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Estimating the location of the posterior interosseus nerve during an extensor digitorum communis-splitting approach: a comparison of methods using the transepicondylar distance

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Background: The posterior interosseus nerve (PIN) may be encountered when using the extensile extensor digitorum communis (EDC)-splitting approach to the elbow. An accurate means of estimating its location remains elusive. The purpose of this investigation is to identify whether the methods described in previous studies can be improved upon to more accurately estimate the PIN's location using the transepicondylar distance (TED).

Methods: Forty-five fresh-frozen cadavers were dissected using the EDC-splitting approach. Method A (N = 39) used an electronic caliper measuring along the midlateral border of the radius from the lateral epicondyle (LE) and radiocapitellar joint in supination, neutral position, and pronation. Method B (N = 16) used a sterile tape measure, measuring from the LE in pronation only along an axis from the LE to Lister's tubercle passing through the center capitellum.

Results: In method A, the mean TED was 63.4 ± 6.1 mm. Of the 6 measurements, the TED was most correlated to the actual distance to the PIN from the LE in pronation (68.3 ± 7.3 mm; $R^2 = 0.266$). The median difference between the estimated and actual distances was −5.6 mm (−19.3 mm to 7.6 mm). In method B, the mean TED was 68.4 ± 8.7 mm, and the mean measured distance from the LE in pronation was 68.7 ± 9.4 mm. The TED closely correlated with the measured distance to the PIN ($R^2 = 0.95$, $P < .001$). The mean difference between the estimated and actual distances was ±2.0 mm (range −4.0 mm to 2.0 mm), significantly more precise than method A ($P = .007$).

Conclusion: Using a tape measure, the TED predicted the PIN's location within a mean ±2 mm in pronation along an axis from the LE to Lister's tubercle, using an EDC-splitting approach. This technique is simple and comparatively more accurate than those used previously.

There is a debate between the use of the posterior lateral Kocher approach and the more anterior extensor digitorum communis (EDC) splitting and Kaplan approaches to the lateral aspect of the elbow joint and proximal radius. Both provide access to structures of interest and carry different risks of iatrogenic injuries to the surrounding structures. The posterolateral Kocher approach is near the lateral ulnar collateral ligament (LUCL) but avoids the posterior interosseus nerve (PIN).[1] The more anterior Kaplan and EDC-splitting approaches avoid the LUCL and offer improved visualization of the radial head and the coronoid for terrible triads but also require careful identification of the nearby PIN in cases necessitating exposure of the proximal third of the radial shaft.[3,4]

The PIN is a branch of the radial nerve and provides motor control of the wrist extensors; iatrogenic injuries to the PIN during dissection can cause serious disability to the patient. An estimator that could be used preoperatively to predict PIN involvement in

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cases of fracture or used intraoperatively to optimize the safe working distance along the proximal radius without exposure of the PIN would be of significant clinical value. Despite multiple investigations, however, a reliable means for estimation of the PIN's location is yet to be described. Most of the large studies utilized a posterolateral approach[9,10]; those that used the EDC-splitting approach had lower power or used formalin-fixed cadavers to achieve higher power.[2,6,8] These studies consistently reported ranges of 2.0 cm about the mean from various landmarks regardless of the forearm position, suggesting no benefit to using one landmark over another and resulting in the minimum safe distance of 4.0 cm from the radiocapitellar joint (RCJ).[5-8,10]

The transepicondylar distance (TED) is a patient-normalized anatomic reference that was shown by Kamineni et al to reliably predict the position of the radial nerve proximal to the lateral epicondyle as it courses anteriorly through the lateral intermuscular septum.[5] However, when the same investigators applied the TED to the PIN's location, they found it performed similarly to other landmarks as previously described.[6] To determine whether the predictive accuracy of the TED was limited by the methods used to identify the PIN in the specimens and whether a modification of the methods could improve the predictive accuracy of the TED, we first employed methods similar to those described by Kamineni et al but instead with a simulated surgical setting using an EDC-splitting approach. The observations from this were then used to generate an alternative methodology with the aim of comparing methods and describing a clinically translatable use of the TED to estimate the PIN's location.

