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Triceps brachii insertional footprint: Under-estimated complexity

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Abstract

Background: The detailed complexity of triceps brachii insertional footprint continues to challenge surgeons as evidenced by continued reports of triceps-associated complications following elbow procedures. The purpose of this study is to describe the three-dimensional footprint of the triceps brachii at its olecranon insertion at the elbow.

Methods: 22 cadaveric elbows were dissected leaving only the distal insertion of the triceps intact. The insertion was defined and probed with a three-dimensional digitizer to create a digital three-dimensional footprint allowing width, height, and surface area of the footprint to be recorded relative to the bare area. The insertional soft tissues of tendon versus muscle along with the shape of the footprints were qualitatively described.

Results: The mean width and surface area of the lateral segment was greater in males than in females (30.07 mm vs. 24.37 mm, p = 0.0339 and 282.1 mm vs. 211. 56 mm, p = 0.0181, respectively). No other statistically significant differences between the sexes were noted. The triceps insertional footprint was “crescent-shaped” and consisted of three regions: central tendon, medial muscular extension, and lateral muscular extension.

Discussion: These findings can help explain the importance of avoiding these muscular structures during triceps-off approaches and provides the framework for future clinical studies.

Clinical Relevance: Basic Science, anatomy study, cadaver dissection.

Keywords

Triceps, tendon, anatomy, distal triceps, footprint

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Introduction

The triceps brachii muscle is an important elbow extensor with a contribution to shoulder function.[1, 2] The anatomy of this muscle and its tendinous insertion has been well-described with several past studies agreeing that there are three independent muscle heads (medial, lateral and long) that coalesce into a single tendinous insertion at the tip of the olecranon process (Figure 1).[3–6] However, recent histologic and gross anatomic studies have suggested a greater complexity to this insertional footprint than previously described.[7–9] The details of this footprint are of particular clinical importance as there are numerous indications for surgical procedures that detach this footprint, necessitating a consequent repair.

Clinical scenarios that warrant surgical intervention involving the triceps brachii tendon include distal humerus fractures, total elbow arthroplasty, contracture release and repair of snapping triceps syndrome.[10–13] The posterior approach is the most common surgical approach used when attempting to access the elbow joint as this provides better joint exposure and has been shown to have a lower risk of cutaneous neuromas and paresthesia compared to medial

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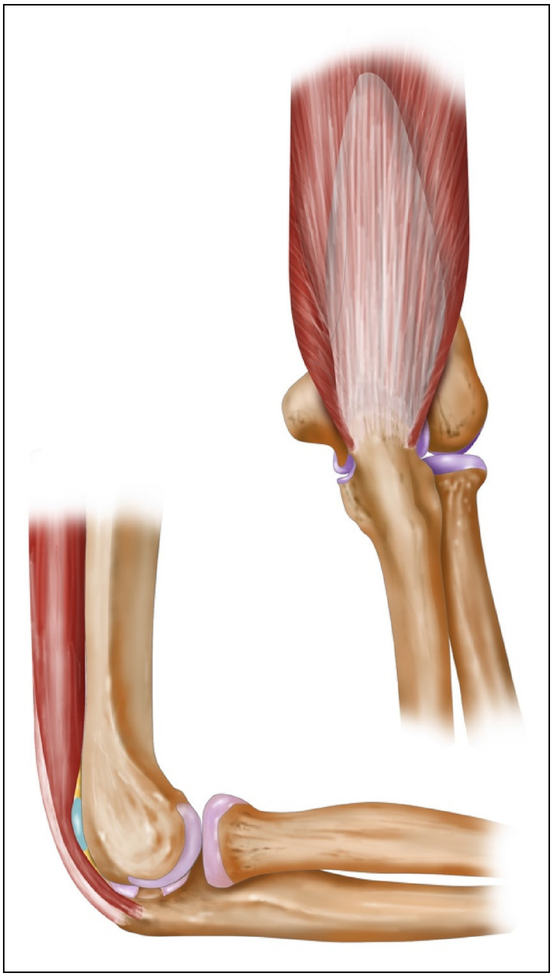

