Anatomical Study for the Treatment of Proximal Humeral Fracture Through the Medial Approach

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Abstract

Background: The treatment of complex 3- and 4- part proximal humeral fractures has been controversial due to numerous postoperative complications. With the further study of medial support and blood supply of humeral head, new techniques and conception are developing. The study aims to illustrate the medial approach of the proximal humeral fracture through cadaver autopsy.

Method: Upper limbs from 19 cadavers have been dissected to expose the shoulder joint. We selected the coracoid process as the bony reference. Vernier caliper will be used to measure the following data, including distance from coracoid process to circumflex brachial artery, distance between anterior humeral circumflex artery (ACHA) and posterior circumflex brachial artery (PCHA) and their diameters. Assessment included the characteristics of the vascular supply around the humeral head, identification of the structures at risk, quality of exposure of the bony structures, and feasibility of fixation.

Results: Medial plate can be easily placed in 86.84% anatomical patterns. An interval of 2 to 3cm (24.29 ± 3.42 mm) was available for internal fixation. ACHA (49.35 ± 8.13 mm, 35.14 - 68.53 mm) and PCHA (49.62 ± 7.82 mm, 37.67 - 66.76 mm) were about 5cm away from the coracoid process. Risk factors including ACHA and PCHA originate in common, PCHA originated from the deep brachial artery (DBA), the presence of perforator vessels; musculocutaneous nerve intersects with ACHA, the diameter of PCHA: ACHA < 1.5. In 13.15% anatomical patterns, this risk factor should be taken seriously.

Conclusion: The medial approach opens a new perspective in the optimal management of complex fractures of proximal humerus. Anatomical research proves that the medial approach is feasible. The interval between ACHA and PCHA is suitable for placement. Anatomical pattern and indication have been discussed, and we hypothesized that ACHA has been destroyed in complex PHFs. With further studies on the anatomy and mechanism of injury, the development of more clinical cases will be an important work of our institution in the future.

Introduction

Proximal humeral fractures (PHFs) are the seventh most frequent fractures in adults, and the third most frequent in the upper limb, with the prevalence varies from 4–10% of all fracture types. In patients aged older than 40 years, a linear increase is present, and only less than wrist and femoral neck fractures in the elderly population (> 65 years) [1–3]. At present, the prevalence of high-energy trauma is decreasing while traumas on osteoporotic bone are increasing [4]. Complex displaced PHFs will occur more often in older women with comorbidities [5, 6]. With the arrival of the ageing of population in China, the rapid increase in PHFs is beyond doubt.

Generally, it is agreed that non- displaced fractures, should be treated non-operatively because of a subsequent satisfactory result [7]. But operative treatment is considered when displacement of the tuberosities or the joint surface. Open reduction and internal fixation (ORIF), intra-medullary nailing (IMN) and reverse shoulder arthroplasty (RSA) are the common surgical interventions. Multiple factors involving the fracture type, patient condition, and the surgeon's experience could affect the clinical outcomes. Although the IMN had a lower complication rate compared to the locking plate group in the treatment of 2-part fractures in a prospective randomized study [8], the reoperation rate of 4-part fractures (63.2%) was significantly higher than 2- (13.6%) and 3- part (17.4%) because of numerous complications such as backing out of the screws, shoulder impingement and joint protrusion of the screws [9, 10]. In a systematic review of 2155 patients, the rate of osteonecrosis was as high as 19.2% in 3- and 4-part fractures [11]. On the other hand, RSA had significantly less postoperative external rotation versus ORIF and hemiarthroplasty [12]. However, tuberosity nonunion remains a concern for hemiarthroplasty. For shoulder arthroplasty, the prognosis is still controversial due to the number of cases and prosthesis revision.

The locking plates is still the mainstream in treating PHF because locking head screws inserted bi-directionally exhibit increased pull out strength in the metaphyseal bone of the humeral head [13]. In a retrospective study of PHF, the locking plate fixation is the most common procedure (48.3%) of surgical procedures, followed by IMN (20.0%), and RSA (5.6%) [14]. ORIF was significantly greater in ASES and Constant score than HA or RSA in a systematic review [12]. If ORIF was adopted, the most important factor for favorable results in the treatment of complex 3-part or 4-part humerus fractures is anatomic reduction [15].

Systematic review of locking plate fixation reported the overall complication rate was 48.8% through standard deltopectoral approach. And the most common complications included varus malunion (16.3%), AVN (10.8%), screw perforation into the joint (7.5%) [16]. There was a trend toward higher complication and failure rates in older patients and more complex fractures because of osteoporosis [17–19]. Loss medial cortical buttress from fracture comminution is the most common cause for varus malunion [16]. Recent studies have found the stability has significant correlation with the medial column [20]. As the proximal humerus is an eccentrically loaded joint, the alignment relies almost entirely on the plate if the anatomical reduction is not achieved. The loss of medial column led to 30% screw perforations while the rate of intact medial column capable of load transfer is only 6% [21]. In mechanical experiment, the medial cortex contact shows better result in fatigue life than screw fixation group [22]. To reinforce the medial column, surgeon came up with several methods: Use calcar screws or endosteal implant; Impact the shaft into the humeral head; Insert an intramedullary fibular strut graft; Use dual plate fixation. The medial plate provided a firm buttress. Good prognosis has been obtained in both biomechanical evaluation and clinical practice in our institution [23, 24]. However, some experts believe that the medial approach will sacrifice the ACHA. Therefore, this paper will focus on the anatomy and precautions of the medial approach.

Materials And Methods

The protocol of this study was approved by the Committee on Medical Ethics of Shandong province Hospital affiliated to Shandong University. 19 frozen cadaveric paired upper limbs from voluntary donor specimens were used, which included both 12 males and 7 females. All cadavers were fixed in 8 %

formalin and preserved in 30 % ethanol. In each body, both left and right shoulders were carefully dissected. Mean donor age was 68.8 years (range 61–87 years) and mean donor height was 168.8 cm (range 153-183 cm). All limbs were examined for the absence of signs of previous surgery, trauma, or obvious gross deformity.

The upper limbs were placed with the arm abducted to 60 degrees on average in supine position. All specimens have been dissected through a medial incision to expose the shoulder joint [24]. The insertion of the pectoralis major tendon onto the humerus was transected and reflected for better visualization. After dissecting and remove of superficial fascia tissue, the short head of biceps brachii and coracobrachialis muscles were exposed and pulled laterally. The brachial blood vessels and the brachial plexus were identified and pulled medially. Between the conjoined tendon of the latissimus dorsi and teres major muscles and the lower border of the shoulder capsule, the medial side of the proximal humerus can be well exposed after the conjoint tendon is dissected (Fig. 1).

Three structures require special attention due to their relative transverse configuration, including ACHA, PCHA and musculocutaneous nerve. The ACHA, PCHA and musculocutaneous nerve was identified, dissected, and their paths were traced after bifurcating from the axillary artery and brachial plexus. The musculocutaneous nerve was seen to travel laterally and anteriorly and pass through the coracobrachialis irregularly. The ACHA was seen to travel laterally under the coracobrachialis and terminates with smaller branches in the greater tuberosity. The PCHA was seen to travel laterally and posteriorly, travels with the axillary nerve, remaining superior to the latissimus dorsi tendon. The interval between ACHA and PCHA is the area that suitable for the placement of the medial plate (Fig. 2). Characteristics of the nerve and vascular risk have been described in result.

The coracoid process was tagged with pin as the landmark. All anatomic relationships were measured using ruler placed in situ and marked to measure the length of each respective distance. All measurements were confirmed by a minimum of two observers. Vernier caliper has been used to measure the following data, including distance from coracoid process to the ACHA and PCHA, distance between ACHA and PCHA and the diameter of ACHA and PCHA. 14 limbs were used to expose the vessels distinctly and to measure the interval between ACHA and PCHA. (Fig. 3)

Descriptive statistics were calculated including mean, standard deviations, and range including minimum and maximum values. The data were further analyzed using a student’s paired t-test for analysis of the diameter of ACHA and PCHA, distance from coracoid to ACHA and PCHA, with statistical significance set at $p < 0.05$.

Results

Based on the following anatomical characteristics, we identified 4 relatively low-risk factors and 2 relatively high-risk factors for the medial approach. Low-risk factors accounted for 1 point, and high-risk factors accounted for 3 points. If the total score is less than 2, the placement of medial approach is practicable. Low-risk factors including ACHA and PCHA originate in common, the diameter of PCHA:

ACHA<1.5, musculocutaneous nerve intersects with ACHA, radial nerve cross between ACHA and PCHA. Relative high-risk factors including PCHA originated from the deep brachial artery (DBA), the presence of perforator vessels. The proportion of 0, 1, 2 and 3 or above was 52.63%, 34.21%, 5.26% and 7.89%, respectively (Table 1) (Fig. 4). In the low-risk group (1 score), musculocutaneous nerve intersects with ACHA had the highest proportion of risk factors (38.46%), while the proportion of radial nerve cross between ACHA and PCHA was the lowest (15.38%).