Materials and methods

We used fresh-frozen (FF) cadavers for dissection. Previous studies suggest FF specimens may maintain the natural mechanical properties of living tissue more so than formalin-fixed specimens.[5] Our dissection utilizes a well-known surgical approach, and controlling for differences in tissue quality by using FF specimens optimizes the clinical translatability of our findings. We excluded specimens with previous dissection about the elbow or with pronosupination less than 70 degrees. Seventeen shoulders (glenohumeral joint to fingertips) including 5 pairs and 28 elbows (mid-humerus osteotomy to fingertips) including 5 pairs were used for dissections. We also collected the available donor demographic information, including age, sex, height, weight, and body mass index (BMI), to account for confounding and identify potential covariates.

Surgical technique

With the elbow in approximately 90 degrees of flexion and neutral forearm rotation, a curvilinear skin incision was made over the lateral epicondyle. Sharp dissection was carried down to the muscular fascia with full-thickness skin flaps. The anterior capsule was released off the distal humerus to identify the RCJ. The EDC was identified, and it was split in line with the mid axis of the radial head and shaft. The forearm was then maximally pronated, the superficial supinator was identified, and the PIN was identified with careful blunt dissection of the supinator using scissors. The same surgical technique was used in method A and method B.

Measurement method A

To simulate the surgical setting, the TED was measured with skin intact on the medial epicondyle and bone exposed on the LE using a Mitutoyo 500-196-30 Digimatic 0-6''/150MM Stainless Steel Digital Caliper (Kawasaki, Kanagawa, Japan). Six total distances to the PIN were obtained: The distance to the leading edge of the nerve was measured in supination, neutral position, and pronation from 2 points, the LE and the RCJ. Figure 1 illustrates the relevant landmarks, the anatomy of an EDC-splitting approach, and the technique used to measure PIN locations in supination, neutral position, and pronation along the axis of the lateral border of the radius.

Measurement method B

A flexible paper measuring tape fixed by an 18G spinal needle to the lateral epicondyle was used to measure the TED, which was marked on the tape measure with a clamp. The tape measure was then rotated anteriorly to measure the difference between the estimated distance indicated by the clamp and the distance to the PIN. To account for soft-tissue bulk and the nonlinear course of the nerve *in situ*, the tape measure was not pulled taut and was allowed to approximately contour to the tissue. At the time of implementing method B, 10 specimens remained from those used in method A. In these specimens, the TED was measured with the LE partially exposed and medial skin intact, and the distance to the PIN was measured with the nerve fully dissected. In 6 undissected specimens, the TED measurements were taken prior to dissection to further account for soft-tissue bulk in each specimen. The forearm was pronated and brought into 90 degrees of radiohumeral flexions prior to the dissection of the supinator, and a second spinal needle was inserted into the radial shaft at a distance equal to the TED along an axis beginning at the LE proximally, projecting through the 3-o'clock position of the radial head, and aligned with the Lister's tubercle distally. The second needle was used primarily for illustrative purposes and to minimize measurement confirmation bias. An undissected specimen is shown in Figure 2 using method B. The use of 6 new undissected specimens and only 10 of the specimens used in method A was a result of the limited availability of new and previously used specimens in the interim period between implementing methods.

Statistics

Data were entered into SPSS (Version 27.0; IBM Corp., Armonk, NY, USA) for analysis. Significance was set at $P < .05$. The normality of distribution was assessed with the Shapiro-Wilk test. Parametric categorical data were assessed with Chi-square test. Parametric continuous data were assessed with Student's independent t-test to compare mean lengths, followed by an analysis of variance when indicated. Nonparametric continuous data were assessed with Mann-Whitney U test. Pearson's R-square statistic was used to assess bivariate and partial correlations. Plots of actual vs. predicted measurements were assessed with linear regression, and goodness of fit is reported as R^2. The landmark-forearm position combination with the strongest linear correlation to the TED from method A was selected for use in method B. For comparisons between measurements from method A vs. method B on the same specimens, paired t-tests (parametric data) or Wilcoxon rank sum test (nonparametric data) were used. A post hoc power analysis following method A determined the minimum number of measurements that would be required using method B to achieve 80% power for detecting differences between the methods.

