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Triceps insertion violation from commonly applied olecranon plating system: a comparison

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Background: Surgeons generally avoid compromising tendon insertions during fracture fixation; however, it is a common practice to violate the triceps tendon insertion during olecranon plate fixation. The assumption in these procedures is that minimal triceps insertion is disrupted. The purpose of this study was to quantify the degree of triceps insertion that is violated, intentionally peeled off, by commonly utilized olecranon plating systems. The secondary objectives are to measure the surface area of the triceps insertion and olecranon using a 3-dimensional (3D) technique and compare them to 2 similar papers that were done using 2-dimensional (2D) measurements. Evaluating the amount of olecranon plates' violation to the triceps insertion was not one of the objectives of those papers. It was hypothesized that olecranon plate fixation violates a larger portion of the triceps footprint than previously thought.
Methods: Six olecranon plate designs and 12 cadaveric upper-extremity specimens were used. Olecranon plates, triceps insertion footprints, and olecranon surface areas were digitized as 3D surface models with a laser scanner (SG100; ShapeGrabber Inc., Ottawa, Canada). The violated triceps insertion footprint area, required to accommodate the plate surface on the olecranon, was calculated using 3D modeling software (MeshLab; ISTI - CNR Research Center, Pisa, Italy). Results were compared with both 2D and 3D measurements and the 2D surface area measurements of 2 previous studies.
Results: The median triceps insertion footprint violation for 6 common olecranon plates was 46% (range, 40%-62%) using 3D analysis, and 47% (range, 41%-64%) using 2D analysis. The greatest footprint violations were observed with Synthes – Wide VA at 62% and Smith-Nephew Peri-LOC (Smith & Nephew, Andover, MA, USA) plates at 58%, while the least violation was seen with Wright Medical EPS (Wright Medical, Memphis, TN, USA) and Synthes – Extended (DePuy Synthes, Raynham, MA, USA) plates at 40%. The median triceps insertion surface area was 254 mm^2 (range, 193-348 mm^2) and 260 mm^2 (range, 171-364 mm^2) using 2D and 3D methods, respectively. Median olecranon surface area was 645 mm^2 (range, 478-775 mm^2) and 573 mm^2 (range, 411-722 mm^2) by 2D and 3D methods, respectively.
Conclusions: Many commonly used olecranon plating systems violate a large portion of the triceps insertion footprint which is up to 62% in this study. A better understanding of the triceps insertion footprint, olecranon anatomy, and clinical implications of triceps footprint disruption may lead to improvements in olecranon plate design and postoperative outcomes. Future studies should assess the possibility of any clinical implications of triceps insertion disruption.

The triceps brachii muscle is the primary elbow extensor muscle, and its injuries and repair techniques have been documented.[2,6] Injuries to the distal triceps are not commonly encountered as they account for about 1% of tendon injuries.[7,12] During fracture fixation, surgeons generally avoid injuring and compromising tendon insertions; however, it is a common practice to violate the triceps