Table 1

Risk of the medial approach

Score	Study subjects (n = 38) N (%)
0	20 (52.63)
1	13 (34.21)
2	2 (5.26)
≥ 3	3 (7.89)

1 point:

a) AHCA and PHCA originate in common

b) Musculocutaneous nerve intersects with ACHA

c) Ratio of PCHA: ACHA<1.5

d) Radial nerve cross between ACHA and PCHA

3 points:

A. PCHA originated from the DBA

B. Presence of perforator vessels

Table 2

Characteristics of the vascular supply

		Study subjects (Total 38), n (%)
1.ACHA and PCHA have same origin	NO	32(84.3)
	YES*	6(15.7)
2.PCHA variation	Classical	33(86.8)
	SSA	4(10.5)
	DBA*	1(2.6)
3.Perforator vessel exist	NO	36(94.7)
	YES*	2(5.3)
4.PCHA: ACHA	Ratio≥1.5	32(84.3)
	Ratio<1.5*	6(15.7)

*: Relatively high-risk factor; *: Relatively low-risk factor

Classical: PCHA originated from the axillary artery

SSA: PCHA originated from the subscapular artery

DBA: PCHA originated from the deep brachial artery

Table 3

Diameter of the arteries (n = 38)

						P value
		Minimum	Maximum	Mean	Std. deviation	
1	ACHA(L)	0.6	2.1	1.39	0.38	0.8103
	ACHA(R)	0.7	2.3	1.36	0.40	
2	PCHA(L)	1.8	4.0	2.75	0.64	0.8925
	PCHA(R)	1.4	3.9	2.72	0.78	
3	ACHA(T)	0.6	2.3	1.38	0.39	<0.0001
	PCHA(T)	1.4	4.0	2.735	0.72	
4	PCHA: ACHA (In pair)	1.10	4.28	2.03	0.68	/

L(Left); R(Right); T(Total)

1,2、3: Diameter of ACHA and PCHA (mm)

4: Diameter of PCHA: ACHA (In pair)

Table 4

Characteristics of the nerve

		Study subjects (Total 38), n (%)
1.Musculocutaneous nerve	I	29(76.3)
	II*	7(18.4)
	III	2(5.3)
2.Radial nerve cross between AHCA and PHCA	NO	36(94.7)
	YES*	2(5.3)

*: Relatively high-risk factor

I: The afferent point to the coracobrachialis is located proximal to the ACHA

II: The musculocutaneous nerve intersects with ACHA

III: The afferent point is located distal to the ACHA.

Table 5

Distance of the vascular supply, (n = 38)

	Maximum	Minimum	Mean	Std. deviation	P value
DISTANCE I (mm)					
Valid,36(94.7)	68.53	35.14	49.35	8.13	0.8172
DISTANCE II (mm)					
Valid,36(94.7)	66.76	37.67	49.62	7.82	
DISTANCE III (mm)					/
Valid,12(85.7)	29.60	19.63	24.29	3.42	
DISTANCE I: ACHA to coracoid process					
Two examples were removed from the sample due to AHCA rupture					
DISTANCE II: PCHA to coracoid process					
Two examples were abandoned because PHCA originated prematurely from SSA					
DISTANCE III: Interval between ACHA and PCHA					
Two examples were abandoned.1)AHCA rupture; 2)ACHA and PCHA originate from DBA					

Normally, the ACHA originates from the anterolateral side of the axillary artery and passes through the coracobrachialis, with low mobility. When ACHA and PCHA originate in common, the interval between them is relatively fixed and the extent of exposure obtained by traction is limited (Fig. 5-a). Generally, 84.3% ACHA and PCHA do not originate in common while 15.7% of cases originate in common, which led to the risk of injury to the ACHA when the PCHA was pulled to expose the operation area (**Table 2**). The detection and protection of ACHA is particularly critical in the medial approach.

A thicker ACHA may play a more important role in preventing avascular necrosis in PHFs. The mean ratio of the PCHA to ACHA is about 2.03±0.68 (1.10~4.28). The mean diameters of the ACHA and PCHA were 1.38 mm (0.60–2.30 mm, SD 0.39 mm) and 2.74 mm (1.40–4.00mm, SD 0.72 mm), respectively. The larger the ratio of the PCHA to ACHA, the less effective the ACHA will be. 1.5 is chosen as the standard. There are 6(15.8%) cases with a ratio less than 1.5 and 31 (81.6%) cases with a ratio greater than 1.5, among which 2 (4 cases) specimens had ratios less than 1.5 on both sides. For the diameter of ACHA and PCHA, there was no statistical difference between the left and right sides. (**Table 3**, Fig. 6)

Variations in PCHA are common during measurement. Typically, PCHA originated from the axillary artery, as is classically described in 86.8% of cases in our research. Besides, PCHA originated from the subscapular artery (SSA) (Fig. 5-b) in 10.5% of cases and originated from the deep brachial artery (DBA) (Fig. 5-c) in 2.6% of cases. When PCHA originated from the subscapular artery (SSA), this variation results in a deeper and higher origin and course of PCHA. This variant is considered as the safer type. On the contrary, the variation that PCHA originated from the DBA may reduce the placement space of the medial plate.

No perforator vessels were found in 94.7% of the cases. A bare spot on the medial proximal humerus existed in the region between ACHA and PCHA. However, in 2 cases (5.3%) the PCHA gave off a branching artery in the direction of the coracobrachialis before penetrating the quadrilateral foramen. (Fig. 5-d) In the absence of perforators, the PCHA has a very high range of mobility, making it ideal for placement and operation of internal fixation. Perforator vessels to the coracobrachialis can be ligated during surgery; this requires a surgeon to be anatomically competent.

Another risk factor is the musculocutaneous nerve intersects with ACHA. According to the anatomical relationship between musculocutaneous nerve and ACHA, we divide the musculocutaneous nerve into 3 categories (**Table 4**) (Fig. 7). I (71.1%): The afferent point to the coracobrachialis is located proximal to the ACHA. II (18.4%): The musculocutaneous nerve intersects with ACHA. III (5.3%): The afferent point is located distal to the ACHA. Because the mucocutaneous nerve needs to be pulled laterally with the coracobrachialis, careful attention should be paid in type II. In contrast, type III has little effect on surgical area exposure because the musculocutaneous nerves tend to be extremely relaxed. In addition, the radial nerve was found to cross between ACHA and PCHA in 2 cases, which may reduce operating space (Fig. 8).

The distance data are as follows. The distance from the coracoid process to ACHA is 49.35 ± 8.13 mm (35.14-68.53mm). The distance from the coracoid process to PCHA is 49.62 ± 7.82 mm (37.67-66.76mm). There was no statistical difference between ACHA and PCHA (P value=0.8172) (Fig. 9). In 12 upper limbs, the interval between ACHA and PCHA was measured; the average distance was 24.29 ± 3.42 mm (19.63-29.60mm). (**Table 5**, Fig. 10). Among the specimens measured, one PCHA originated from DBA. The distance between PCHA and ACHA is only about 5cm, so it was not included in the data statistics. In addition, the ACHA of one specimen was cut off during measurement, and the data were invalid.

Discussion

This article aims to summarize the anatomical characteristics of the medial approach for proximal humeral fractures, of which the study of arteries is the most important. PCHA may play a more important role than ACHA in preventing AVN because of its larger diameter and less variation. Earlier anatomic dissection studies indicated the vascularization of humeral head was mainly through the ACHA while the PCHA vascularized only a small part of the head [25]. But this result could not explain the absence of necrosis in the cases of severe fracture as the ACHA is vulnerable is such cases. Another study shows that humeral head can be completely perfused after ligation of ACHA [26]. In another quantitative assessment of the vascularity, PCHA provided 64% of the blood supply while the ACHA only supply 36% [27]. First, the small diameter of the ACHA (0.3mm-2mm) in comparison to that of the PCHA (1.2-5.5mm) is also funded by other studies [24, 26, 28]. Second, in clinical study of treatment for complex PHFs, no intact ACHA were found in 16 cases except 1 patient But successful fracture healing was achieved in all 17 cases [29]. Last, Natalie Keough et al emphasized the variations exist for the course of the ACHA, which suggest a more significant contribution from the PCHA to the epiphysis [30]. In our study, a separate origin for the ACHA and PCHA was 84.3%. This is consistent with their study. So, the role of the PCHA is revalued as its distinctive branches penetrating the region of the bone cartilage area.