Results

Specimen characteristics

Forty-five FF cadavers were included in the study. All PINs were found within the supinator muscle. The specimens' donor demographic variables (age, sex, height, weight) summarized in Table I were evaluated for bivariate and partial correlations to the

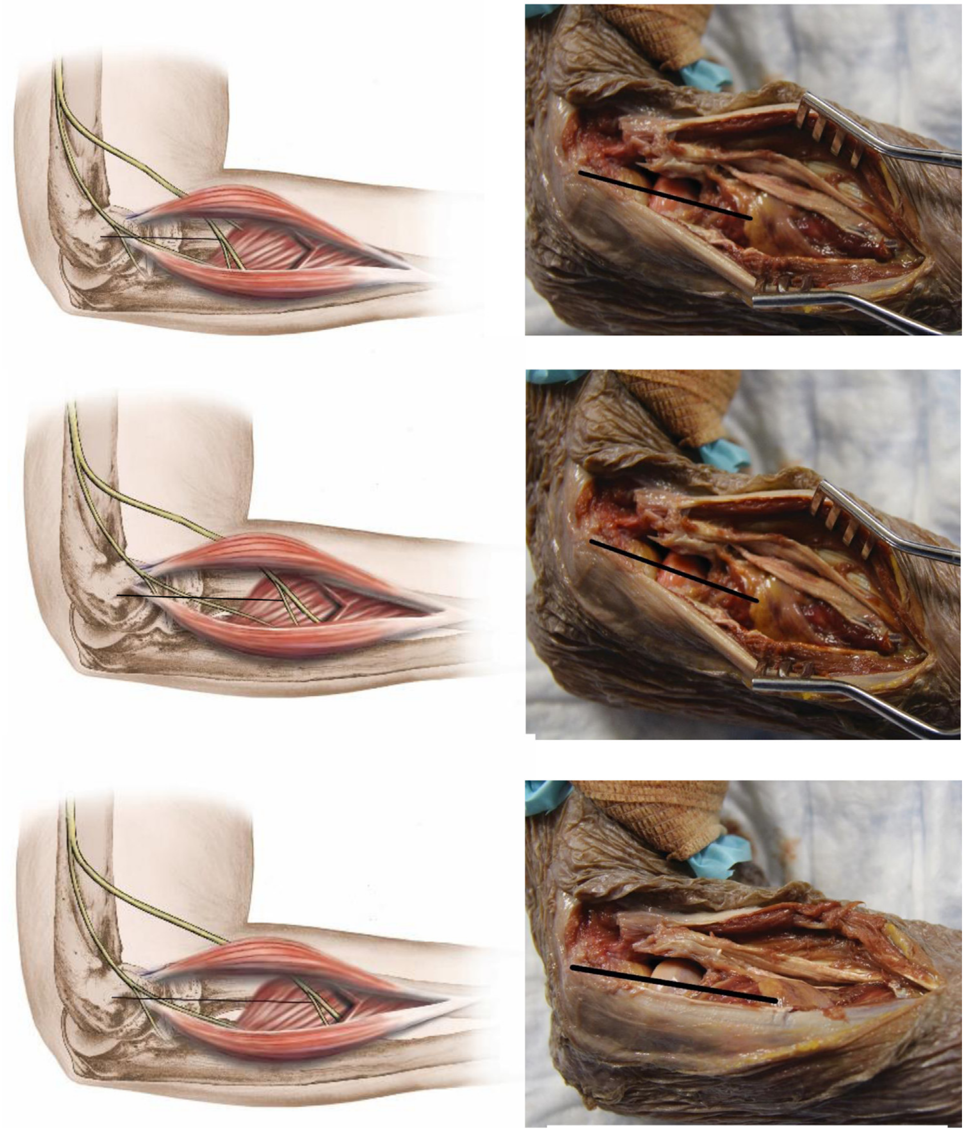

Figure 1 (Top, left and right) Supination, (middle, left and right) neutral position, and (bottom, left and right) pronation. *The black line* demonstrates the axis of measurement from the LE to the PIN along which the LE to PIN and RCJ to PIN distances were measured. In cases where the PIN had arborized to the target muscles, such as those illustrated above that are innervating the supinator muscle bellies, the measures represent the distance to the first PIN branch encountered. *LE*, lateral epicondyle; *PIN*, posterior interosseous nerve; *RCJ*, radiocapitellar joint.