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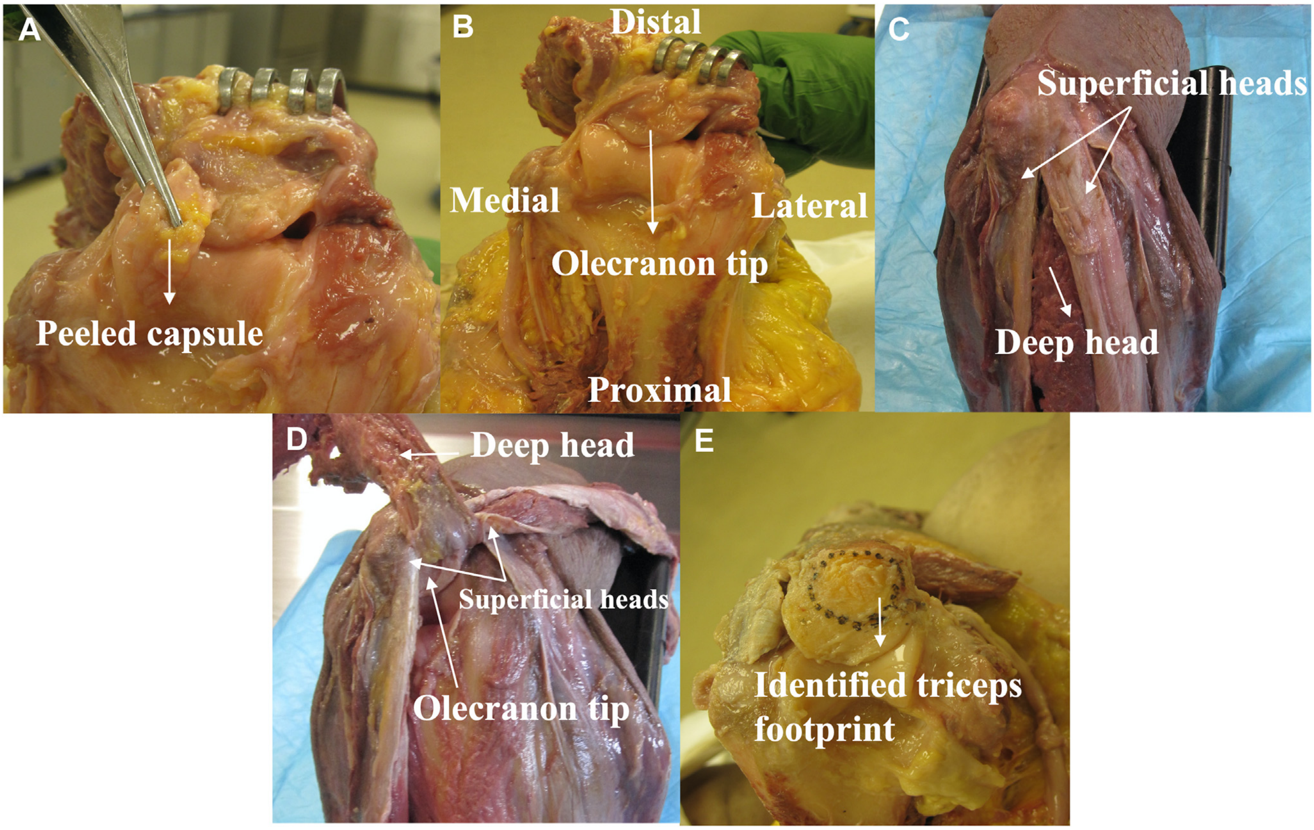

Figure 1 (**A**) Separation of the capsule from the deep triceps insertion. (**B**) Triceps insertion and the uncovered surface of the olecranon between the tendon and the olecranon tip after removal of the posterior capsule. (**C**) Split superficial head of the triceps with muscle belly of the deep head beneath. (**D**) Reflected superficial and deep triceps heads. (**E**) Marked footprint of the triceps insertion after excising the superficial and deep insertions of the triceps.

tendon insertion during olecranon fracture fixation. Violation of the insertion can be defined as the peeling of part of the tendon insertion which is done intentionally in olecranon plating which was studied in the literature via some ultrasound and magnetic resonance imaging (MRI).[11] Much of the current olecranon plating systems require direct contact on the olecranon surface and as such require peeling and releasing of potentially a major portion of the triceps tendon insertion. The general concept is that during olecranon plating, a small part of the triceps tendon is peeled off from the olecranon process to accommodate the current olecranon plating systems. However, the degree of this tendon insertion disruption in 3-dimensions (3D) has not been evaluated.