Figure 1. Typical representation of triceps distal anatomy and insertion in most literature.

and lateral incisions.[14] The posterior approaches can further be divided into triceps-off, triceps-on, triceps-splitting, and posterior trans osseous approaches.[15–17] When approaches involve incision or detachment of the triceps tendon at its olecranon insertion, a detailed knowledge of this anatomic footprint is required to restore function and avoid complications.[18]

Numerous complications have been described that have been associated with detachment and repair of the triceps brachii insertional footprint, including subsequent rupture of the tendon and triceps insufficiency.[19–25] The purpose of this study is to provide an increased understanding of the insertional anatomy of the triceps brachii tendon in order to better guide surgical decision-making when operating in this region.

Materials and methods

Twenty-two cadaveric arms from eleven "soft" preserved cadavers were dissected, leaving only the intact distal triceps insertion. There were six males and five females; 11 left and 11 right, and no specimen had any visible pathology.

Meticulous dissection and significant time was spent in tracing all elements of the triceps to the insertion site. The posterior capsule and fat pad were removed, until the triceps fibers, traced to the proximal muscle/tendon fibers, were identified. The first stage was visual inspection to carefully document the whole insertion, and define tendon insertion onto bone, versus muscle insertion onto bone, with little / no macroscopically visible intermediary tendon material.

The second stage was three-dimensional mapping and measurements. The outline of the whole triceps footprint was recorded using a three-dimensional digitizer (FARO, Faro Technologies, Lake Mary, FL, USA) mounted with a 1 mm ball probe (Renishaw, Gloucestershire, UK).

The digitized specimens were registered on a three-dimensional inspection software (Figure 2), Geomagic Qualify version 12 (Geomagic, Research Triangle Park, NC). A 3-dimensional virtual model was subsequently created from the point cloud, and a surface fitted. The footprint components (tendon versus muscle insertion onto bone) were then characterized based on their shape and relative locations with respect to the olecranon (Figure 3 and 4).

In order to "normalize" the anatomy and consistently use a normalized parameter for subsequent anatomic description, a reference plane was constructed along the central ridge of the greater sigmoid notch as this is a reproducible normalized, sagittal plane, landmark in the olecranon. All subsequent measurements were based on this normalized reference plane (Figure 5). The surface length and width were taken using the central and distal points on the bone surface with the contours of the bone taken into consideration (Figure 3). The height measured was the maximum height of the footprint anywhere along its length, parallel to the normalized sagittal plane. The area of the muscle insertion was computationally derived.

A Student t-test for two independent samples was used to determine the presence of any statistical difference between males and females and between the medial versus the lateral extensions, and a Student's t-test for two dependent samples was used between the left and right sides. SPSS version 20 was used (SPSS, IBM corporations, Somers, NY) and a P-value of less than 0.05 was considered significant.

Results

The average age of the elbows was 80.5 years (range 68–92). The initial aspect of this study focused on the visual inspection of the triceps footprint, of which two findings were highly relevant. In all cases, the central portion of the insertion footprint was "dome-shaped" with thinner extensions distally, extending medially and laterally along