TED and to the measured distances to the PIN. Age and sex covaried with height, and height was found to correlate strongly with the TED (R = .772, $P < .001$). However, height did not independently correlate with PIN distances. We assessed for confounding factors among specimens with the analysis of variance which revealed differences in average age ($P = .016$), height ($P = .017$), and BMI ($P = .017$) between whole shoulder vs. elbow-only specimens. After controlling for height, no differences were found between whole shoulder vs. elbow-only specimens, paired vs. individual specimens, left-sided vs. right-sided specimens, or the specimens used in method A (n = 39) vs. those used in method B (n = 16). These comparisons are reported in Supplementary Appendix SA-SC.

Method A

The average TED was 63.2 ± 6.1 mm (mean ± standard deviation; range 52.5 mm to 76.0 mm). The TED showed no significant linear correlation to any of the distances measured from the RCJ. From the LE, the TED had the strongest linear correlation to the measured distance in pronation (Pearson's R-squared = .265, $P < .001$). Qualitatively, it was a weak correlation, and the median difference between the TED-predicted distance and the actual measured distance from the LE in pronation was −5.6 mm and ranged from −19.3 mm to 7.6 mm. The PIN's apparent translation with pronation is reported as "Dp" (Dp, displacement; pronation minus supination distance) and was a mean 13.0 ± 5.1 mm (range 4.6-30.0 mm) measuring from the RCJ and 15.0 ± 4.6 (range 9.0-26.9 mm) from the LE. A summary of the average distances to the PIN from the LE and RCJ in supination, neutral position, and pronation, and the respective correlation(s) with the TED, is provided in Table II.

Method B

Sixteen specimens were available for implementation of method B, which was optimized for measurements taken from the