Given the anatomical features of ACHA, we hypothesized that the integrity of ACHA has been lost in complex PHFs as the ACHA was firmly attached to the subscapularis tendon [31]. While the ACHA has been lost, extent dissection of periosteum by deltopectoral approach will increase the risk of necrosis as the vascular supply to the callus area is derived mainly from the surrounding soft tissues. Instead, the medial approach does not require excessive dissection because of its loose subcutaneous tissue. Besides, the longitudinal incisions on the medial side contribute to the concealment of the incisions and have little effect on cutaneous blood supply and cutaneous nerves without any flap. If the ACHA is intact, preoperative localization of ACHA can be of great help to the operation. Method of guiding the quick access to ACHA by landmarks have been proposed [32]. In this study, the distance from ACHA to coracoid was 49.2 mm, which was consistent with our study. This technique provides favorable guidance for preoperative localization of ACHA. CTA can be used to determine the continuity of artery before surgery but is often not used routinely due to its high cost and unclear development (Fig. 7). In addition, Location of the ACHA by intraoperative ultrasound is possible due to the loose subcutaneous tissue in the medial upper arm as using intraoperative ultrasonography in treatment of acute achilleas tendon rupture yield less surgical time [33].

The entry point of arcuate artery, which regard as an important intraosseous anastomosis, is in the outer upper quadrant of the humeral head [34]. We also find there are no nutrient arteries from PCHA and ACHA in medial side. Based on the above observation, the interval between ACHA and PCHA is practicable for the placement of medial plate. The variation of the origin of PCHA is also noteworthy. According to literature reports, the typical PCHA accounted for 77.1%, PCHA arises from SSA accounted for 12%, PCHA arises from DBA accounted for 8.4% [35].These data in our observations are 86.8%, 10.5% and 2.6% respectively. When the PCHA arises from the subscapular artery, its origin is located proximal to the typical type. We think it is safer because the deeper course of PCHA. But when it comes from the deep brachial artery, the interval between ACHA and PCHA is limited.

Compared to other nerves, the musculocutaneous nerve is the only nerve that requires special attention in medial approach. The medial brachial cutaneous nerve is away from the incision because it pierce the fascia at about 15 cm proximal to the medial epicondyle [36]. We found that the axillary nerve was generally located behind the PCHA, so the medial approach did not increase the risk of axillary nerve injury. It is reported that shoulder abduction could protect the axillary nerve and radial nerve when working near the latissimus dorsi tendon insertion [37]. The musculocutaneous nerve is the only nerve that normally appears in the surgical area. The exposure of the operative field is influenced by the distance between its origin from the brachial plexus and its afferent coracobrachialis muscle, and by its position with the ACHA. We divide the musculocutaneous nerves into three categories. Type I. The entry point is proximal to the artery. Type II. The entry point is located adjacent to the artery (musculocutaneous nerve intersects with ACHA). Type III. The entry point is located distal to the artery. In this research, 65.8% fits type I. As all the musculocutaneous nerve should be pulled laterally to facilitate the placement of the implant during surgery, so the type I and type III is beneficial to surgery. In a study on the relationship of the musculocutaneous nerve, approximately 83% entry points that musculocutaneous nerve penetrates the coracobrachialis were shorter than 5cm from the humeral head [38]. This is consistent with type I in this article, and the proportion is even higher.

The conjoined tendon of the latissimus dorsi and teres major muscles needs to be cut off. But its function is almost unaffected because Modified L'Episcope procedure have been proposed [39].The follow-up shows that active internal rotation remained unchanged (7.6 ± 2.0 compared to 7.5 ± 2.4). So, the dissection of the conjoined tendon will not affect the function of the shoulder.

Current implants are not successful in treating complex fractures. 22%-23% failure rate of the locking screw construct has been reported [40]. It is agreed that intraoperative anatomic reduction and restoration of the medial cortical support are the essentials for successful surgical fixation of proximal humerus fractures [22, 41, 42].Without anatomic reduction or inferomedial screws, placing locked plates from a lateral tension-band position may lead to early loss of reduction and cutout of the locking screws can cause severe cartilage damage [21, 43, 44]. The medial approach can reduce the fracture fragments under direct vision. A varus deformity may lead to secondary screw perforations changes the pretension of the rotator cuff [45].

There are several ways to strengthen the medial column. Michael J et al. provide compressive strength to a comminuted medial column by using a fibula allograft, which showed encouraging results in both clinical and biomechanical. The drawbacks associated with its use are limited supply, high cost, and infection risk, as the axillary nerve need separate from the deltoid for consistently exposure. Dual plate techniques with PHILOS plate and VA-LCP distal radius plate have been used for severely fractures of PHF. However, its clinical prognosis and effects on the posterior rotation brachial artery and axillary nerve are still controversial.

The parallel double plate fixation showed significantly greater integral and stiffness in biomechanical test [23, 46]. The “arch” structure of parallel placement gives the comminuted or osteoporotic bone intrinsic stability [47]. This fixation is also suitable for the treatment of PHF because of its eccentric-load and cancellus-filled structure. The parallel system provided higher stability under physiological load [48, 49]. The perpendicular plating has a lower stress on the deformation of the opposite side, while the parallel system, like i-type curved beam, can compensate for each other.

About indication, unstable medial cortical reconstruction have been proposed [29]. Beside 3- and 4-parts fractures, any medial cortical deficiency can be restored through a medial approach. Poor prognosis with PHILOS is associated with osteoporosis, so the patient's age, gender, job and other factors should be considered. The metaphyseal bone of the humeral head has been described as an egg shell as there is little bone in the center of the head [13]. Tingart et al. found the cortical bone mineral density was 15% higher in the lesser tuberosity region compared to the greater tuberosity region [50, 51]. This provides a theoretical basis for the good purchase of the medial plate. Double plate interlocking also provides higher overall stability. In the case of coracoid process injury, dislocation and other injuries, related tissue repair can also be carried out through the medial approach under direct vision. Short calcar segment (8 mm), Disrupted medial hinge (2 mm dislocation), and some fracture pattern predict of ischemia of humeral head [52]. The imaging evidence is consistent with injury to the ACHA. In such cases, the medial approach is no longer limited by ACHA, and the exposure is more sufficient. If medial support is selected, the medial approach will stimulate the soft tissue less than the deltopectoral approach.

There are still several deficiencies in this research. First, the influence of age, gender, occupation and races affected the anatomical structure is not considered. Other specifications were also ignored for the scope of this study, including how height, weight correlate to the distances measured. Second, the average area of exposure of deltoid-splitting, deltopectoral approaches were 1404.39 mm^2, 1325.41mm^2 respectively [53]. The extent of exposure from the medial approach remains to be studied. Third, results are limited by the number of specimens and measurement errors. Accurate assessment of risk requires more clinical validation.

Conclusion

The medial approach opens a new perspective in the optimal management of complex fractures of proximal humerus. Anatomical research proves that the medial approach is feasible. The interval between ACHA and PCHA is suitable for placement. Anatomical pattern and indication have been discussed, and we hypothesized that ACHA has been destroy in complex PHFs. With further studies on the anatomy and mechanism of injury, the development of more clinical cases will be an important work of our institution in the future.

Abbreviations

ACHA, anterior circumflex humeral artery; PCHA, posterior circumflex humeral artery; PHF, proximal humeral fracture; DBA, deep brachial artery; SSA, subscapular artery; ORIF Open reduction and internal fixation; IMN intra-medullary nailing; RSA reverse shoulder arthroplasty; AVN avascular necrosis.

Declarations

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Authors’ contributions

XH and WF contributed to the idea of this study. WY and HY searched literatures and screened them independently. XH, WY, WF and HY screened data and make Tables. XH, WY, WF and HY played an important role in analyzing the outcomes. XH and WF conducted the data analyses and make graphs. XH, WY, YYL, LFX, LQS, KLP, LMZ, HY and WF wrote the first draft, polished and approved the final version.

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Availability of data and materials

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

Ethics approval and consent to participate

This study was approved by the medical ethics committee of Shandong Provincial Hospital Affiliated to Shandong University.

Consent for publication

All participants signed informed consent forms for publication.

Competing interests

The authors declare that they have no competing interests.