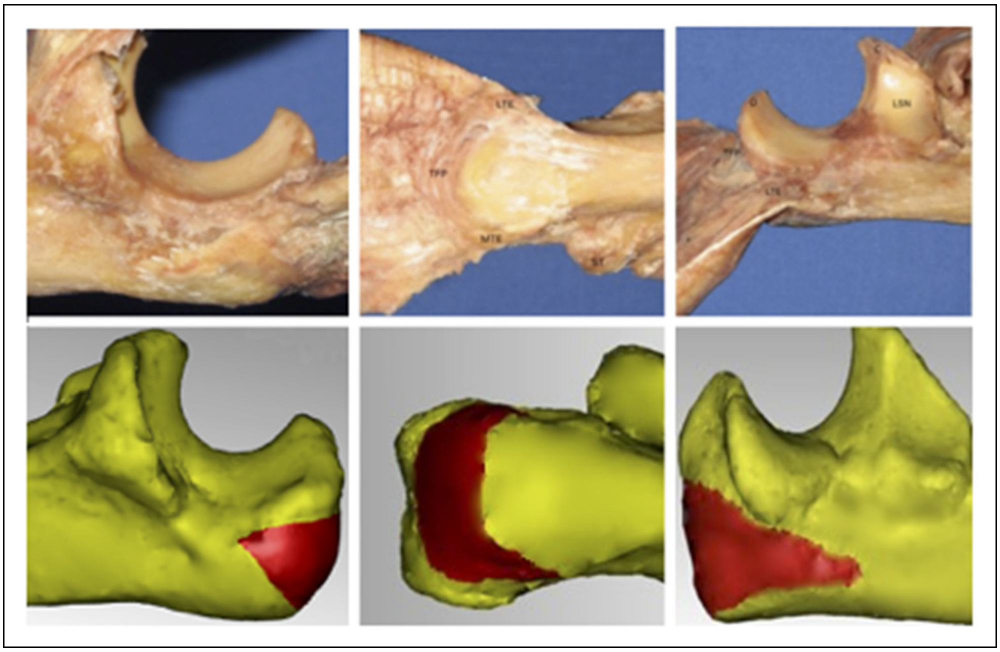

Figure 2. Triceps fully dissected, with preservation of all elements of the musculotendinous unit, with the accompanying digitized medial, posterior, and lateral insertional views (MTE- medial triceps extension, LTE- lateral triceps extension, TFP- central tendon footprint, ST- sublime tubercle, LSN- lesser sigmoid notch, O- olecranon tip, C- coronoid).