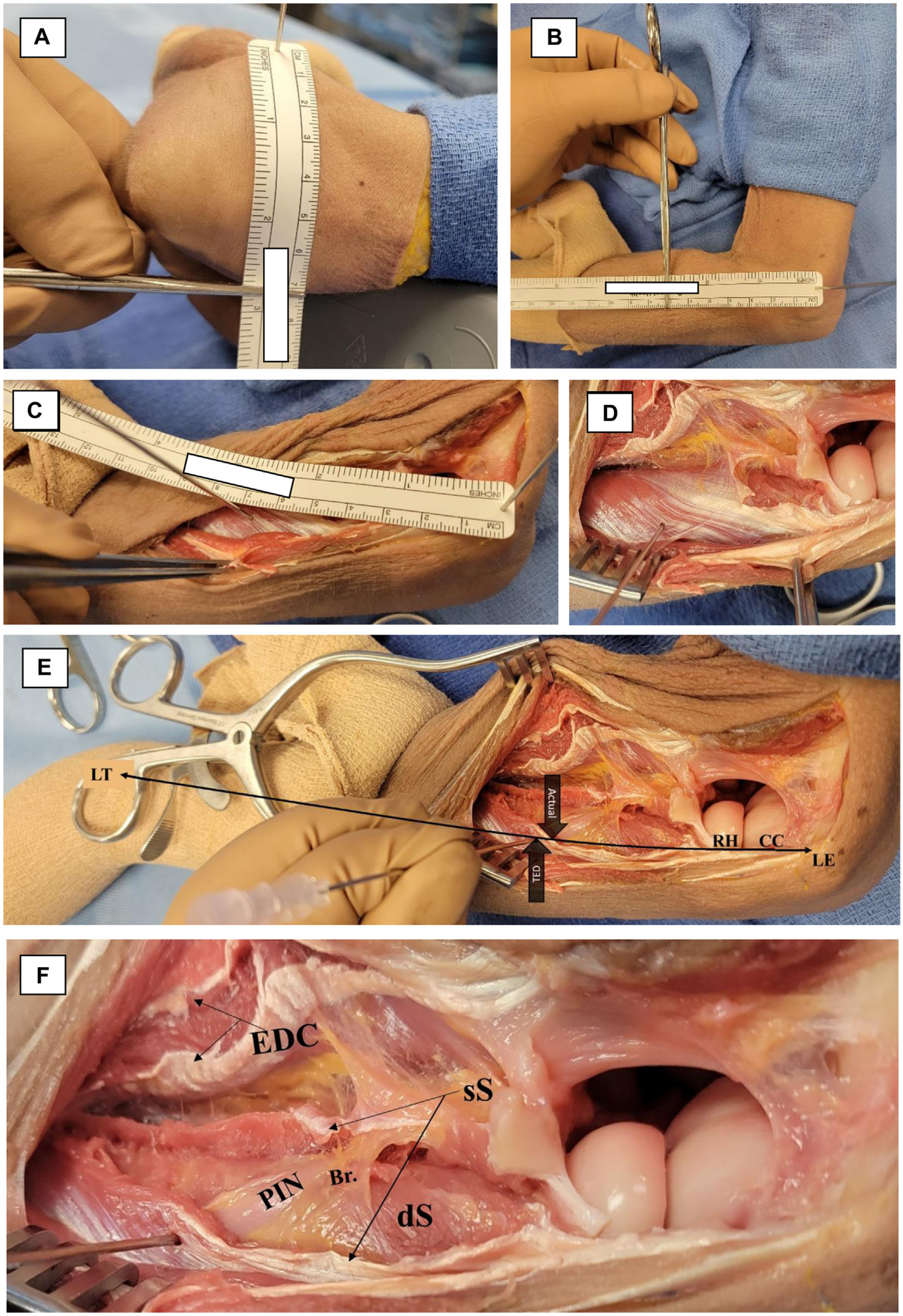

Figure 2 Method B: (**A**) measuring the TED. (**B**) Approximating distance to PIN prior to incision; the needle was withdrawn for the incision and then replaced into the original defect in the LE. (**C**) Tape measure is affixed to the LE by the proximal spinal needle, and the TED-estimated distance is indicated by the distal spinal needle placed after splitting the EDC but prior to the dissection of supinator. The needle was placed through the *center* of the tape measure proximal to the clamps. (**D**) Dissection and elevation of superficial supinator fibers proximally. (**E**) Measurement axis (↔) following the contour of the radial bow with forearm pronation, beginning at the LE proximally, passing through *center* capitellum (CC) and the *center* of the radial head (RH), with elbow flexed such that the axis is aligned with the Lister's tubercle (LT) distally; the labeled black arrows depict the estimated distance (TED) and measured distance (actual) to the PIN along this axis. (**F**) Magnified view of (**E**), demonstrating the PIN through an extended EDC-splitting approach in pronation with labeled structures: *PIN*, posterior interosseus nerve; *Br.*, branch to supinator; *EDC*, extensor digitorum communis (retracted split edge); *dS*, deep supinator muscle; *sS*, superficial supinator muscle (reflected edges); *TED*, transepicondylar distance; *LE*, lateral epicondyle.

Table I
Demographic information available for *N* specimens.

Initially included	N (%)	Mean ± SD	Minimum	Maximum
Age (y)	39 (100)	61.5 ± 16.9	23.0	90.0
BMI (kg/m^2)	26 (67)	31.6 ± 15.3	14.0	68.0
Weight (kg)	29 (74)	65.7 ± 25.3	19.0	102.5
Height (cm)	28 (72)	169.9 ± 11.1	154.9	192.8
TED (mm)	39 (100)	63.4 ± 6.11	52.45	76.01
Added *post hoc*	**N (%)**	**Mean ± SD**	**Minimum**	**Maximum**
Age (y)	6 (100)	61.5 ± 14.3	41.0	78.0
BMI (kg/m^2)	4 (67)	27.4 ± 9.6	16.0	38.4
Weight (kg)	4 (67)	65.7 ± 25.3	19.0	102.5
Height (cm)	4 (67)	170.0 ± 14.3	160.0	180.0
TED (mm)	6 (100)	66.8 ± 7.0	56.0	69.0

SD, standard deviation; *BMI*, body mass index; *TED*, transepicondylar distance.
"Initially included" specimens reflect the 39 original specimens that comprised 100% of the sample in method A and 63% of the sample in method B. "Added Post Hoc" reflects the additional 6 specimens included in method B only.

Table II
Method A: summary of measurements (mm) and correlation with the TED (N = 39).