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Figures

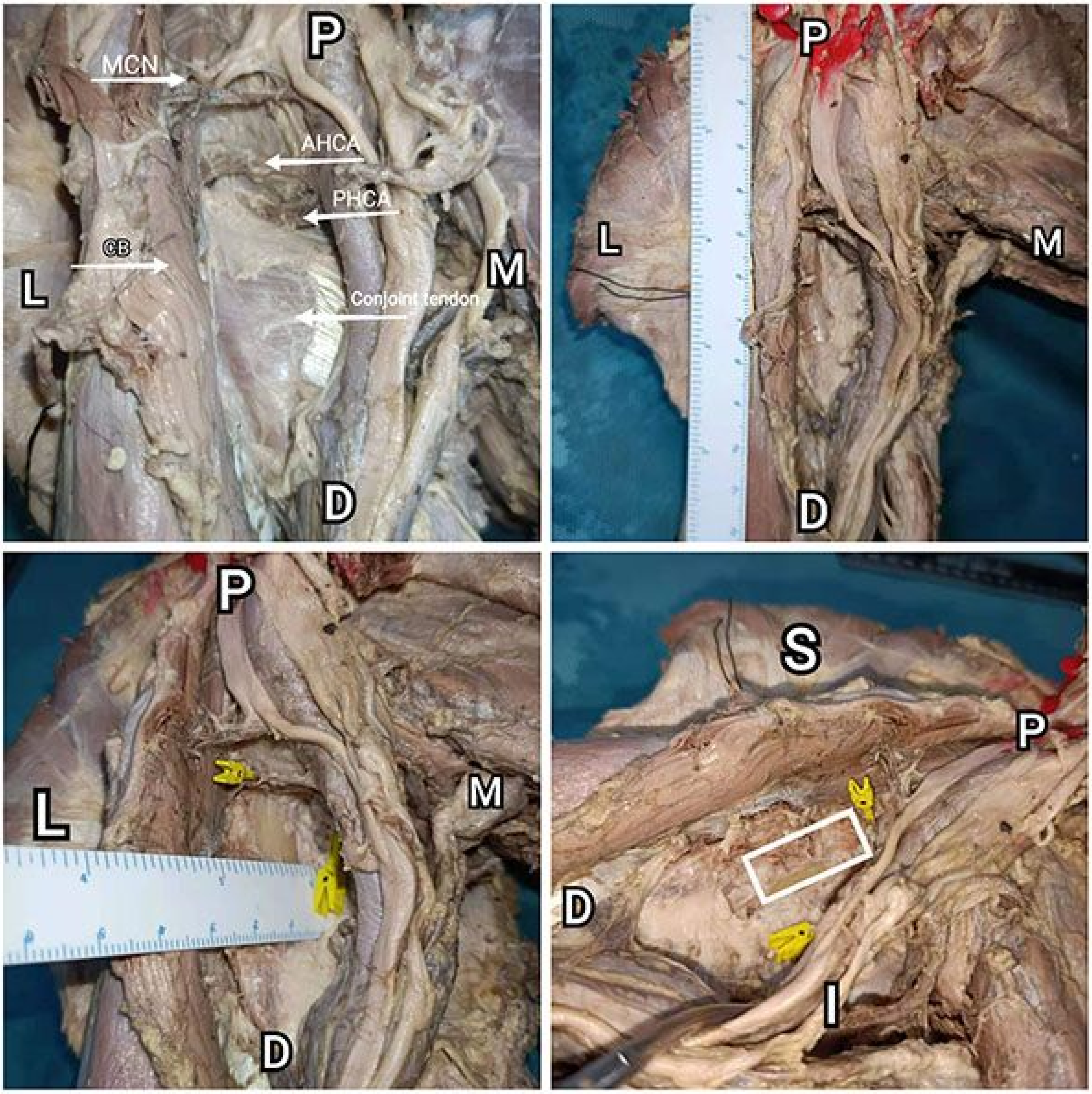

Figure 1

Front view of shoulders (Right)(P: proximal D: distal M: medial L: lateral) ACHA: Anterior circumflex humeral artery; PCHA: Posterior circumflex humeral artery; MCN: Musculocutaneous nerve; CB: Coracobrachialis The conjoint tendon lies between the coracobrachialis and the brachial plexus. (The pectoralis major was removed for a better view). The distance from the coracoid process to the ACHA was measured. After conjoint tendon removed, the bone surface of proximal humerus is exposed.

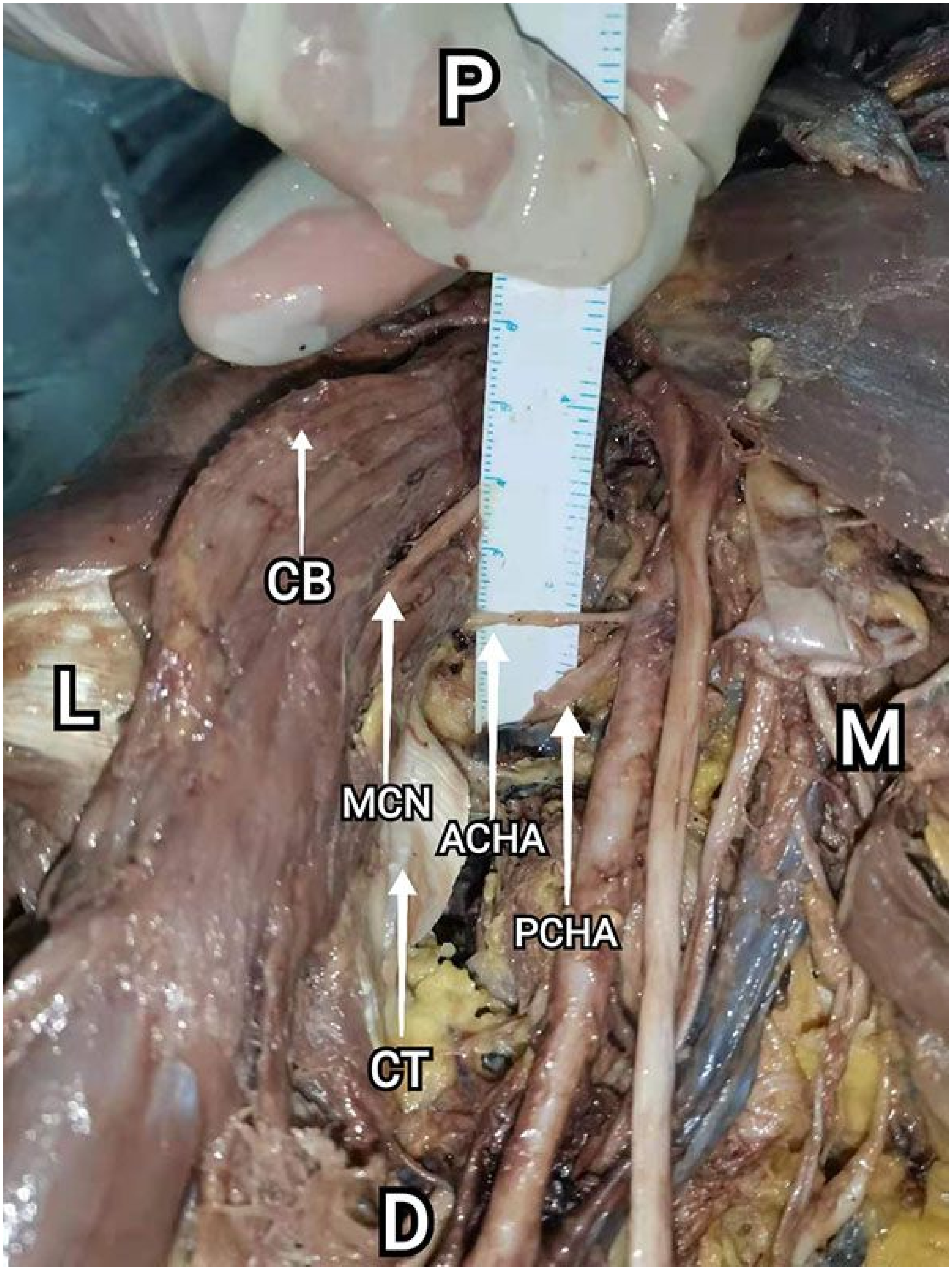

Figure 2

Inferior aspect of axilla (Right) (P: proximal D: distal M: medial L: lateral) CT: Conjoint tendon of the latissimus dorsi and teres major muscles; ACHA: Anterior circumflex humeral artery; PCHA: Posterior circumflex humeral artery; MCN: Musculocutaneous nerve; CB: Coracobrachialis Structures at risk: ACHA, PCHA, musculocutaneous nerve. The interval between ACHA and PCHA is the area that suitable for the placement of the medial plate