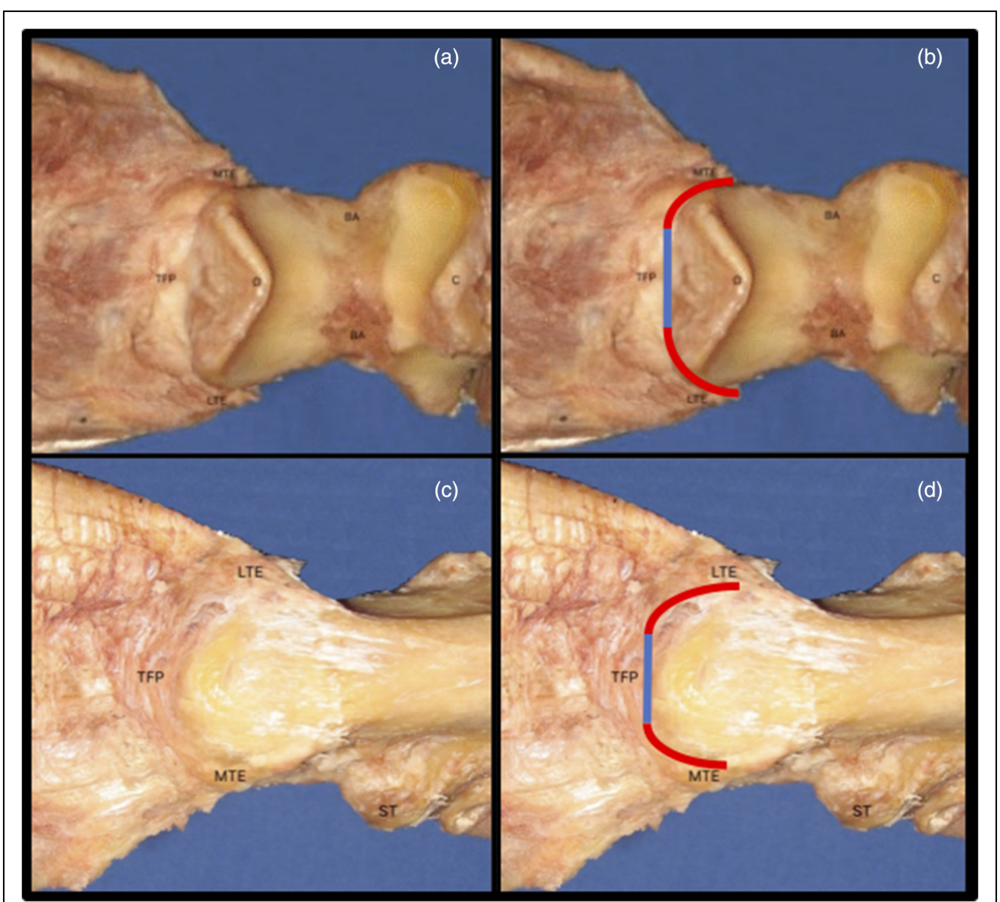

Figure 3. Figure 3a: Anterior view of Triceps insertion and olecranon, figure 3b: anterior view with demarcation between central tendon insertion to bone (blue) and muscle fibres inserting to bone (red), figure 3c: posterior view, figure 3d: posterior view with demarcation between central tendon insertion to bone (blue) and muscle fibres inserting to bone (red) (MTE-medial triceps extension, TFP-central tendon foot print, LTE – lateral triceps extension, O-olecranon tip, BA-Bare Area, C-Coronoid).

the olecranon in a "C" or crescentic shape (Figures 2–4). These medial and lateral extensions did not extend distal to the bare area of the olecranon in any specimen. A second key finding was related to the difference in proportional contribution between muscle and tendon. The central tendon insertion could trace tendinous material to the bone interface for the apical "flat" area of the olecranon. For the medial and lateral extensions, while there was a variable superficial tendinous/aponeurotic component (Figure 1), the deep insertional structure was muscular, without a visible tendinous component.

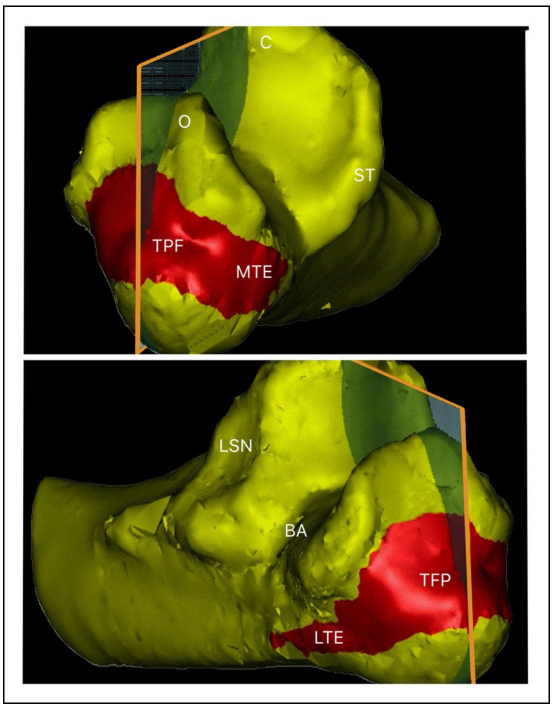

Figure 4. 3D reconstructions of the digitized data of triceps insertion, depicting muscular extensions of the medial and lateral heads that insert into the olecranon without a significant length of tendinous material at the interface. C-Coronoid, LSN-Lesser Sigmoid Notch, ST-Sublime Tubercle, BA-Bare Area, THP-Central Tendon Footprint, LTE-Lateral Triceps Extension, MTE-Medial Triceps Extension.

The structure of the insertional interface at the bone, between the central tendon and medial and lateral extensions was significantly different in all specimens. In all cases, the medial and lateral heads insert onto the medial and lateral olecranon, respectively, without any macroscopically visible tendinous material on the deep surface, while the long head has a truly central tendinous insertion.

The mean width was 53.43 mm (range 38.2–70.3), mean height was 16.56 mm (range 10.9–21.2), and mean total surface area was 523.98 mm^2 (range 323.0–742.7) The mean surface area of the medial segment was 274.45 mm^2 (range 160.1–443.0) and the lateral segment was 249.55 mm^2 (range 133.9–410.2). No significant differences were found between left and right arms, nor the surface area between the medial and lateral segments. Significant differences were found between males and females with regards to mean width of lateral extension from midpoint 30.07 mm^2 vs 24.37 mm^2 ($p = 0.0339$), and the mean surface area of lateral extension from midpoint 281.2 mm^2 vs 211.56 mm^2 ($p = 0.0181$). The results are shown in Tables 1 and 2.