To evaluate the degree of triceps insertion violation during olecranon plating, an understanding of triceps insertion anatomy is required. However, previous anatomic and radiographic studies only assessed the 2-dimensional (2D) anatomy of the triceps insertion; although, their intention was not to evaluate olecranon plate interference with the insertion.[3,6,9,11,14] By gaining more knowledge about the triceps insertion footprint in 3D and quantifying the amount of triceps insertion violation by some of the commonly used olecranon plates, surgeons can make more informed decisions about olecranon plate osteosynthesis systems and their impact on the triceps insertion footprint. This could also have implications for future olecranon plate designs by having the least insertion violation possible. The primary purpose of this study was to quantify the degree of triceps footprint violation by commonly used olecranon plating systems. This study aimed also in the secondary objectives to further outline the 2D and 3D footprint of the triceps insertion and olecranon surface. It also compared the triceps insertion surface area and measurements in relation to the olecranon surface area with what has been previously reported in the literature in the 2D model. However, looking at the amount of triceps insertion violation while using olecranon plates was not a part of these studies. It was hypothesized that during olecranon plate fixation, a third or more of the triceps footprint is violated.

Materials and methods

Cadaveric specimens and anatomic dissection

A total of 12 specimens (3 female, 7 male, 2 unidentified) were examined after obtaining ethics clearance from Queen's University Health Sciences & Affiliated Teaching Hospitals Research Ethics Board on December 9, 2020, No. 6031436. The specimens did not have previous elbow trauma, surgery or advanced arthritis. The mean age was 81.3 ± 12.8 years (range, 60-93 years). The anatomical dissections were performed by upper-extremity–trained orthopedic surgeons. To identify the triceps insertion surface area (Fig. 1), we made a posterior midline incision, dissected down to the superficial triceps fascia, separated the deep and superficial heads of the triceps. We followed a similar method as described by Keener et al,[6] identified the capsule, and separated and excised it from the deep head (Fig. 1, *D*). The superficial and deep heads of the triceps were peeled off the olecranon process while marking out the periphery of their insertion (Fig. 1, *E*).

2D and 3D evaluations of the triceps insertion

Two methods were performed to measure the triceps insertion surface areas using a digital vernier caliper with precision up to 0.1

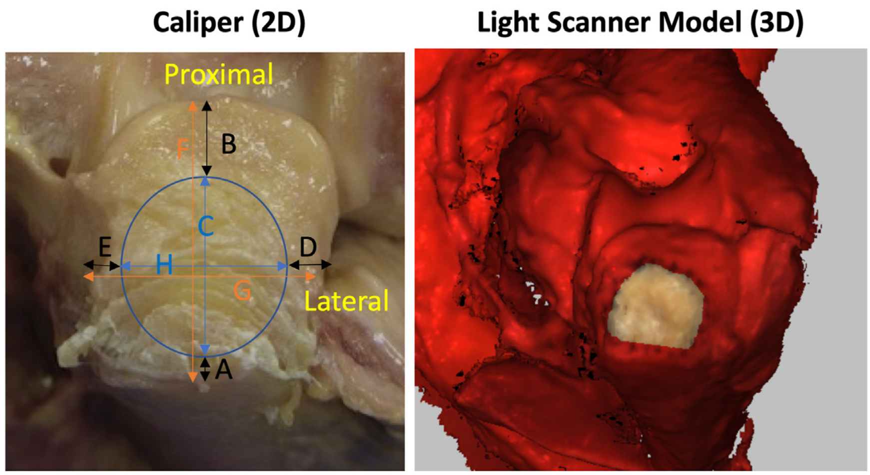

Figure 2 Comparison of 2-dimensional and 3-dimensional methods for measuring the triceps insertion and olecranon. (**A**) Base to tendon distance. (**B**) Tendon to tip distance. (**C**) Triceps insertion length. (**D**) Lateral to tendon distance. (**E**) Medial to tendon distance. (**F**) Olecranon length. (**G**) Olecranon width. (**H**) Triceps insertion width.