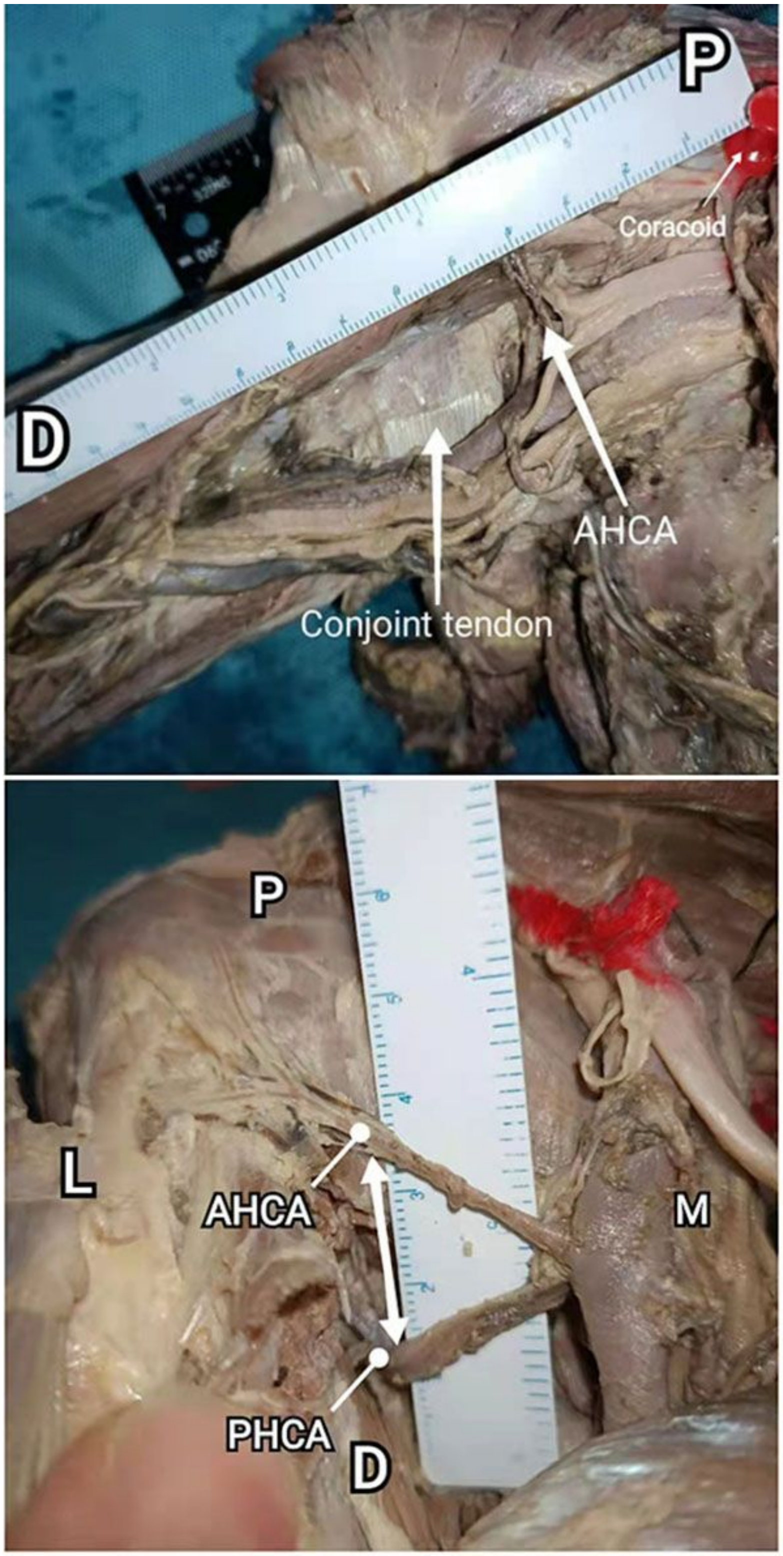

Figure 3

Measurement of data (Right) (P: proximal D: distal M: medial L: lateral) Distance from coracoid process to the ACHA and PCHA. Distance between ACHA and PCHA. Diameter of ACHA and PCHA. The interval between ACHA and PCHA was measured.

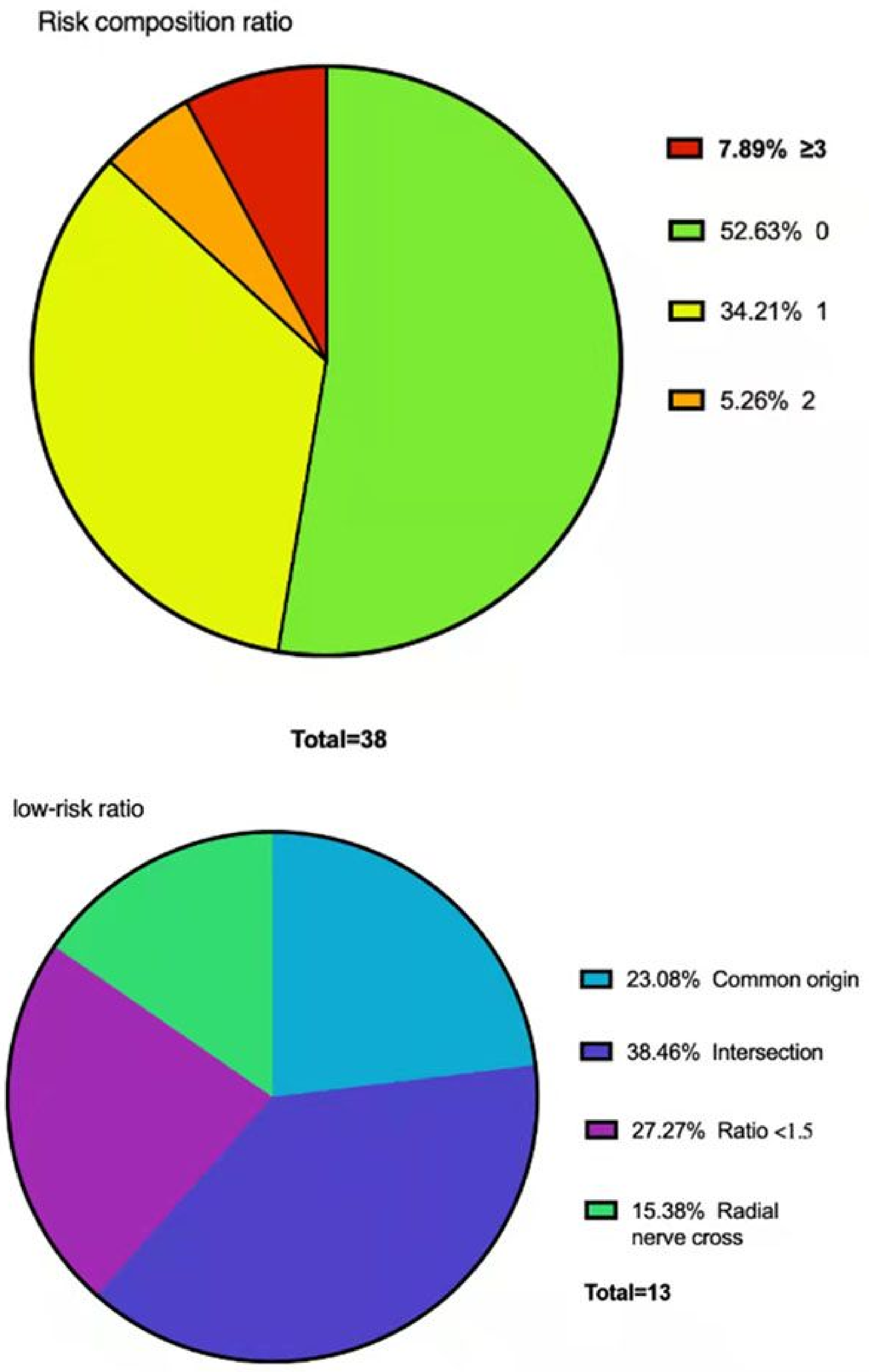

Figure 4

Proportion of risk score 0 (52.63%) 1 score (34.21%): b (38.46%); c (27.27%); a (23.08%); d (15.38%). 2 (5.26%): b + c (2.63%); a + c (2.63%) ≥3 (7.89%): B + a (5.26%); A + b