Discussion

There is currently limited literature that describes the insertional footprint of the triceps brachii muscle/tendon onto the olecranon process of the ulna. The purpose of this study was to utilize a three-dimensional digitizer to provide a more detailed description of this clinically important anatomy. There were two findings from this study that are particularly noteworthy, one of which is related to the general shape of the muscle at the site of insertion and the other of which pertains to the distinction between muscle and tendon at this site.

Previously, the triceps insertion footprint has been described as dome-shaped consisting of both medial and lateral expansions.[4] Our findings confirm that the central portion of the insertion footprint is indeed dome shaped. However, we have found that the consistent distal

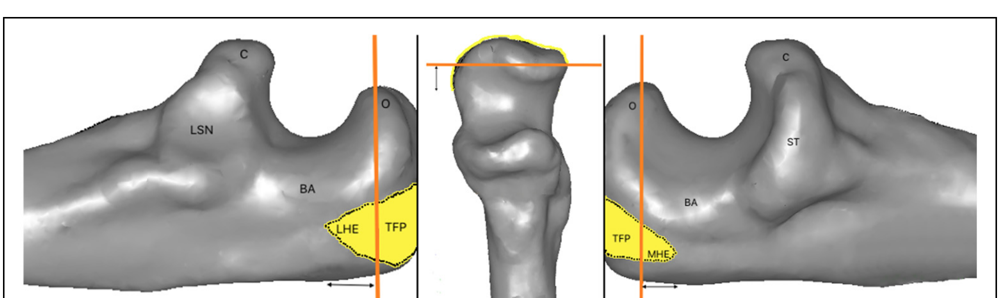

Figure 5. A reference plane was constructed on the central ridge of the greater sigmoid notch. All subsequent measurements were based on this reference plane. C-Coronoid, LSN-Lesser Sigmoid Notch, ST-Sublime Tubercle, BA-Bare Area, TFP-Central Tendon Footprint, LTE-Lateral Triceps Extension, MTE-Medial Triceps Extension.

Table 1. Quantitative Measurements from All Specimens.

Sex	Side	Width (M to L) (mm)	Width (L to C) (mm)	Width (M to C) (mm)	Height (mm)	Projected Height (mm)	SA of Side to Center (mm^2) M	SA of Side to Center (mm^2) L	SA Total (mm^2)
M	R	50.8	28.5	22.3	18.1	19.1	209.2	285.4	494.6
	L	61.9	36.5	25.4	14.3	14.9	232.5	282.1	514.6
F	R	66.2	32.3	33.9	17.9	20.9	443	248.5	691.5
	L	57.4	27.4	30	19.5	21.6	308.6	241.9	550.5
M	R	58.2	24.1	29.1	10.9	11	282.5	133.9	416.4
	L	56	31.8	24.2	14.2	14.9	254.8	244.4	499.2
F	R	43.2	17.8	25.4	12.8	13.2	160.1	162.9	323
	L	49.3	19.1	30.3	15.6	17.6	241.1	169.9	411
M	R	41.4	17.1	24.3	13.9	14.6	240.8	143.9	384.7
	L	47.4	21.9	25.5	21.2	22.5	336	280.2	616.1
F	R	41.9	24.1	17.8	15.5	15.9	190.4	214.3	404.7
	L	38.2	18.9	19.3	14	14.6	207.6	182.5	390.1
F	R	46.1	22.6	23.5	17.3	18.1	242.8	207.3	450.1
	L	55.1	28.8	26.3	14.8	15.1	218.7	181.9	400.6
M	R	66.1	35.3	30.8	18.1	18.7	339.7	381.7	721.4
	L	63.9	27.7	36.2	19.6	20.3	377.7	312.1	689.8
M	R	68.9	40.5	28.4	20.6	23.5	332.5	410.2	742.7
	L	50.9	30.7	20.2	16.2	18.2	277.2	330.3	607.5
F	R	48.5	26.3	22.2	17.7	18.7	343.2	239.4	582.5
	L	46	26.4	19.6	17.5	18.2	283.8	267	550.8
M	R	47.8	28.8	19	18	18.7	244.8	247.6	492.4
	L	70.3	38	32.31	16.6	17.5	270.8	322.6	593.4

