The posterior interosseous nerve crosses the radial head midline and increases its distance from bony structures with supination of the forearm

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Background: This study investigated whether forearm movements change the relative position of the posterior interosseous nerve (PIN) with respect to the midline of the radial head (Rh) under direct arthroscopic observation.
Methods: The PIN was identified in 10 fresh frozen cadaveric specimens dissected under arthroscopy. The forearm was moved first in full pronation and then in full supination, and the displacement of the PIN from medial to lateral with respect to the midline of the Rh was recorded. The shortest linear distance between the nerve and the most anterior part of the Rh was measured with a graduated calliper inserted via the midlateral portal with the forearm in neutral position, full pronation, and full supination.
Results: The PIN was identifiable in all specimens. In all cases the PIN crossed the Rh midline with forearm movements, moving from medial in full pronation to lateral in full supination. The distance between the PIN and Rh is significantly greater in supination than in the neutral position and pronation ($P = .0001$).
Conclusions: This study confirms that the PIN movement described in open surgery (medialization with pronation) also occurs during arthroscopy. The role of pronation in protecting the PIN in extra-articular

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procedures is therefore confirmed. Supination, however, increases the linear distance between the PIN and Rh and should therefore be considered to increase the safe working volume whenever intra-articular procedures are performed on the anterolateral aspect of the elbow.

Level of evidence: Anatomy Study; Cadaver Dissection
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In open elbow surgery, pronation of the forearm is recommended to protect the posterior interosseous nerve (PIN) during standard lateral or posterolateral approaches.[3,9,12,36] This is based on the strict anatomic relationship between the nerve and the arcade of Frohse, which brings the nerve toward a median position in pronation.[28,32,35] This fact is evident in open surgery when the patient is supine and the elbow is in a semiextended position, in which the PIN is taut. The same precautions are used in arthroscopic surgery, although the position of the elbow and the amount of soft tissue exposure are profoundly different; moreover, joint distension caused by intra-articular irrigation may displace the nerve to a more anterior-inferior direction, altering the movement patterns described in "dry" cadaveric settings.[3,12]

The protective effect of pronation on the PIN has not yet been demonstrated in arthroscopy. This study investigated whether pronation and supination of the forearm change the relative position of the PIN with respect to the midline of the radial head (Rh) as measured from an intra-articular point of view to confirm whether forearm position influences the risks of nerve lesions during arthroscopic procedures.

This cadaver study tested the hypothesis that a displacement of the PIN with respect to the midline of the Rh would be recordable in at least 50% of the cases. Displacement was defined as the PIN crossing the anterior projection of the Rh midline with forearm movements, moving from medial in pronation to lateral in supination.

Materials and methods

Fresh frozen specimens from 10 deceased donors (mean age at death, 77.9 ± 7.4 years), including the complete middle third of the humerus and the entire hand, without pathologies or traumatic injuries to the nervous structures of the elbow, were prepared to mimic an arthroscopic setting in lateral decubitus. The specimen was positioned with the elbow flexed at 90°, leaving the forearm hanging free with gravity force.

Standard posterior and posterolateral portals were created, and the posterior compartment was first examined to exclude lesions to the posterior aspect of the radiocapitellar joint. A midlateral portal was created on the soft spot of the elbow, in the middle of a virtual triangle formed by the olecranon's tip, the medial epicondyle, and the supinator crease, immediately above the superior margin of the radial head. A proximal anterolateral portal was then created 2 cm proximal and 1 cm anterior to the lateral epicondyle, and a proximal anteromedial portal was created 2 cm proximal and 1 cm anterior to the intermuscular septum. A standard meniscal biter was in-

serted via the anteromedial portal while looking from anterolateral with a standard 30° arthroscope to perform an anterior capsulectomy of the entire the lateral compartment. After capsulectomy, the PIN was identified. All of the dissections were performed by 2 surgeons (P.A., E.G.) with extensive experience in arthroscopic elbow surgery.

Subsequently, while maintaining the forearm in neutral position, a probe was inserted from the midlateral portal and used to mark the anterior-posterior axis of the Rh. This probe was then maintained fixed, so that its position would remain unchanged when the Rh was rotated, serving as a reference for measurements.

The position of the PIN was then observed while the forearm was moved from full pronation to full supination. The end-range ("full") position was defined as that in which forceful rotator movements by the examiner did not provoke further rotation of the Rh observed arthroscopically. The passage of the nerve from a position medial to the anterior-posterior axis of the Rh (as marked with the aforementioned probe) in pronation to a lateral in supination was defined as medial-to-lateral nerve displacement.

