the upper and lower cortical surfaces of the coracoid process.

Table III Results for the averages of the measurements made in male patients by the 2 observers

Variable	No. of cases	Average, mm	Minimum-maximum	Standard deviation	95% Confidence interval
Average cP-cor	34	29.3	13-40	5.1	27.57-31.13
Average Lat lat-cor	34	21.5	15-34	3.8	20.22-22.89
Average cP-ac	34	29.3	16-37	3.9	**28.02-30.77**
Average Ap-clav	34	19.2	13-26	2.9	18.20-20.23
Average cc-clav	34	10.5	6-14	1.5	9.99-11.09
Average cc-cor	34	16.6	12-22	2.3	15.81-17.42

The value in **boldface** is statistically significant.
cP-cor, measurement from the convergence point to the distal cortical apex of the coracoid process; *Lat lat-cor*, lateral distance from the coracoid process, running through the convergence point; *cP-ac*, measurement from the convergence point to the articular surface of the acromial end of the clavicle, at the acromioclavicular joint; *Ap-clav*, anteroposterior distance of the clavicle, running through the coracoid process; *cc-clav*, the craniocaudal distance between the upper and lower cortical surfaces of the clavicle; *cc-cor*, the craniocaudal distance between the upper and lower cortical surfaces of the coracoid process.

chosen because it allows standardization of the slices and a better definition of the cortical bone studied. We have rounded the values measured—and avoided using tenths of a millimeter—with the objective of pursuing intraoperative applicability in the future.

According to Bhatia et al,[1] the length of the coracoid process is 44.5 mm in men and 38.3 mm in women. Similarly, Salzmann et al[18] made the same measurement and obtained 46 mm and 42 mm, respectively. If we divide the coracoid process into 3 parts, our point of interest dealt with in this study is to be located approximately at the intersection of the first and second thirds (with the first third being the most proximal one, ie, the base). We have come to this conclusion while checking the measurements of the distance from the cP to the apex of the coracoid process (cP-cor), whose values of 29.3 mm in men and 24.9 mm in women

Table IV Results for the averages of the measurements made in female patients by the 2 observers

Variable	No. of cases	Average, mm	Minimum-maximum	Standard deviation	95% Confidence interval
Average cP-cor	40	24.9	13-32	3.93	23.66-26.18
Average Lat lat-cor	40	19.1	13-25	2.96	18.15-20.04
Average cP-ac	40	25.6	13-38	4.86	24.08-27.19
Average Ap-clav	40	16.5	12-22	2.24	15.85-17.29
Average cc-clav	40	9.6	7-14	1.51	9.19-10.16
Average cc-cor	40	13.1	7-19	2.20	12.43-13.84

cP-cor, measurement from the convergence point to the distal cortical apex of the coracoid process; *Lat lat-cor*, lateral distance from the coracoid process, running through the convergence point; *cP-ac*, measurement from the convergence point to the articular surface of the acromial end of the clavicle, at the acromioclavicular joint; *Ap-clav*, anteroposterior distance of the clavicle, running through the coracoid process; *cc-clav*, the craniocaudal distance between the upper and lower cortical surfaces of the clavicle; *cc-cor*, the craniocaudal distance between the upper and lower cortical surfaces of the coracoid process.

correspond to about two-thirds of its total length as measured in anatomy studies.[1,18]

There is yet another way for determining the location of the cP in the coracoid process by using as a parameter the study conducted by Salzmann et al.[18] According to the measurements taken by these authors, the cP would be located 3.9 mm and 6.3 mm for men and women, respectively, anterior to the midpoint of origin of the trapezoid ligament (the most anterior of the 2 coracoclavicular ligaments). Irrespective of gender, these measurements would be immediately posterior to the precipice, the name given by Salzmann et al[18] to the site of the inferior and lateral angulation of the coracoid process.

The issue concerning which tunnel size is to be used in the coracoid process can also be subject to analysis. In all studies that involved creating bone tunnels in the coracoid,[2,5-7,13-15,20,22] the width measurement of the drilled tunnel, although it varies according to the author, never exceeded the measurements of the distances between the reference points and the point found in this study. According to the literature, the bone tunnel in the coracoid process ranged from 3.5 mm[20] to 7 mm[13,14] in width, therefore showing that creating a transosseous tunnel is possible at our cP. Measurements showed that the coracoid process (Lat lat-cor) is 21.5 mm in men and 19.1 mm in women in width.

It can be concluded that in creating a large-diameter tunnel (7 mm) and calculating the remaining distance between the tunnel and the bone edges of the coracoid process, both the medial and the lateral ones, for male and female patients, we will find it to be 7.25 mm and 6.05 mm, respectively. This in turn leads us to conclude that the hole drilled at our cP is created in the central region of the base of the coracoid process and that in female patients, extra caution is needed to avoid complications.

