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Safety of Anteromedial Portals in Elbow Arthroscopy: A Systematic Review of Cadaveric Studies:

Anteromedial Elbow Cadaveric Review

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Abstract

Purpose: To systematically review available literature comparing location and safety of two common anteromedial portals with nearby neurovascular structures in cadaveric models and to determine the correct positioning and preparation of the joint prior to elbow arthroscopy.

Methods: The review was devised in accordance with PRISMA guidelines. Inclusion criteria consisted of original, cadaveric studies performed by experienced surgeons on male or female elbows evaluating anteromedial portal placement with regards to proximity of the arthroscope to neurovascular structures. Exclusion criteria consisted of case reports, clinical series, non-English

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and non-cadaveric studies. Statistical analysis was done to measure reviewer reliability after scoring of each study.

Results: 2,596 studies were identified during screening and 10 studies met final inclusion as original, cadaveric investigations of anteromedial portal proximity to neurovascular structures. The difference in distance between proximal and distal portals was less than 1mm for the brachial artery and less than 1.5mm for the medial antebrachial cutaneous nerve, whereas the ulnar nerve was 4.17mm further from the distal portal and the median nerve was 5.07mm further from the proximal portal. Joint distension increased the distances of neurovascular structures to portal sites with the exception of the ulnar nerve in distal portals. Elbow flexion to 90 degrees increased distances of all neurovascular structures to portal sites.

Conclusion: The results show proximal anteromedial portals puts less structures at risk compared to the distal portal. Elbows in 90-degrees flexion with joint distension carry a lower risk of neurovascular injury during portal placement. These findings suggest the proximal anteromedial portal to be the safer technique in anteromedial arthroscopy of the elbow.

Clinical Relevance: Discrepancies in placement of portals have existed in literature indicating differing safety margins regarding surrounding neurovascular anatomy. The present study aims to link the literature-based evidence together in order to describe the safest anteromedial portal variation.

Introduction

In the field of elbow arthroscopy, physicians face many challenges that centralize around the safety and complexity of accessing the joint capsule and preserving neurovascular structures in target joints. Within the limited space of the elbow lies the ulnar, radial, and median nerves, many cutaneous nerves, and major blood vessels - within range of potential injury from arthroscopic instrumentation. Previous notions existed in the early 20th century that elbow arthroscopy was too dangerous and impractical given risks to surrounding neurovascular anatomy.^{1,2} However, there have been well documented reviews of diagnostic and procedural techniques associated with elbow arthroscopy since the 1980s, which all detail the importance of maintaining adequate safety in what is considered to be one of the most high-risk arthroscopic procedures routinely performed.^{3,4}

One of the earliest reviews by Andrews and Carson concluded the need for extreme delicacy during arthroscopic inspection of the elbow compared to more accessible knee joints since instrumentation must pass through deeper muscular layers and in close proximity to neurovascular structures.³ Over the past few decades, multiple authors have described the risk and benefit of certain arthroscopic portal locations including the anteromedial, anterolateral, and posterior approaches. However, many discrepancies exist among upper extremity surgeons pertaining to the proper location and safety of these portals. These discrepancies are due to the multitude of techniques and approaches utilized in existing cadaveric studies, which were done with different portal locations, variable levels of joint distension, and varying elbow positioning.³⁻¹²

The purposes of this study were to systematically review available literature comparing the location and safety of two common anteromedial portals with nearby neurovascular

structures in a cadaveric model and to determine the correct positioning and preparation of the joint prior to elbow arthroscopy. Additionally, we aimed to determine the correct positioning and preparation of the joint prior to elbow arthroscopy. We hypothesize that both proximal and direct anteromedial portals, coupled with joint distension and elbow flexion, provide equal risk to surrounding neurovascular structures of the elbow.

Methods

Design, Eligibility Criteria and Search Strategy

An initial search for literature was performed using the PubMed, EMBASE, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Mendeley, and Google Scholar databases according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Figure 1).¹³ Last search queries were completed in November 2018. The search terms within each database included combinations of “elbow”, “elbow arthroscopy”, “arthroscopy”, “portal”, “anteromedial”, “cadaver”, and “anteromedial portal”. Inclusion criteria consisted of original, cadaveric studies performed by surgeons experienced in elbow arthroscopy evaluating the placement of the anteromedial portal on male and female cadaveric elbows with regards to proximity of the arthroscope to neurovascular structures and safety profile. Exclusion criteria consisted of case reports, clinical series, non-English and non-cadaveric studies. No restrictions were placed on publication date or status.