Finally, a graduated calliper inserted from the midlateral (soft spot) portal was used to measure the distance between the most anterior part of the Rh and the PIN (Fig. 1). This measure was recorded with the forearm in full pronation, neutral position, and full supination and normalized to the specimen's transepicondylar distance, defined as the ratio between the distance measured and the transepicondylar distance.[17] One examiner (P.A.) performed all measurements.
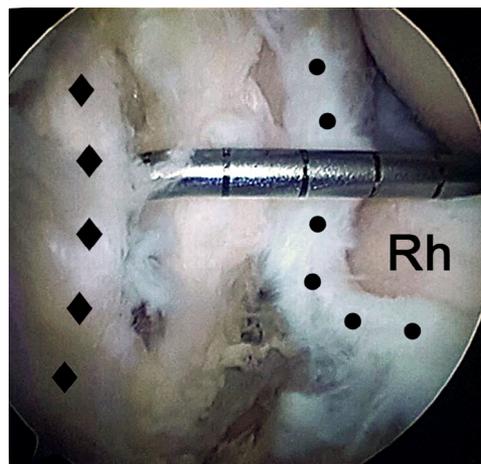

Figure 1 Measurement of the linear distance of the posterior interosseous nerve from the most anterior part of the radial head (*Rh*). After capsulectomy (*circles*), a graduated calliper was inserted from the midlateral portal, aimed at the posterior interosseous nerve (*diamonds*).

Statistical analysis (A.M.) was performed using GraphPad Prism 6.0 software (GraphPad Software Inc., La Jolla, CA, USA). The normal distribution of the sample was evaluated with the Shapiro-Wilk normality test. Continuous variables are expressed as median and interquartile range (first and third quartiles) or as mean ± standard deviation, as appropriate. After analysis of outliers, statistical evaluation of the differences among the groups was performed using 1-way analysis of variance with the post hoc Tukey multiple comparisons test. The significance level was set at $P < .05$.

Results

The PIN was identified in all 10 specimens (left elbow, 63.6%; median transepicondylar distance, 65 mm; interquartile range, 58.5-68.0 mm). The PIN in all specimens crossed the Rh midline with forearm movement from supination to pronation, moving from medial in pronation to lateral in supination (Fig. 2).

The 10 complete sets of distance measurements were analyzed for outliers, and 1 specimen was excluded (Fig. 3). The mean (and normalized) distances between PIN and Rh were 11.3 ± 3.4 mm (0.18 ± 0.06 mm) in neutral position, 8.4 ± 2.0 mm (0.14 ± 0.04 mm) in pronation, and 15.7 ± 5.2 mm (0.25 ± 0.08 mm) in supination. A repeated-measures 1-way analysis of variance was performed ($P = .0001$) on the 9 remaining sets, and the Tukey multiple comparisons test revealed statistically significant differences between all pairs of measures: supination–pronation ($P ≤ .001$), supination–neutral ($P ≤ .01$), neutral–pronation ($P ≤ .01$; Fig. 4). The study design was insufficient to clarify whether the outlier originated from an anatomic variation or from issues related to the specimen preparation.

Discussion

The main finding of this study is that the relative position of the PIN to the midline of the Rh changes with forearm move-
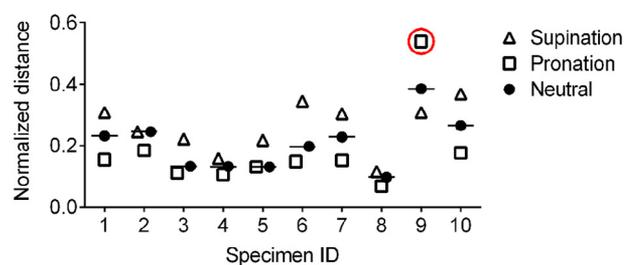

Figure 3 Relative distance of the posterior interosseous nerve from the most anterior part of the radial head, measured in millimeters and then normalized to the specimen's interepicondylar distance, with forearm in full pronation, neutral position, and full supination. The outlier are marked with a *red circle*.

ments, moving from lateral in supination to medial in pronation. This particular behavior had yet to be described in an arthroscopic cadaveric setting and may have relevant implications on surgical procedures and diagnostic techniques. Furthermore, this study demonstrated that the distance between the PIN and the Rh is significantly greater when measured with the forearm in maximal supination compared with measurements obtained in neutral and pronated positions.