Figure 3 Picture of 5 of the studied olecranon plating systems ordered from the *Left* to the *Right* as the following: Synthes – Narrow LCP, Synthes – Extended, Acumed – Long, Smith-Nephew – Peri-LOC, Synthes – Wide VA. * Wright Medical – EPS (missing in this image).

mm (2D method) and the Artec Eva light scanner (Artec 3D, Senningerberg, Luxembourg) (3D Method). The 2D method was performed following previous studies where the triceps insertion footprint was calculated by multiplying the length and width of the footprint.[3,14] The different 2D measurements of the olecranon and triceps insertion were taken as illustrated in Figure 2. The 3D analysis was done using a light scanner as demonstrated in Figure 2 where a minimum of 10 scans varying in orientations were taken for each specimen. The scans were then processed by aligning the scans to create a cohesive 3D surface model. To reduce overlap and outliers, filters were applied to the 3D model before calculating the triceps insertion surface area.

Olecranon plates 3D scanning and calculation of triceps insertion violation

Six common olecranon plating systems were used in this study (Narrow LCP, DePuy Synthes, Raynham, MA, USA; Extended, DePuy Synthes, Raynham, MA, USA; Long, Acumed, Hillsboro OR, USA; Peri LOC Smith & Nephew, Andover, MA, USA. Wide VA, DePuy Synthes, Raynham, MA, USA; EPS, Wright Medical, Memphis, TN, USA) (Figs. 3 and 4). To identify the surface area where the olecranon plating systems violated the triceps insertion, a reverse mold was created to outline the inner surface and this was then 3D laser scanned (SG100; ShapeGrabber Inc., Ottawa, Canada) (Fig. 5). First, the 3D model of the total inner surface area of the olecranon plate flange was calculated (MeshLab; ISTI - CNR Research Center, Pisa, Italy), where we only considered the location at which the olecranon plating systems could cover and violate the triceps insertion labeled as C and H (Insertion length and width) in Figure 2. Next, measurements A (4.76 mm) and B (12.02 mm) from Figure 2 were used to determine the areas distal and proximal to the triceps insertion. The surface areas in these two parts were subtracted from the total inner surface area of the olecranon plate flange as those sections do not directly violate the triceps insertions. Lastly, the percentage of triceps insertion violated by each olecranon plating systems was determined using each specimen's triceps insertion surface area as seen in the equation below. These mathematical calculations were utilized to quantify the anticipated degree of triceps insertion violation, based on the surface area of the plate section specifically designed to interact with the tendon insertion. This method of virtual plating of the olecranon has not been validated.

$$\%\ of\ Triceps\ Insertion\ Violated = \frac{Olecranon\ Plate\ Surface\ Area\ covering\ triceps\ insertion}{Triceps\ Insertion\ Surface\ Area} \times 100\%$$

Statistical analysis

The 2 measurement methods for the triceps insertion surface areas were compared using nonparametric statistical tests, Kruskal-Wallis and Mann-Whitney *U* tests with a significance level of 0.05 ($\alpha = 0.05$). This statistical analysis was chosen due to the small sample size of our study and not being able to assume that the data were normally distributed.

Results

Triceps footprint violation

The median triceps footprint violation by the 6 olecranon plates using the 3D method was 46% (40%-62%) compared to a median of