Proximal landmark-forearm position	Minimum	Maximum	Mean ± SD	R value	*P* value
LE					
S	41.82	69.13	53.34 ± 6.25	.387*	.011
N	43.83	74.74	58.55 ± 7.68	.385*	.023
P	56.28	87.61	68.35 ± 7.80	.516†	<.001
Mid	51.28	73.62	59.95 ± 6.01	.558†	<.001
Dp	9.05	26.87	15.01 ± 4.56	.353*	.033
RCJ					
S	23.86	47.87	35.89 ± 5.70	.19	.261
N	25.79	57.05	42.06 ± 7.43	−.01	.932
P	29.54	63.93	48.88 ± 8.38	−.08	.621
Mid	26.70	53.91	42.39 ± 6.69	.03	.870
Dp	4.64	29.98	12.99 ± 5.13	−.340*	.034

mm, millimeters; *TED*, transepicondylar distance; *SD*, standard deviation; *LE*, lateral epicondyle; *S*, supination; *N*, neutral; *P*, pronation; *Mid*, midpoint = average of supination and pronation measures; *Dp*, displacement = difference of supination and pronation measures; *RCJ*, radiocapitellar joint.
Of the measurable values (S, N, P), the strongest (linear) correlation was found measuring from the LE in pronation.
*Pearson's R correlation is significant at the 0.05 level (2-tailed).
†Pearson's R correlation is significant at the .001 level (2-tailed).

LE in pronation based on the results of method A. The mean TED was 68.4 ± 8.7 mm, and the mean distance from the LE in pronation was 68.7 ± 9.4 mm; the TED was a mean 5.0 mm wider while using method B. There was a strong linear correlation between the actual and predicted measurements using method B (R-squared = 0.95, $P < .001$). The difference between the actual and predicted distances was a median 0.0 mm with a narrower range of −4.0 to 2.0 mm. The post hoc power analysis result for the sixteen specimens was .817, above the widely used threshold of 80%. Method B was significantly more accurate and precise than method A ($P = .007$). Comparisons between the methods are summarized in Table III, and the linear regressions of methods A and B are displayed in Figure 3.

Discussion

There is a risk of injury to the PIN when utilizing an EDC-splitting approach. However, this approach affords excellent visualization of the radial head, LUCL, and coronoid that may need to be addressed in cases of complex elbow trauma.[1,3,4,7,11] Therefore, we evaluated whether a TED-based estimate could more accurately and reliably localize the PIN if the dissection was performed with an EDC-splitting approach on FF cadavers (method A) instead of the tissue-sparing dissection performed on embalmed cadavers as previously described. When we achieved similar results, we developed a different methodology (method B) that was more representative of the surgical setting and more accurate than previous investigations, including our own.

Method A

Our initial aim was to demonstrate that the TED could be more accurate than previously described[6] if we performed a similarly powered investigation using a surgical approach on FF specimen and collected specimen demographic data to ensure representation of a broad range of adults. In the latter endeavor, we were successful, with an age range of 23 to 98 years, height from 5 feet-1 inch to 6 feet-6 inches, and a BMI range of 14 to 68 kg/m^2. The results reported here challenge the previously described 4.0-cm minimum safe distance from the RCJ[7] in supination. Similar to previous investigations challenging the 4.0-cm value, we found the PIN to be as close as 2.4 cm from the joint and 4.2 cm from the epicondyle using method A.[3,6] We also corroborate the correlation between patient height and the TED and demonstrate that taller individuals have a wider TED. While method A ultimately demonstrates that a different surgical approach and specimen type did not improve the TED's predictive accuracy when using methods previously described, in no instance did the TED-estimated and actual values exceed 25 mm. Therefore, given a mean TED of about 6.5 cm, the results of method A further support the notion that the 4.0-cm value is not representative of most patients.[3,6,9]

Method B

Compared to method A, we used a tape measure instead of calipers, modified the position of the elbow for these measurements, and measured along a curvilinear access that aligned with the Lister's tubercle distally. The decision to use a flexible tape measure only in method B was intended to simulate a surgical setting but had the secondary benefit of accounting for soft-tissue bulk to some degree when laid along the curvature created by the skin, soft tissue, and triceps tendon. Additionally, by being affixed to the LE with a spinal needle, the tape measure was more likely to account for the angle of the epicondylar axis as it was brought to the most prominent palpable point of the medial epicondyle; measurements with electronic calipers that only spanned the perpendicular axis of the humeral shaft at the level of the epicondyles could erroneously result in TED values that were 2.0 ± 1.0 mm shorter on average. Using a tape measure and needle resulted in a TED value that was 5.0 mm greater in the same specimens from method A. In the 6 specimens that were not dissected in method A, the TED was measured prior to incision over the LE because the soft tissue, held taut, facilitated needle placement into the bone. The TED was the same before and after dissection when the needle was replaced into the original bore hole, suggesting the TED could just as well be measured after dissection with equivalent results.