The PIN (C5-C6) originates from the radial nerve as it descends the arm laterally, where it divides into a superficial, sensory branch and a deep, motor one, namely, the PIN. The PIN then passes below a fibrous arch formed by the proximal margin of the superficial head of the supinator muscle, the arcade of Frohse. It innervates the 2 heads of the supinator and the muscles involved in wrist and digits extension.[6,21,28] Rare variations of the course of the PIN associated with an anatomic variation of the supinator muscle have been encountered and described.[10]

The knowledge of the close relation of the PIN with the supinator is critical in open elbow surgery. When exposing the proximal radius, the surgeon must strip the supinator subperiosteally from the radius or divide the superficial
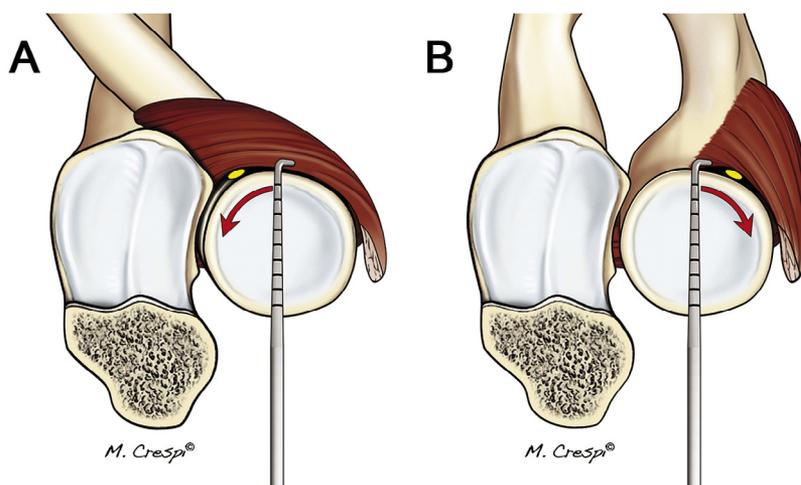

Figure 2 In a simulated arthroscopic setting with the elbow in 90° flexion, with respect to the radial head midline, the posterior interosseous nerve moves from (**A**) a medial position with the forearm in full pronation to (**B**) a lateral position with the forearm in full supination.
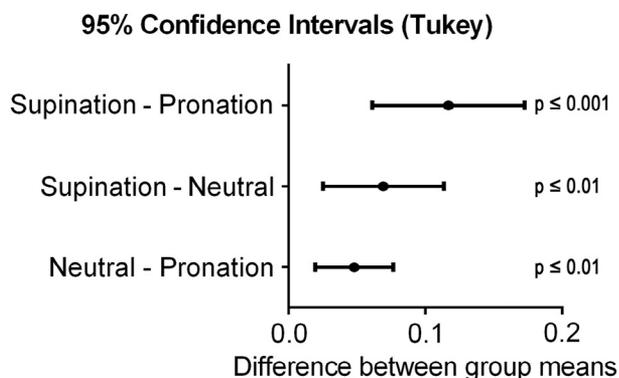
95% Confidence Intervals (Tukey)

Figure 4 Repeated-measures 1-way analysis of variance graph shows the 95% confidence intervals (*horizontal lines*) computed by the Tukey multiple comparisons test for the difference between the average linear distance that can be measured between the nerve and the most anterior part of the radial head and the posterior interosseous nerve with the forearm in one position, compared with every other position. The confidence intervals for the mean pairs do not include 0, which indicates that the difference between these means is statistically significant.

humeral head to expose the nerve itself. Pronation is considered a valid method to increase the zone of safety for lateral approaches because it translates the PIN approximately 1 cm anteriorly.[3,12,33] In elbow surgery, the arcade of Frohse and the supinator muscle are important anatomic landmarks to localize the PIN, the protection of which is stressed in all lateral approaches to the elbow. These approaches can be used for fixation of intra-articular fractures, repair or reconstruction of the lateral ligaments, removal of osteophytes or loose bodies, Rh excision, and capsulectomy.[9,18,34]

In the Kocher approach, the intermuscular interval between the anconeus and the extensor carpi ulnaris is used, whereas the Kaplan approach develops the interval between the extensor digitorum communis and the extensor carpi radialis longus and extensor carpi radialis brevis to expose the underlying capsule and access the Rh. An extensor digitorum communis-splitting approach has also been described.[18,31]

Studies of fresh cadaveric upper extremities dissected using various approaches to the proximal part of the radius confirmed that the distance from the radiocapitellar joint to the point where the PIN crosses the lateral midline in full pronation is greater than in neutral position and full supination.[3,9,12,13,21,31] Nevertheless, uninterrupted prolonged periods of hyperpronation are not recommended, since this may increase excessively the pressure on the PIN beneath the arcade of Frohse.[22]

In arthroscopic surgery, injury to the PIN is known as a possible complication,[4,8,11,15,16] although it has been reported as an extremely rare or absent adverse event.[19,26,27] Care has to be taken to avoid iatrogenic injury during elbow arthroscopy. Several articles have described pearls and pitfalls on this subject.[2,5,14,29,30] Traditionally, the same safety precautions developed in open elbow surgery have been applied in elbow arthroscopy.