*M to L: medial to lateral *L to C: lateral to center.
*M to C: medial to center.
SA: surface area.

contributions from both the lateral and medial expansions result in the entire insertional footprint conforming to a "C" shape that can be described as "croissant-shaped." This updated anatomical description and understanding of the triceps footprint can be clinically useful for surgeons operating in the elbow region.

An additional important finding from this study is with regard to the difference in proportional contribution between muscle and tendon at the insertion site. In the previously referenced anatomic study by Keener et al.; the authors described in great detail the three-dimensional structure of the triceps footprint including both its medial and lateral expansions. In this study, the authors describe a medial tendon that blends with the central tendon into the olecranon and a lateral expansion that's continuous with the superficial fascia of the anconeus muscle.[4] A 2006 study by Windisch et al. similarly describes a lateral extension that forms a retinaculum that then

Table 2. Mean Quantitative Measurements and p-values.

	Total	Right Side	Left Side	p-value	Males	Females	p-value
Mean Width (mm)	53.43	52.65	54.22	0.709	56.97	49.19	0.0527
Mean Width Lat-Cent (mm)	27.48	27.04	27.93	0.7588	30.07	24.37	0.0339
Mean Width Med-Cent (mm)	25.73	25.15	26.30	0.613	26.47	24.83	0.4707
Mean Height (mm)	16.56	16.44	16.68	0.8314	16.81	16.26	0.6230
Mean Total Surface Area (mm^2)	523.98	518.55	529.42	0.8389	564.4	475.48	0.0857
Mean SA Medial Segment (mm)	274.45	275.36	273.53	0.9507	283.21	263.93	0.5365
Mean SA Lateral Segment (mm)	249.55	243.19	255.9	0.6952	281.2	211.56	0.0181

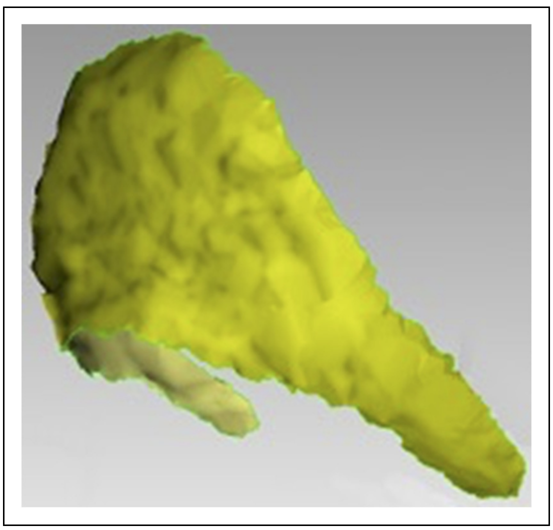

Figure 6. 3D extraction of the digitized whole triceps insertional footprint.

becomes confluent with the anconeus distally.[5] In 2017, Barco et al. further confirmed these previous findings and additionally described three distinct areas at the site of insertion on the olecranon that corresponded to the posterior capsular insertion, deep muscular portion and superficial tendinous portion of the triceps.[3] Although each of these studies contributed to a better overall understanding of the insertional anatomy of the triceps muscle, none of these studies distinguish between true tendinous versus muscular insertion onto bone. This study is the first to suggest that the medial and lateral extensions of the triceps brachii consist of muscle, not true tendon, that directly inserts onto bone.