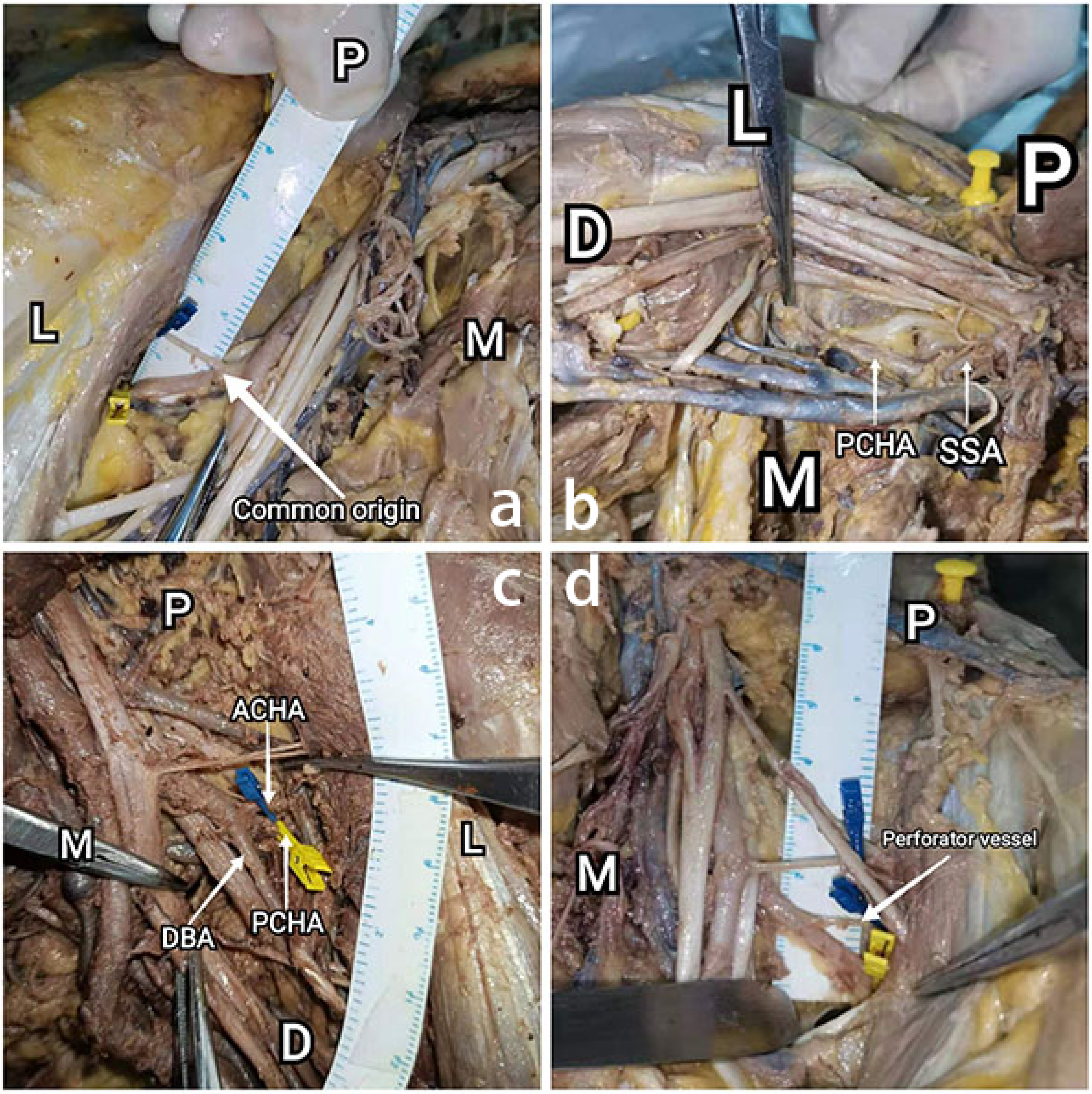

Figure 5

The variation of artery a. ACHA originated from the PCHA (common origin) (right) b. ACHA originated from the subscapular artery (SSA) (right) c. PCHA originated from the deep brachial artery (DBA) (left) d. Branching arterioles in the direction of the coracobrachialis (left)

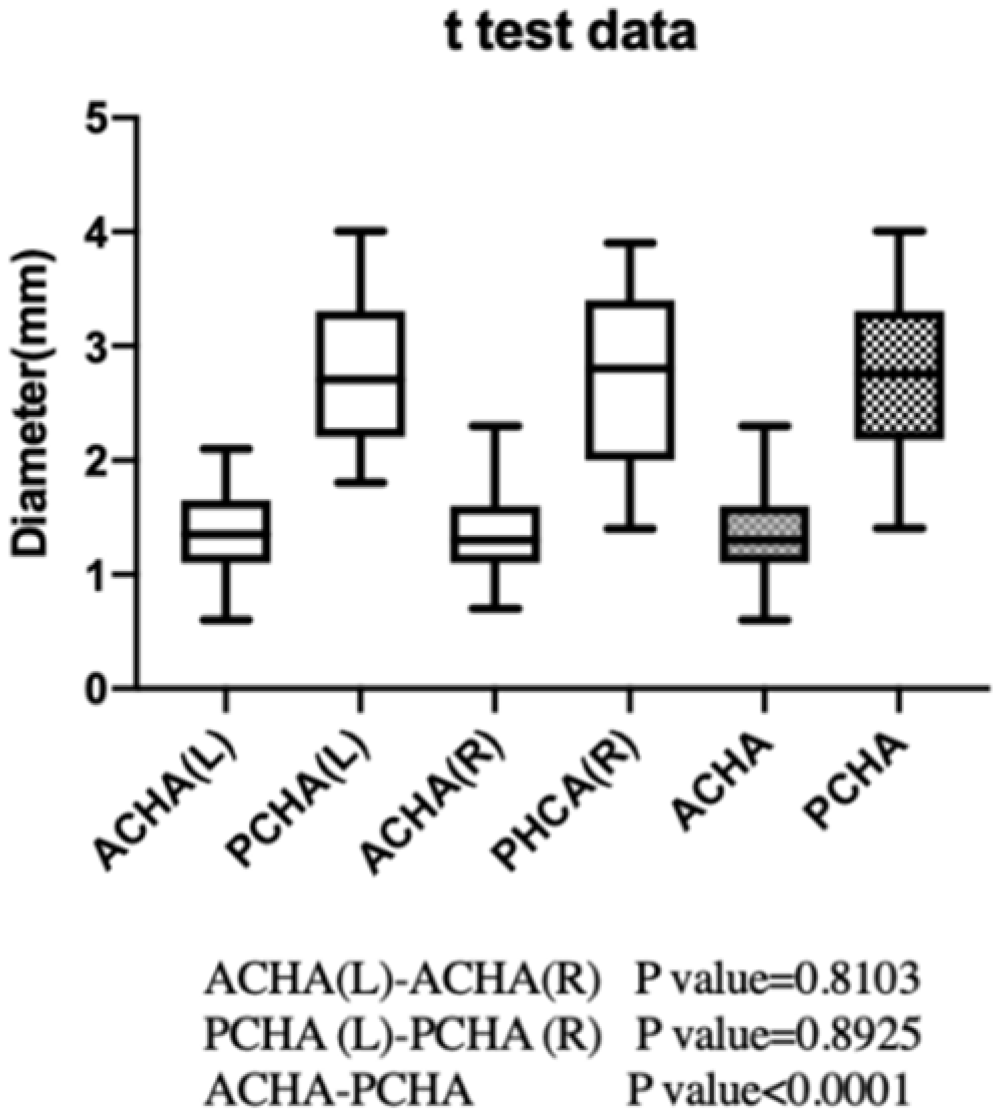

Figure 6

The diameter of the ACHA and PCHA The mean diameters of the ACHA were 1.38±0.39mm (0.6~2.30mm). The mean diameters of the PCHA were 2.74±0.72mm (1.4~4.00mm). The mean ratio of the PCHA to ACHA is about 2.03±0.68 (1.10~4.28).