The results of this study confirm that the PIN movement described in open surgery (medialization with pronation) also occurs in arthroscopy. In fact, the PIN in all studied cadavers crossed the Rh midline with forearm pronation movements, moving from medial in pronation to lateral in supination. Therefore, pronation of the forearm, which displaces the nerve anteromedially, remains recommended whenever performing extra-articular procedures on the lateral side of the Rh with sharp instruments, such as when establishing the anterolateral portal, inserting a screw for fracture fixation, or removal of large loose bodies through lateral portals.[2,5,11,24,25,33] Alternatively, PIN protection can be achieved by inserting a retractor through an additional proximal anterolateral portal located approximately 3 cm proximal and 1 cm anterior to the lateral epicondyle and directed to the radiocapitellar joint.

Our study also documented a significant increase in the linear distance between the PIN and the Rh when the forearm is moved in maximal supination compared with neutral and pronated positions, providing a statistically sound confirmation to a previous report that suggested the possibility of an increased distance of the PIN in supination but did not examine enough specimens to reach a definitive conclusion.[1] This finding implies that to obtain a wider safe working volume when working intra-articularly, as opposed to extra-articular procedures, it is advisable to fully supinate the forearm because this can increase the distance between the PIN and the most anterior part of the Rh.

These results add valuable information to the available data on the course of the PIN in relation to the proximal radius. Hackl et al[12] used a radiopaque marker and 3-dimensional x-ray scans to measure the course of the nerve with the elbow placed in full extension (as in a ventral approach) and in approximately 60° of flexion (as in a posterolateral approach) and observed that forearm rotation did not alter the location of the nerve at the level of the radiocapitellar joint. Our study, which was performed with the elbow placed in 90° flexion (as in an arthroscopic setting), showed that in this position forearm rotation does indeed alter the location of the nerve, which is significantly more distant from the Rh with the forearm in full supination compared with the other examined positions.

We presume that these contrasting results are produced by the different mobility of the PIN at different degrees of elbow flexion: the soft tissues in the antecubital fossa are taut in extension and progressively become more mobile with increasing flexion.[7,20,23] Therefore, it is reasonable to expect an increased mobility of the PIN in a cadaveric setting that simulates elbow arthroscopy than in one which simulates open surgery. Knowledge of this behavior of the nerve with forearm movements can be helpful when performing anterior procedures, as capsulectomy, and future studies with dedicated setting could shed light on the role of flexion on PIN movements.

This study has some limitations. First, the age of patients who usually undergo arthroscopic elbow surgery is younger than that of the included specimens, which suggests care when transferring these results to clinical practice.

However, ageing is not supposed to influence the behavior of the PIN.

Second, the studied population is relatively small: this could amplify bias related to anatomic variants and to the dissection technique. To minimize bias related to the arthroscopic procedure, only 2 surgeons with extensive experience in arthroscopic elbow surgery were selected to perform the dissections, and a single examiner performed all the study measurements. This served to minimize bias related to data collection technique, but the consistency of these observations among different investigators was not evaluated.

To investigate PIN movements under direct visual control, the anterior joint capsule had to be removed, and we acknowledge this represents an inevitable bias in our anatomic model. No studies have investigated yet whether the PIN becomes more mobile (elimination of a rigid constraint) or less mobile (increase nerve tension by unconstrained fluid distension) after capsulectomy. Future studies are therefore needed to investigate how capsule integrity influences the PIN distance to the Rh.

Furthermore, the presence of a layer of adipose tissue between the PIN and the anterolateral capsule has been described.[1] This tissue could constitute an element of PIN stability, maintaining the nerve in place also after capsulectomy or, on the contrary, it could rapidly absorb water, dilate, and additionally displace the nerve after capsulectomy. The structure of this adipose tissue, its reaction to fluid distension, and its role in PIN stability have yet to be defined. To minimize biases related to unexpected behavior of this tissue, care was taken not to manipulate it after capsulectomy and during measurements.

Finally, we focused primarily on the description of the position of the PIN in relation to the Rh. The study was neither designed to investigate the risk of PIN injuries in specific surgical procedures nor to detect the effect of systemic connective tissue diseases or local pathologic changes on the soft tissue of the lateral side of the elbow. Nevertheless, care was taken in evaluating the specimens for any visible signs of previous trauma, gross instability, or deformity. Further research is warranted to define the relevance of changes in the PIN position with respect to specific arthroscopic gestures on the lateral aspect of the elbow.

Conclusions

PIN protection is a critical issue in elbow surgery. This study demonstrates that the PIN crosses the Rh midline when the forearm is moved from pronation to supination also in arthroscopy. The role of pronation in protecting the PIN whenever extra-articular procedures are performed on the lateral side of the Rh is therefore confirmed in arthroscopic surgery. Moreover, supination significantly increased the distance between the PIN and the Rh: therefore, supination of the forearm is recommended when working intra-articularly to increase the safe working volume between the PIN and the most anterior part of the Rh.

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