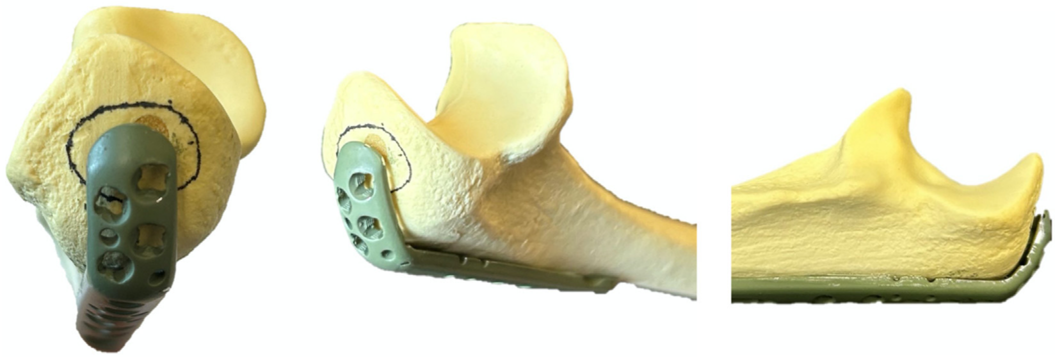

Figure 4 Front, oblique, and side views of a Sawbones model of the proximal ulna demonstrating olecranon plate position with the triceps insertion outlined in black.

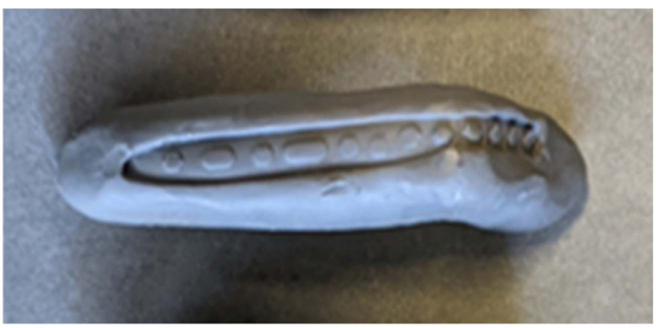

Figure 5 An example of a reverse mold which is made using the inner surface of the olecranon plate and then scanned using 3-dimensional laser–scanned (SG100 ShapeGrabber). This reverse mold is for the Wright Medical – EPS olecranon plate.

48% (41%-64%) using the 2D method. Synthes – Wide VA and Smith-Nephew Peri-LOC plates demonstrated the largest amount of triceps violation by 62% and 58% respectively using the 3D method while Wright Medical – EPS and Synthes – Extended plates had the least violation by 40% for both (Table I and Fig. 6). There was no statistically significant difference ($P = .58$) when comparing the triceps footprint violation between 2D and 3D methods.

Surface areas of olecranon plate flange, triceps insertion, and olecranon

The surface areas of olecranon plate flange were found to be in the following order from the least to the highest: Synthes - Narrow LCP, Wright Medical – EPS, Synthes – Extended, Accumed – Long, Synthes - Wide VA, Smith-Nephew - Peri-LOC. The total inner surface areas of the olecranon plate flanges ranged from 133 mm^2 to 281 mm^2 with a median of 170 mm^2. The total inner surface area of the olecranon plate flanges violating the triceps insertion ranged from 103 mm^2 to 162 mm^2 with a median of 121 mm^2 (Table II).

The median triceps insertion surface area was 254 mm^2 (193 mm^2-348 mm^2) and 260 mm^2 (171 mm^2-364 mm^2) using the 2D and the 3D methods respectively (Fig. 7). The median olecranon surface area was 645.1 mm^2 (478 mm^2-775 mm^2) and 573 mm^2 (411 mm^2-722 mm^2) using the 2D and the 3D methods respectively (Fig. 8). 2D and 3D triceps insertion surface areas were not statistically different ($P = .98$); however the 3D olecranon surface area was 11% smaller than the 2D olecranon surface.

Table I
Percentage of triceps violation by 6 commonly used olecranon plates using 2-dimensional and 3-dimensional methods.

Olecranon plates	Three-dimensional inner surface area of the olecranon plate flange violating triceps insertion [mm^2]
Synthes – Narrow LCP	110 (91-126)
Synthes – Extended	103 (85-118)
Acumed – Long	131 (108-150)
Smith-Nephew – Peri-LOC	151 (124-172)
Synthes – Wide VA	162 (134-185)
Wright Medical - EPS	104 (85-118)

They are reported using the median with the interquartile range.