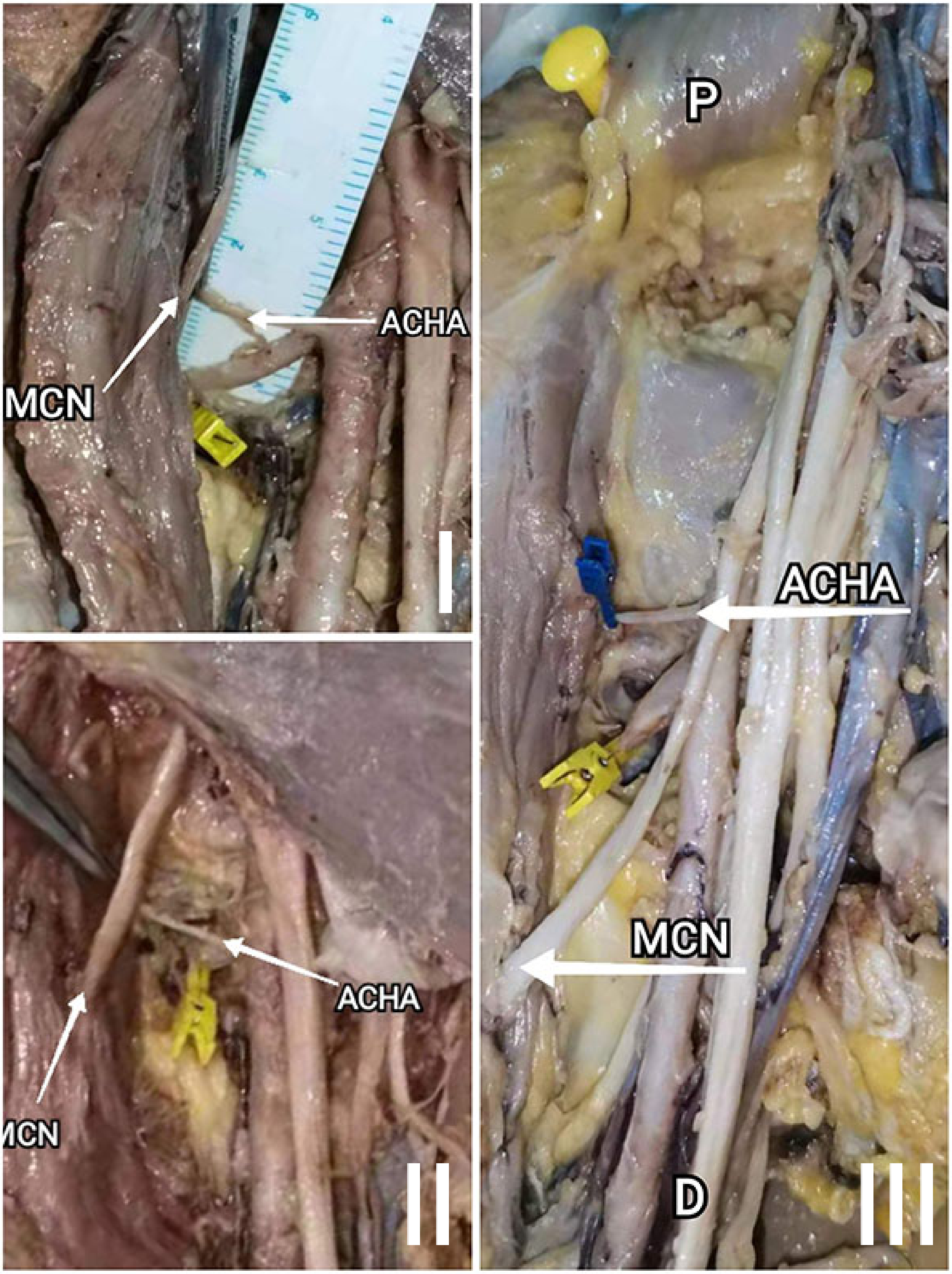

Figure 7

Relation between musculocutaneous nerve and circumflex brachial artey (Right) I: The point of afferent to the coracobrachialis is located proximal to the ACHA. II: The musculocutaneous nerve intersects with ACHA. III: The point of afferent to the coracobrachialis is located far distal to the ACHA.

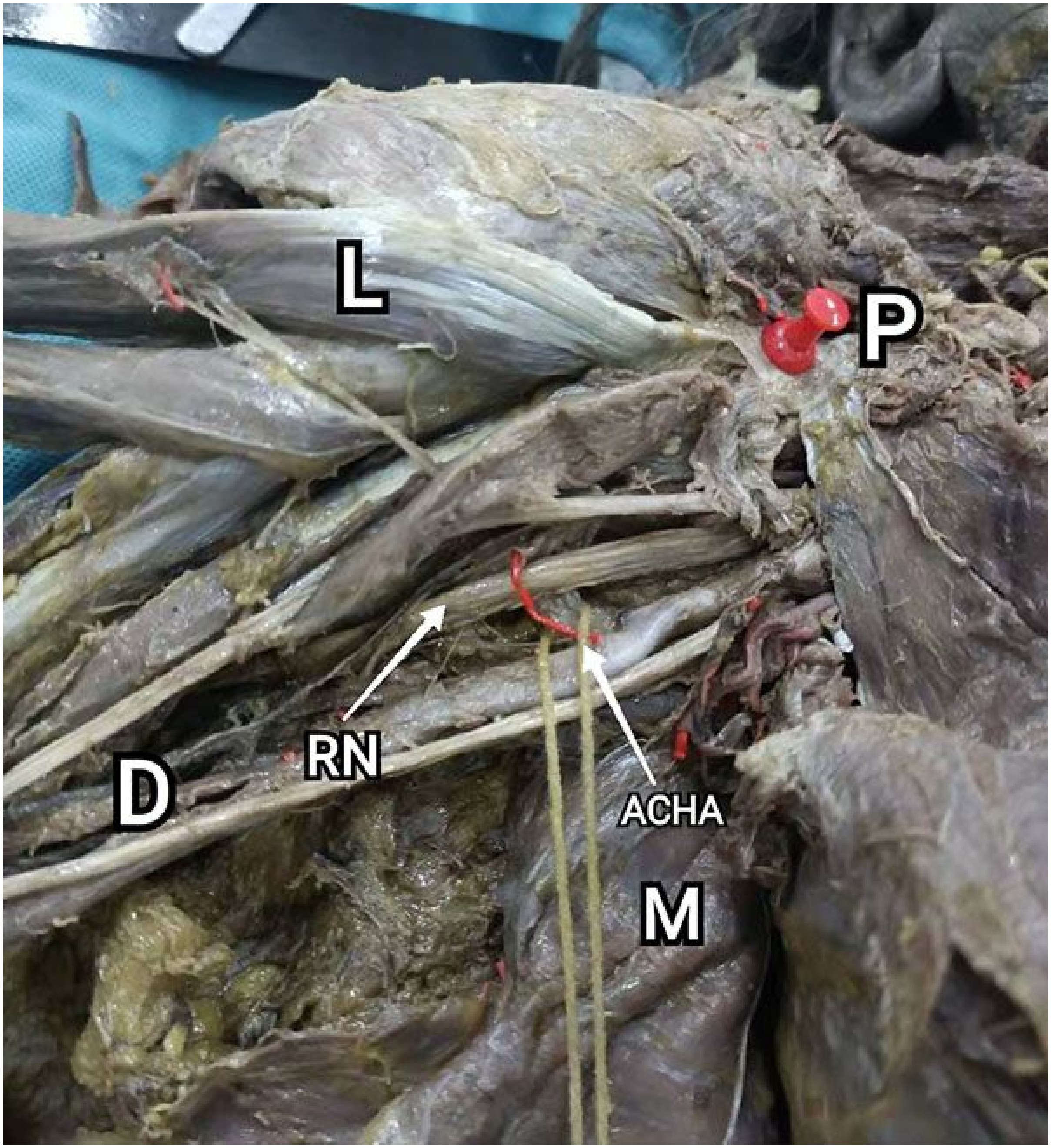

Figure 8

Radial nerve cross between ACHA and PCHA (Right)