Indeed, this finding is consistent with a previous study that analyzed the electromyographical activity of the triceps through electrodes that were placed near the olecranon insertion in the medial, central and lateral triceps. Electrical activity was generated throughout the arc of extension in both the medial and lateral insertional components of the triceps implying that active contractile function exists even in these distal ends and dispelling the previous belief that the triceps footprint is wholly tendinous.[26] This is clinically significant as skeletal muscle, unlike tendon, has limited regenerative capacity when tightly bound by suture.[27–29] Muscle that is firmly affixed by suture to a bony footprint undergo fibrosis, thereby losing their contractile ability.[27–32] Our results demonstrate that, while the central triceps terminates in a long tendinous structure amenable to anatomic repair, the same is not true for the medial and lateral extensions as these consist of combined muscular and aponeurotic elements at the insertion. Therefore, repairing these extensions will result in loss of contractility and should be preserved whenever possible during surgical exposures.

In conclusion, the insertional footprint of the triceps is better described as "crescent" shaped given its consistency in all 22 of our specimens (Figure 6). We observed that the insertion of the long head of the triceps was a true tendinous interface to bone. However, the insertion of the lateral and medial heads lacked any significant tendinous insertion, instead primarily composed of contractile muscular extensions which approach the bare area of the olecranon, with a superficial static aponeurosis. While some anatomic illustrations appear to depict this, this has not previously been described in detail, and in context to the functional implication. Our study found that about 60% of the specimens had a longer extension medially than laterally, the functional significance of which is yet to be determined. The extent of the medial and lateral insertional footprint is often underappreciated. Previous descriptions of a "dome-shaped" tricipital insertion are over simplistic, as they fail to account for the extent of the medial and lateral extensions. Instead, the tricipital insertion is more accurately described as crescentic shaped (Figures 7 and 8), with a recognition of important contractile medial and lateral, predominantly muscular, extensions, superficially covered by aponeurosis.

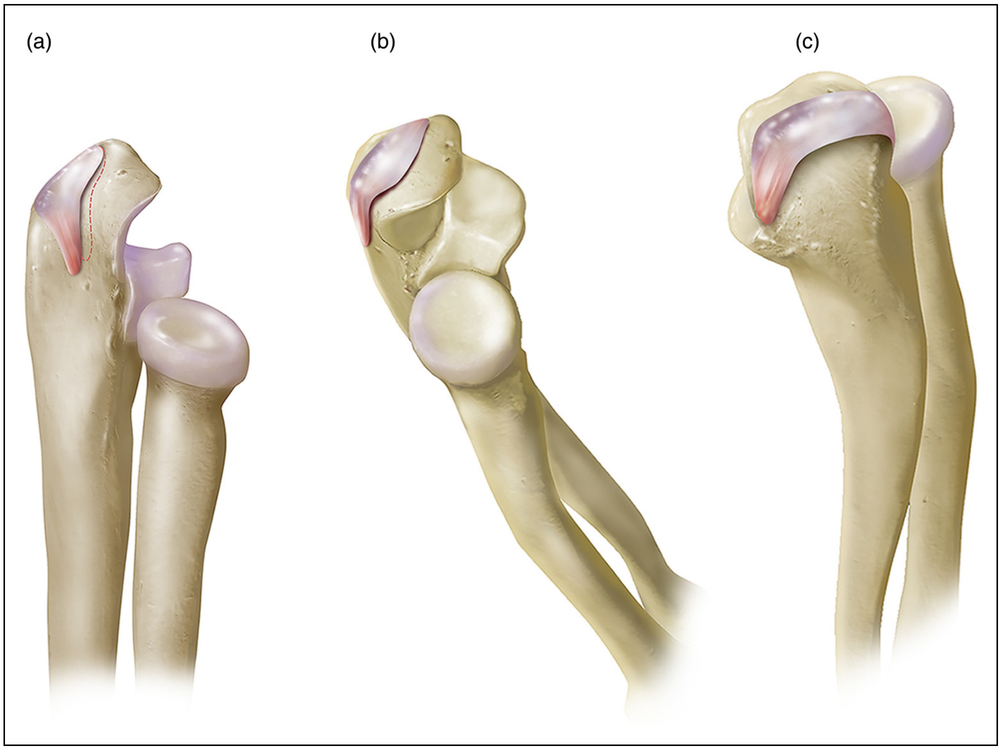

Figure 7. 3D rendered image of the triceps insertion from three different viewpoints.