Triceps insertion and olecranon dimensions

Table III and Figure 2 show the mean dimensions of the triceps insertion and olecranon in the longitudinal and horizontal axes. The distances from each side of the triceps insertion to the corresponding border of the olecranon were summarized and compared to the studies of Keener et al and Barco et al (Table III). A few of the measurements were not obtained in those studies as shown in the table.

Discussion

Triceps insertion violation

There are no studies assessing the clinical function of the triceps after olecranon plate osteosynthesis and no studies have assessed the degree of triceps violation during this type of surgery. Triceps compromise after olecranon fracture fixation might be overlooked and thought to be related to the expected postoperative course. However, by understanding the anatomy of the triceps footprint and quantifying the amount of it that is violated during surgery, surgeons may need to assess how this might have an impact on the triceps function.

In the current study, almost 50% of the triceps insertion was found to be violated on average with the studied olecranon plating systems. Evaluating the triceps insertion violation while using olecranon plates based on their 3D evaluation in this study showed comparable results even when compared to the triceps insertion measurements by Keener et al and Barco et al.[3,6]

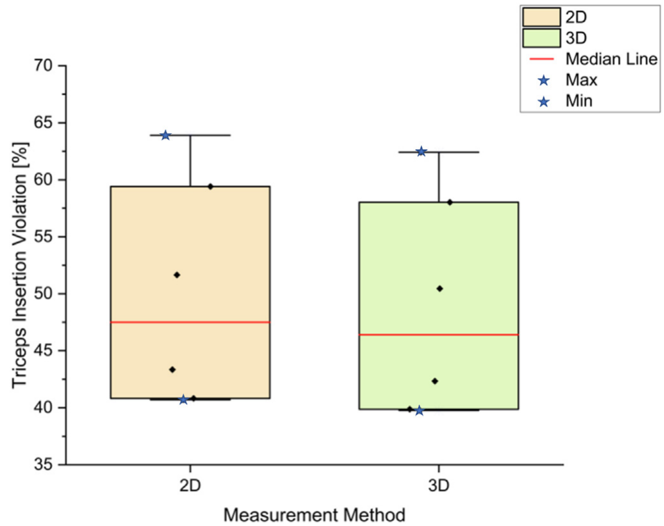

Figure 6 Box-whisker plot comparing 2-dimensional and 3-dimensional measurements for amount of triceps violated by olecranon plating systems.

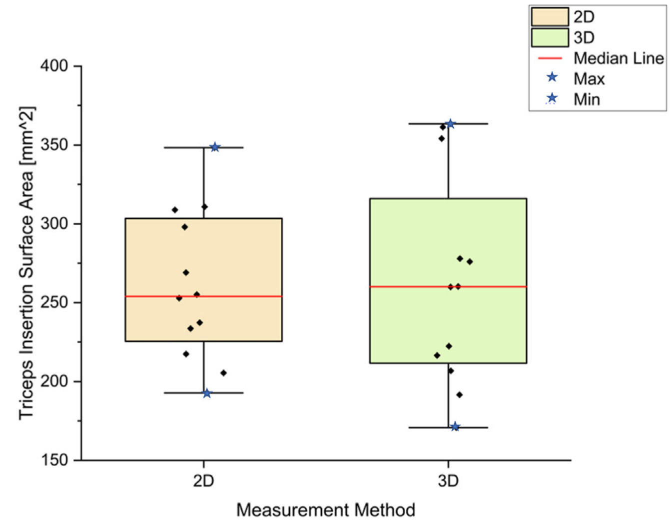

Figure 7 Box-whisker plot demonstrating the measured triceps insertion surface areas in 2-dimensional and 3-dimensional methods.

Table II
Calculated 3-dimensional surface areas of the olecranon plates' portion overlying olecranon.

Olecranon plates	Percentage of triceps violation [%]	
	Two-dimensional method	Three-dimensional method
Synthes – Narrow LCP	43 (37-48)	42 (37-51)
Synthes – Extended	41 (34-45)	40 (35-48)
Acumed – Long	52 (44-57)	50 (45-61)
Smith-Nephew – Peri-LOC	59 (50-66)	58 (51-71)
Synthes – Wide VA	64 (54-71)	62 (55-76)
Wright Medical – EPS	41 (35-45)	40 (35-48)

They are reported using the median with the interquartile range.