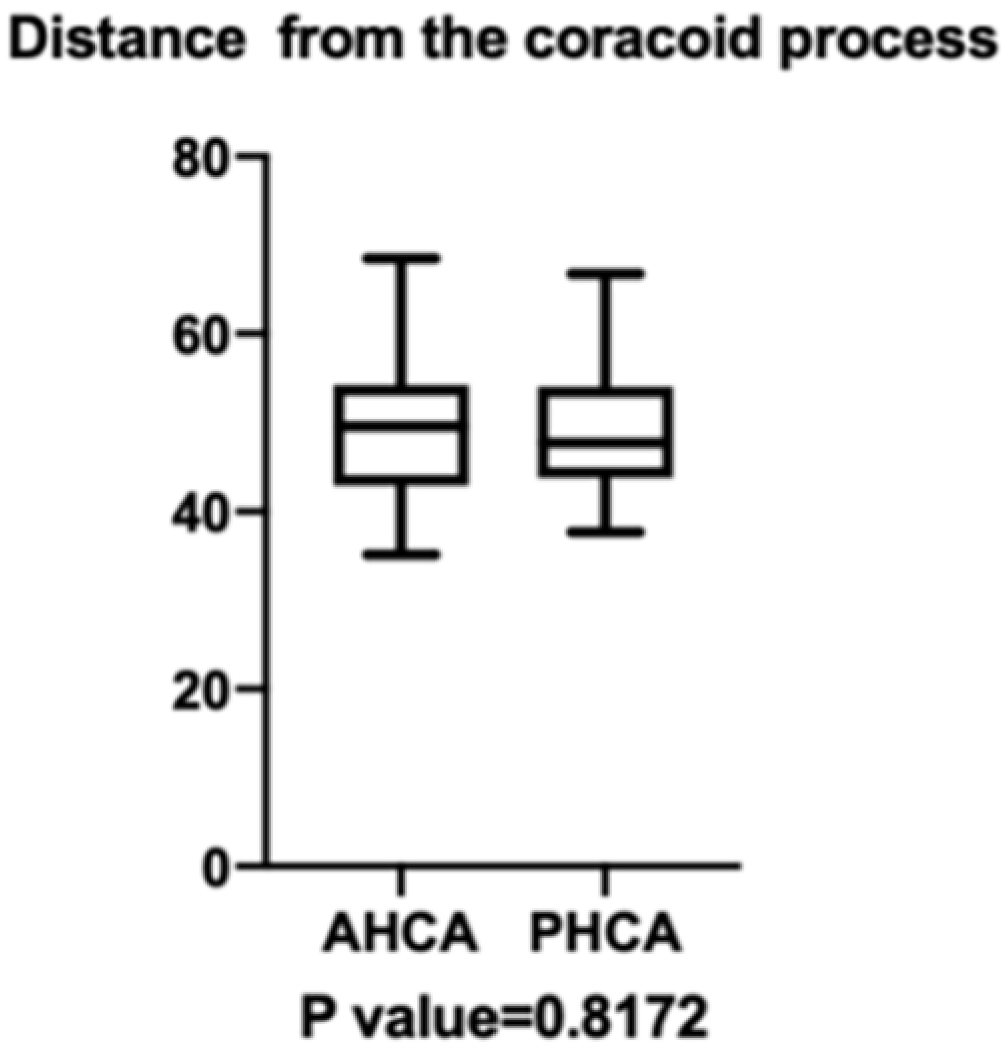

Figure 9

Distance from artery to bone marker (coracoid process) (38 upper limbs) The distance from the coracoid process to ACHA is 49.35±8.13 mm (35.14-68.53mm) The distance from the coracoid process to PCHA is 49.62±7.82 mm (37.67-66.76mm)

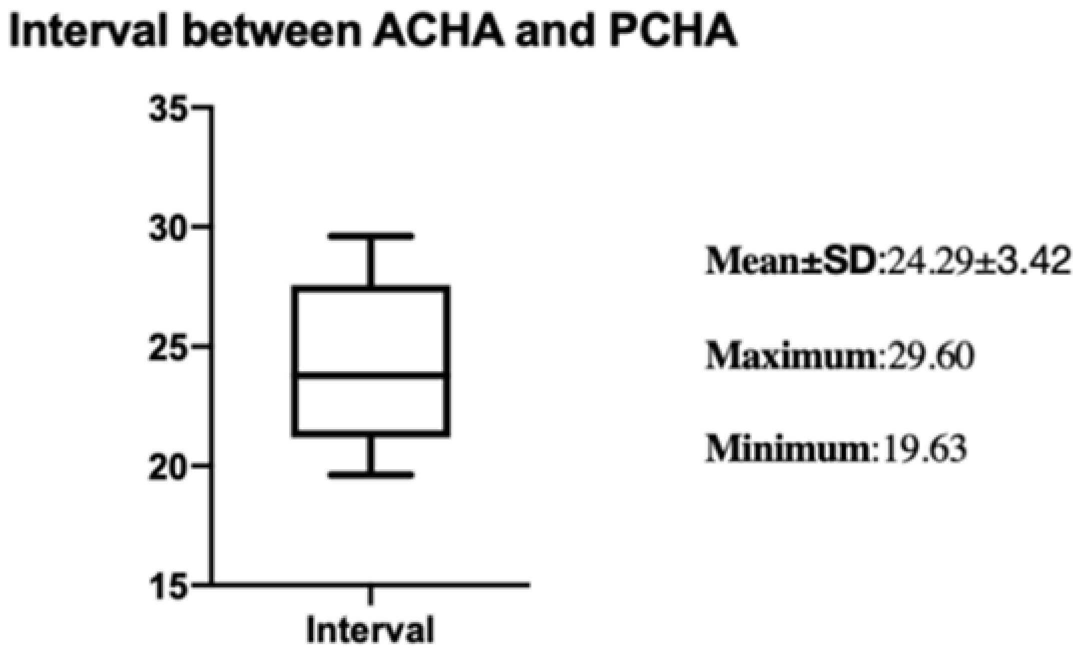

Figure 10

The average distance in 12 upper limbs between ACHA and PCHA was 24.29 ± 3.42 mm (19.63-29.60mm).

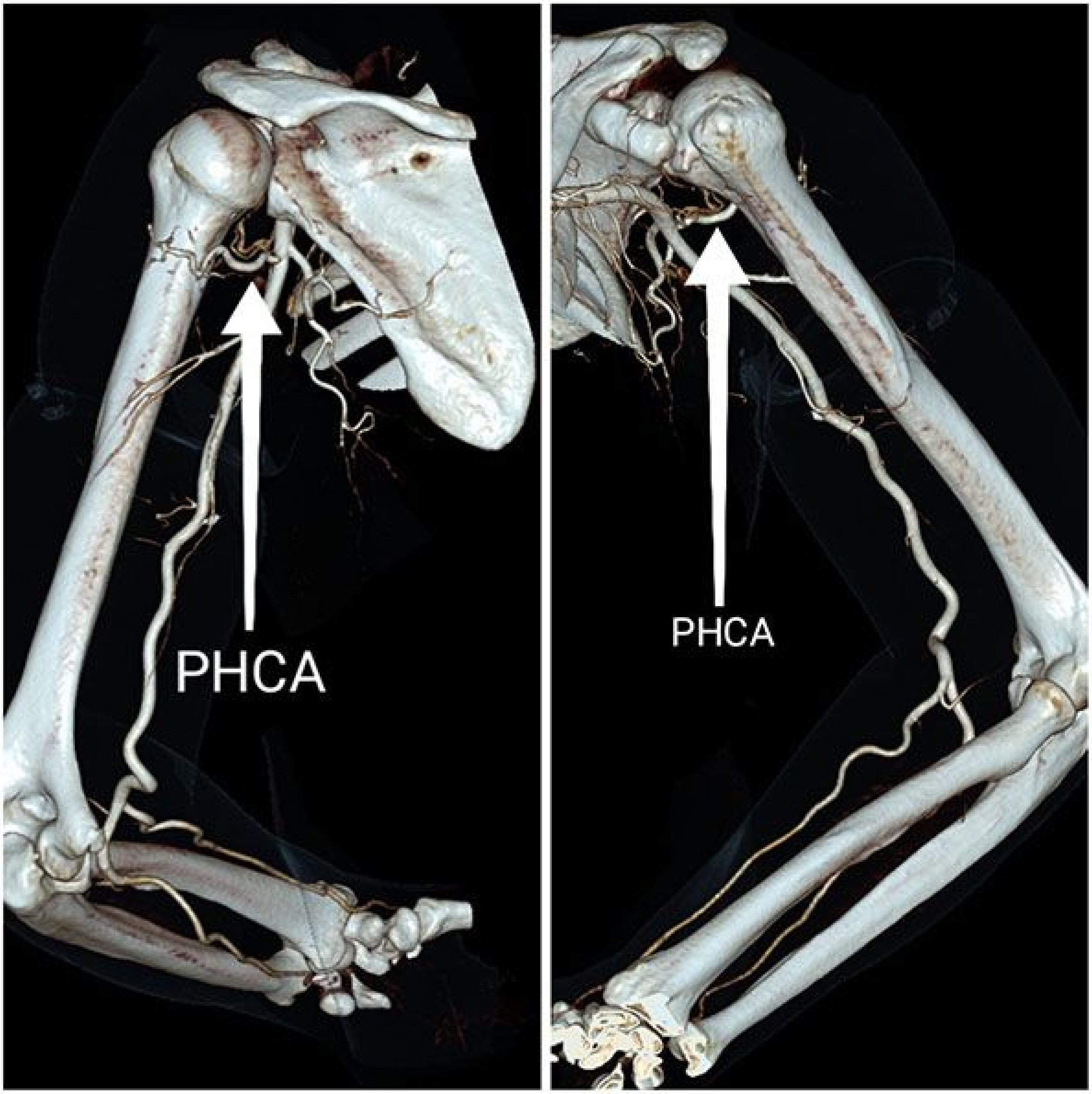

Figure 11

CTA of upper left limb. The ACHA is difficult to visualize in CTA