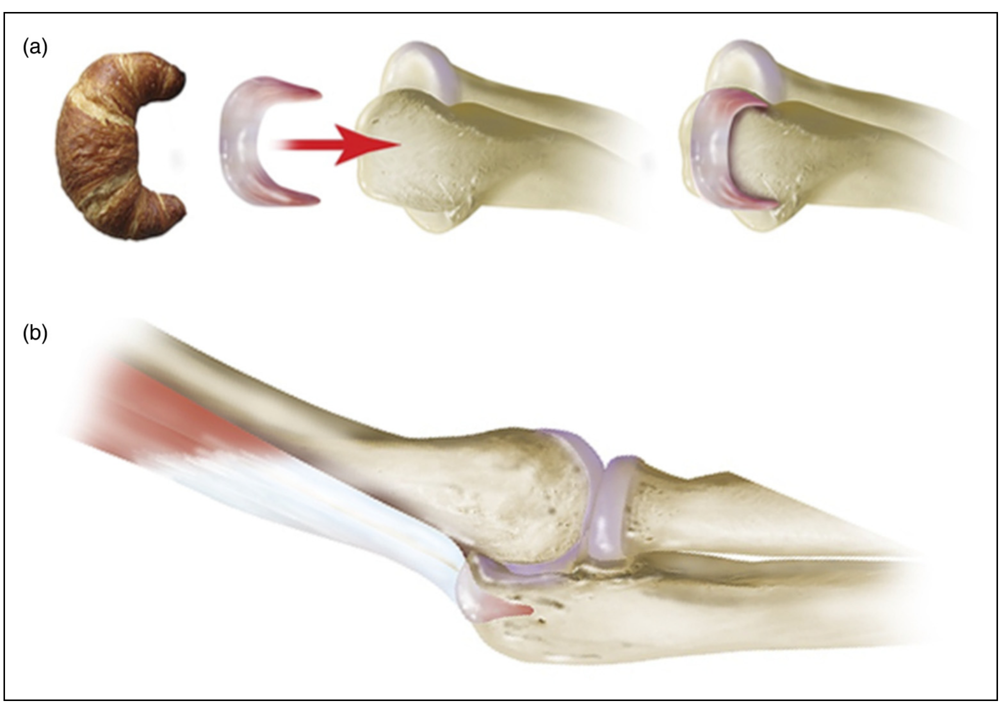

Figure 8. (a) Graphic rendered image of the triceps insertion with a "croissant" like 3D shape wrapped around the posterior, medial, and lateral olecranon process. (b) A more accurate illustration of the triceps insertional footprint, with the superficial aponeurosis of the lateral muscular extension removed.

Limitations of the study

This was an anatomical study performed on preserved cadaveric elbows, with relatively few specimens. A larger cohort of fresh, non-preserved specimens would possibly have been able to decrease the variance, which is high in this relatively limited sample study.

Conclusion

The height and surface area of lateral extension from midline was larger in males than females. No other differences were found between the genders. The shape of the tricipital insertion was very consistent as all specimens had central "dome" shaped insertion with predominantly muscular medial and lateral extensions extending along the olecranon distal to its apex. This study corroborated previous EMG data by demonstrating under-appreciated muscular elements underneath the superficial aponeurotic structure laterally and medially.

Our study found that the "dome-shaped" appearance of the tricipital insertion is not adequate as it does not appreciate the extent of the medial and lateral extensions. Instead, we propose the tricipital insertion is better described as crescentic or "croissant" shaped. These findings suggest that every attempt should be made to avoid the release and reattachment of the medial and lateral triceps insertional extensions in order to protect these contractile elements, and particular caution should be used when operating in the medial aspect of the bare area. Additionally, this improved understanding of the insertional anatomy may play a role in future developments of biologic therapy for triceps repair.

IRB: No IRB approval was needed for this cadaveric anatomical study

Declaration of Conflicting Interests

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