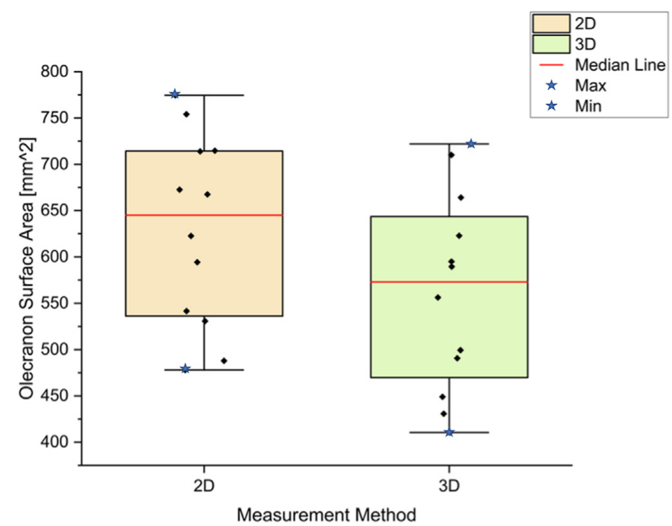

Figure 8 Box-whisker plot to compare the olecranon surface areas using the 2-dimensional and 3-dimensional assessments.

Keener et al measurements of the triceps footprint anatomy are in keeping with the values observed in our study which were summarized in (Table III). Additional measurements were obtained in the current study for olecranon dimensions and the distances between triceps and olecranon borders (Table III); of which, many were not checked by Keener et al and Barco et al.

Our study demonstrates that the triceps insertion measurements were comparable using either the 2D or the 3D method; 254 mm^2 and 260 mm^2, respectively. The olecranon surface area differed between methods and was found to be 11% less in 3D compared to the 2D method, 573 mm^2 and 645 mm^2, respectively. This might be related to the rounded geometry of the olecranon surface area that is better evaluated using 3D techniques. The 2D evaluation using height times width overestimated the total surface area of the olecranon since it is calculated as a rectangle instead of a circle.

The triceps insertion violation that results from the use of olecranon plates may be of clinical concern, especially if the amount of triceps footprint disruption is significant and not repaired. However, even if repaired, it certainly cannot be repaired to bone when the plate is occupying that space. The bigger the plate flange, the more likely it is for surgeons to peel off the triceps insertion sideways since a midline triceps insertion split might not be sufficient to fit the plate well. Even in cases where the amount of triceps violation is partial, it is difficult to know with the current state of the available literature if there are any clinical implications. The number of reported cases in the literature of symptomatic partial triceps injuries is increasing.[2,5,8,10] There is concern that a significant triceps violation, if not repaired well at the time of index surgery or repaired and not healed well after, could simulate a clinical picture of a partial triceps tear. The likelihood of partial triceps tears being symptomatic is higher in young patients and athletes.[8] It would be reasonable for surgeons to favor using plate designs that have less violation of the triceps insertion or ones that are meant to be applied over the triceps (i.e. Triceps-on designs) when the fracture pattern is amenable. However, further studies are needed to evaluate the clinical implications of triceps violation during olecranon plate osteosynthesis.

Triceps insertion

The triceps insertion is described to be layered resulting from the course of its 3 heads proximally. The lateral and long heads become confluent in the distal arm and insert superficially whereas the medial head which is the deep part of the triceps inserts deeper on the olecranon. The superficial insertion of the tendon becomes thin distally and forms the lateral expansion while it appears to be thick medially.[4] Better understanding of the insertional anatomy of

Table III
Summary comparing the averages of triceps insertion dimensions, olecranon dimensions, and the distances between triceps and olecranon border of each study.