According to the study conducted by Ferreira et al,[6] the best bone tunnel that can be created at the base of the coracoid process, from a biomechanical point of view, is that which starts in the central or medial region of the upper cortical surface and ends in the central region of the lower cortical surface. Another biomechanical study[2] showed that tunnels smaller in diameter (4.5 mm across) and drilled at the base of the coracoid process are, biomechanically, the safest, which avoids complications. The authors warned that the bone tunnel should not be placed in more distal regions for the risk of fracture is then increased.[2] Considering the point we have studied, it is located at the base and in the central region of the coracoid process, which thus minimizes the risk of fracture, especially in drilling holes smaller in diameter (approximately 4.5 mm). It is a safe and appropriate location for drilling the tunnel.

With regard to the cP in the clavicle, Morrison and Lemos[15] made a tunnel measuring 2 $\times$ 6 mm (oval hole) at the junction of the anterior middle third, 30 mm medial to the acromioclavicular joint, above the base of the coracoid process. In their study, Renfree et al[17] measured the distance from the medial edge of the insertion of the trapezoid ligament in the clavicle to its lateral end to be 28.2 mm in men and 26.6 mm in women. Comparing them with our study, the cP in the clavicle, in accordance with the cP-ac measurement, is located close to this position—given the measurements in men (29.3 mm) and women (25.6 mm)—and near the medial edge of the insertion of the trapezoid ligament and therefore between the coracoclavicular ligaments.

Among the authors recommending only 1 tunnel in the clavicle,[3,8,10,11,15,16,22] some state that this should be created between the middle and anterior, only in the anterior third,[8,10,11] or only in the middle third[16]; some report that its distance should be 30 mm from the acromioclavicular joint[15] or even only above the coracoid process.[8,16] Some authors do not determine the exact placement of the clavicle tunnel.[22] Our cP is located, as mentioned before, 29 mm in men and 25 mm in women from the acromioclavicular joint (cP-ac) and above the coracoid process, similar to the previous studies mentioning the acromioclavicular joint as a reference.

As for the diameter of the tunnel drilled in the clavicle, data in the literature vary between 1.5 mm[8] and 5 mm,[22] and none of the articles reported any complications arising from it.[8,12,13,15,22] The anteroposterior distance from the clavicle at the level of the cP (Ap-clav measurement) is 19 mm in men and 16.5 mm in women, therefore without interference as to the diameter of the tunnel that can be created.

In this study, we then concluded that it is possible to identify the cP between the coracoid process and the clavicle by taking measurements with the aid of CT, identifying their relationships with nearby anatomic landmarks. In the coracoid process, the distance between the apex and the cP is 29.3 mm in men and 24.9 mm in women, the width of the coracoid process at this site is 21.5 mm in men and 19.1 mm in women, and its thickness is 16.6 mm in men and 13.1 mm in women. In the clavicle, the distance between the cP and the acromioclavicular joint is 29.3 mm in men and 25.6 mm in women, the width at this site is 19.2 mm in men and 16.6 mm in women, and the thickness is 10.5 mm in men and 9.7 mm in women. In the acromioclavicular dislocations requiring surgical treatment, the space between the coracoid process and the clavicle is increased. We suggest that a flexible ruler be used for making measurements of both the coracoid process and the clavicle, thereby allowing location of the cP for the transosseous tunnel.

As a limitation of our study, we performed analyses and measurements on CT scans without the proof thereof in vivo. Furthermore, we cannot affirm that the cP is actually the best biomechanical location, given that this study did not aim at that. Further biomechanical studies are required to demonstrate such properties.

Conclusion

In this study, we reached the conclusion that it is possible to identify the cP between the coracoid process and the clavicle by making measurements on CT scans and identifying their relationship with close anatomic landmarks.

For practical use by a surgeon, the following values were reached. In male patients, the cP in the coracoid process is located, on average, 29.3 mm from the apex, the width at the site is 21.5 mm, and the thickness is 16.6 mm; whereas in the clavicle, the cP is located, on average, 29.3 mm from the acromial end, the width at the site is 19.2 mm, and the thickness is 10.5 mm. In female patients, the cP in the coracoid process is located, on average, 24.9 mm from the apex, the width at the site is 19.1 mm, and the thickness is 13.1 mm; whereas in the clavicle, the cP is located, on average, 25.6 mm from the acromial end, the width at the site is 16.5 mm, and the thickness is 9.6 mm.

Disclaimer

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