Previous anatomic[12] and radiographic[13] investigations of the PIN's course demonstrate that, except for the lateral supracondylar ridge and lateral border of the radius, the nerve is farther off the surface of the bone and bears a more complex 3-dimensional relationship to the 2-dimensional surface anatomy. We considered this when developing how best to position the specimens such that a wide TED might affect the course of the PIN. In the sagittal plane, the EDC-splitting approach is usually developed in pronation to provide anterolateral exposure of a supine patient's posterior/dorsal lateral structures, which will have translated distally with

Table III
Comparing the specimens used and measurements obtained using method A (calipers, N = 39) to method B (tape measure, N = 16).

Specimen characteristics	Method A, N = 39		Method B, N = 16		Sig.[a,b]
	Ratio	Mean	Ratio	Mean	
Shoulders:Elbows	5:8		7:9		.716[a1]
Females:Males	7:6		1:1		.796[a2]
Age		61.5 ± 16.9		67.7 ± 12.5	.194[b]
Height (m)		1.7 ± 0.1		1.7 ± 0.1	.418[b]
BMI (kg/m^2)		31.6 ± 15.3		23.5 ± 7.8	.103[b]
TED (mm)		63.4 ± 6.1		68.4 ± 8.7	.018[b]
Pronation (mm)		68.3 ± 7.8		68.7 ± 9.1	.889[b]
Difference between Pronation and TED, median (range, mm)	−5.6 (−19.3 to 7.6)		0.0 (−4.0 to 2.0)		.007[c]

BMI, body mass index; *TED*, transepicondylar distance.
Pronation, distance to the posterior interosseous nerve (PIN) in pronation from the lateral epicondyle. Sig., *P* value: a) proportions compared using Pearson's Chi-square statistics = .176[1] and .076[2]; b) paired t-test, 2-tailed, equal variance assumed based on Levene's test; c) Wilcoxin rank sum test statistic = −2.688. The TED was the only difference between these groups.