Parameter [mm]	Current study	Keener et al.	Barco et al.
Triceps Insertion Length (C)	13.4 ± 2.3	13.4	18.7
Triceps Insertion Width (H)	18.6 ± 2.3	20.9	26.0
Olecranon Length (F)	25.9 ± 2.4	Not measured	Not measured
Olecranon Width (G)	24.3 ± 2.5	26.9	Not measured
Base to Tendon Distance (A)	2.8 ± 1.7	Not measured	Not measured
Tendon to Tip Distance (B)	9.0 ± 2.4	14.8	11.0
Lateral to Tendon Distance (D)	3.6 ± 1.3	Not measured	Not measured
Medial to Tendon Distance (E)	3.0 ± 1.0	Not measured	Not measured

They are reported using the mean with the standard deviation.

the triceps tendon will help guide surgeons in treating triceps injuries and in decision making around tendon handling and implant selection for olecranon fixation. Several studies have investigated the insertional anatomy of the triceps. Our study confirms previous findings that the triceps insertion has a layered appearance that includes 3 areas: the superficial tendinous insertion, the deep muscular insertion, and the capsular insertion.[2,3,6] Some of these studies correlated their 2D measurements with MRI.[1,2,11] Barco et al evaluated the width and height of each of the 3 insertions using 2D measurements.[3] Keener et al commented on how the distinction between the 3 insertions is not completely separated.[6] Keener et al and Barco et al described how the deep muscular insertion of the triceps originates from the medial head of the triceps; whereas, the superficial tendinous insertion originates from the long and lateral heads.[3,6] Both studies evaluated took their measurements using sliding digital caliper similar to our study. Weggmann et al have studied the triceps insertion and olecranon anatomy using a digital image analysis of images obtained by high resolution digital camera. Their mean total surface area of the muscular and tendinous insertions was 356.3 mm^2 in which is higher than what was reported in our study (254 mm^2) and by Keener et al (280 mm^2) which we calculated based on their reported mean triceps insertion length and width. However, it remains lower than the findings of Barco et al, who reported a surface area of 486 mm^2.[13] Athwal et al reported how the medial head of the triceps inserted separately deep to the long and lateral heads in 53% of their 15 specimens.[2] Akamatsu et al have demonstrated how these insertions are not completely distinct histologically and on MRI.[1] These findings raise the importance of evaluating these different insertion areas when studying the impact of any triceps footprint violation.

Strengths and limitations

This study quantifies the amount of triceps insertion violation using commonly used olecranon plates. Based on our review of the literature, this is the first 3D study that evaluates the triceps insertion and provides a more thorough assessment of the triceps insertional anatomy. The study presents triceps and olecranon measurements that were not evaluated in similar previous studies including olecranon length, olecranon base to tendon distance, and distances medial and lateral to the triceps tendon insertion. One of the limitations of this study is doing the expected triceps insertion violation based on mathematical calculations after measuring the insertion objectively on cadavers rather than applying the plates themselves and then repeating the measurements. However, the used method made it possible to use the same cadaveric specimen with each of the studied plate designs which led to a larger sample size per plate. A future study with a larger sample size could also assess the insertion violation after the physical application of olecranon plates. Many of the cadaver specimens were from older subjects; however, none of them had signs of significant arthritic changes or a previous elbow surgical intervention. This study focused on studying the impact of olecranon plates on triceps insertion since they are commonly used devices in such cases but future studies could compare their advantages and disadvantages in relation to other olecranon fixation techniques; especially in relation to their compromise of the insertion.

Conclusions

Many commonly used olecranon plates violate a large portion of the triceps footprint which is up to 62% in this study. There is a large variation in the percentage of triceps footprint violation among plate designs. Future studies should assess the implications of triceps footprint disruption in biomechanical studies and clinical settings. A better understanding of the triceps footprint and olecranon anatomy may lead to improvements in plate design to minimize injuring the triceps during surgery.

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