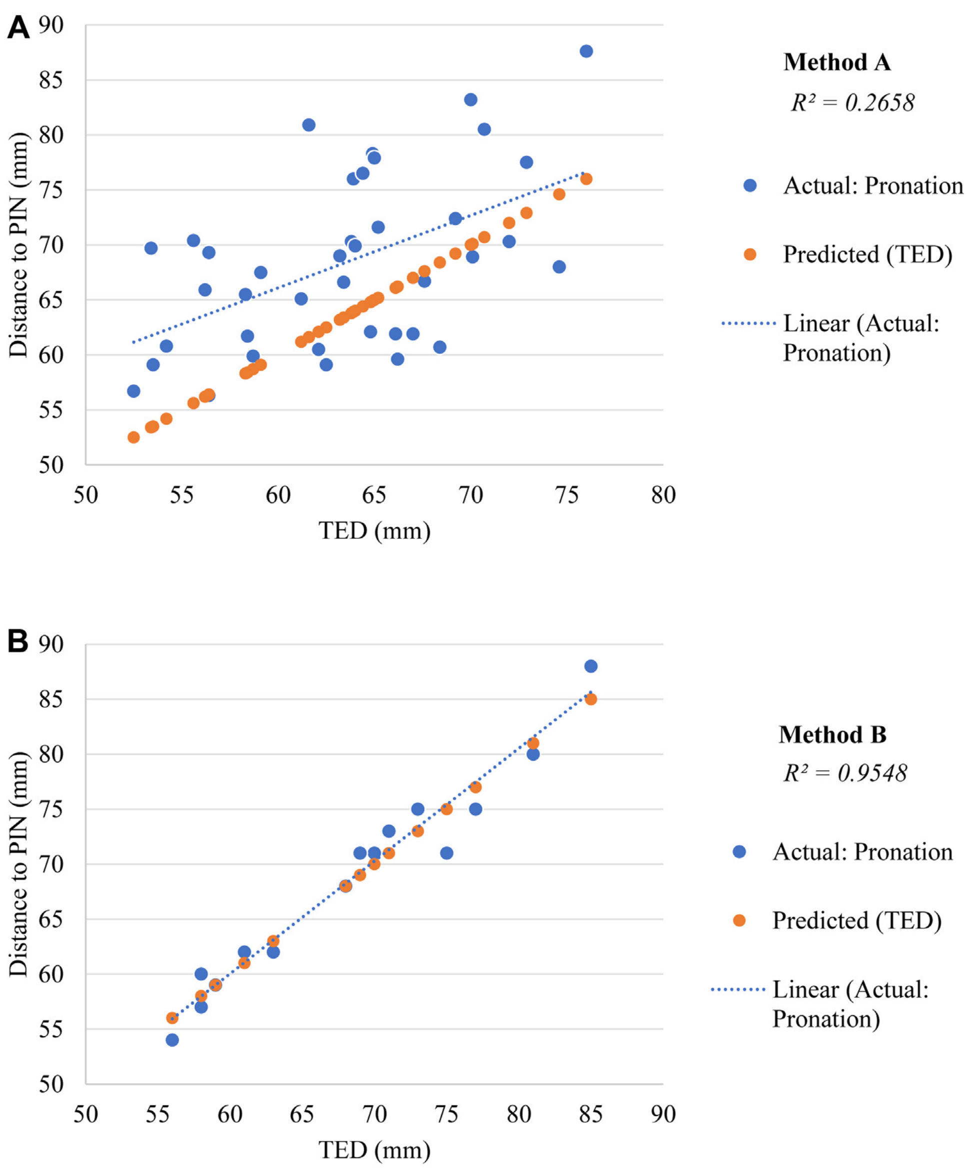

Figure 3 Method A (top) vs. method B (bottom) illustrating the actual distance to the PIN in pronation and the predicted distance using the TED. The paired actual and predicted measures for each specimen are aligned vertically. Pearson's R-squared statistic was found to be significant at $P < .001$ for both plots. *TED*, transepicondylar distance; *PIN*, posterior interosseus nerve.

pronation. In the axial plane, the PIN is relatively centered over the radial head near the 12-o'clock position as it traverses the RCJ with forearm pronation and elbow flexion, so we used an axis that matched the contour created by the radial bow and was aligned with the Lister's tubercle distally (the 12-o'clock position of the distal radius). However, as can be discerned from the images in Figure 2, measurements taken off the described axis—such as those aligned with the radial tubercle as previously described[6]—can vary widely due to the obliquity of the PIN's course over the radius. While there may be some leeway with the degree of pronation and elbow flexion, our observations suggest the axis of measurement is the most critical step in estimating the location. Therefore, even with an accurate estimation of the PIN's location along the most dorsal aspect of the radius when brought into pronation, the surgeon must still recognize that the PIN will appear in the surgical field proximal to this estimate when dissecting along the most lateral aspect of the radius.

Limitations

Access to previously dissected and new specimens was the most limiting factor when implementing method B. This resulted in a narrower spectrum of biometric values, especially BMI, in method B and a narrower power overall for the latter technique. The sample size in method B was also underpowered to detect between-specimen biometric differences and effect sizes ($n = 6$; $1-\beta = 0.75$, $P = .05$). The *de novo* methodology described here came after the experience of many dissections, potentially introducing confirmation bias and/or decreased generalizability to lower-volume surgeons that do not dissect 45 elbows within a few months. Lastly, these results were found using uninjured specimens and may not be reproduced with the same accuracy in an injured elbow.[3,11]

Conclusion

Previous investigations suggest the TED is not more accurate for estimating the location of the PIN intraoperatively than other anatomic references. Using similar methods through an EDC-splitting approach on uninjured FF cadavers, we demonstrate the TED is normalized to varying patient anatomy, but not more accurate than previously described. However, when we instead used a tape measure, a contoured axis between the lateral epicondyle and Lister's tubercle, and forearm pronation, the TED was accurate within a mean ±2 mm (range -4.0 to 2.0 mm). This simplified technique is amenable to intraoperative application and demonstrated a predictive accuracy that may be suitable for clinical application.

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Supplementary data

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