Study Screening and Data Abstraction

Four independent investigators, including one medical student, one orthopedic resident and two orthopedic surgeons, qualified each manuscript that met final inclusion for reference to the present study. Two senior authors, FS and MO, fellowship trained orthopedic surgeons, were the final decision makers for the inclusion of any manuscripts referenced in our study. After this qualifying period, 10 studies met final inclusion into the present study.^{3–12} Discrepancies in study inclusion were resolved by reviewer consensus and agreement. Two independent reviewers, TC and ZF, one medical student and one orthopedic resident, performed data abstraction and included the following variables: study characteristics (author, year), number of cadavers used, and portal location relative to neurovascular anatomy, joint distension, and arm positioning. Variables were collected and recorded in a Microsoft Excel (2017) worksheet. Results were obtained for each variable where reported and all were systematically compared to each other (Tables 1, 2 and 3). The primary outcome assessed in each cadaveric dissection was the distance between neurovascular anatomy and the path of the arthroscope (Table 2). Some studies incorporated additional variables such as forearm and elbow positioning when portals were placed. These results were added to the comparison and their values reported as a separate entity (Table 3).

Quality Assessment and Data Analysis

Quality assessment of all included literature was performed using the Quality Appraisal for Cadaveric Studies (QUACS) scoring method.¹⁴ QUACS is used exclusively for studies that performed cadaveric dissections. Each of the 13 criteria, if applicable, is given a score of either a 0 or 1, with a maximum score of 13. Studies that do not contain statistical

methodology can only receive a maximum score of 12. Two independent reviewers recorded ratings for each included study and the total QUACS score (%) was determined. Studies with a QUACS score of 80% or greater were considered high-quality, studies with QUACS scores of 51–79% were considered moderate-quality and those with QUACS scores of 50% or below were considered low-quality. Discrepancies between scores were discussed and if needed, the senior author was consulted for direction. The Intraclass Correlation Coefficient (ICC) measure of reliability was calculated based on QUACS scores. ICC ranges from 0 to 1 where a value of 1 indicates excellent interrater reliability.

Results

A total of 2,596 studies were identified after searching literature databases (Figure 1). After duplicate articles were eliminated, a total of 2,231 articles remained for review. 2,123 of these studies were non-cadaveric and excluded. 108 full text articles were then assessed for eligibility based on title and abstract. 98 of these potentially eligible studies were excluded because they failed to address distances and safety profiles between the anteromedial elbow portal and neurovascular anatomy. Overall, 10 articles met inclusion criteria for assessment of the anteromedial portal.^{3–12} Across all studies that met inclusion criteria, there were a total of 102 cadavers dissected (Table 1). However, one of these studies by Andrews and Carlson originally described their clinical experience with 12 patients followed by a cadaveric study of an undisclosed number³, which would therefore increase the sample size, if reported.^{4–12} The 10 included studies were published between 1985 and 2016 (Table 1). Study quality was determined from average QUACS scores reported by the two independent reviewers (Table 1). As a result, there were two low-quality studies,^{3,12} five medium-quality studies,^{4,5,6,7,8} and three high-quality studies.^{9,10,11} There was considerable agreement between the reviewers during quality assessment (ICC of 0.98).

There were five separate definitions identified for anteromedial elbow portals (Figure 2), each grouped into two main categories according to their location relative to the medial epicondyle: the distal and proximal portal. Andrews and Carlson originally described the first anteromedial portal as a distal approach.³ Poehling et al later described the first proximal anteromedial portal.¹⁶ Adolffson et al⁷, Stothers et al⁸, Unlu et al⁹ and Chaware et al¹⁰ were the four studies that compared both the distal and proximal anteromedial portals.

Portal Categories, Definitions, and Locations

Distal AM Portal Placement

Eight articles reported the placement of the distal anteromedial portal. Seven of the eight studies reported using the original definition of the distal portal as described by Andrews and Carlson^{3,4,7,8,9,10,12}, 2cm distal and 2cm anterior to the medial epicondyle. Verhaar et al⁶ reported use of a 2cm distal and 1cm anterior portal.

Proximal AM Portal Placement

Six articles reported using a proximal anteromedial approach. Of these six studies, four compared the distal and proximal anteromedial approaches. The earliest definition of the proximal anteromedial portal appears to be established by Linfield et al⁵, describing it as

1cm proximal and 1cm anterior to the medial epicondyle. Four studies report the use of this original definition of the proximal portal^{5,7,9,11} and two studies report the use of a 2cm proximal anteromedial portal, with and without specified anterior positioning.^{8,10}

Average distance to Neurovascular Structures

Proximal vs. Distal Portal Technique

The difference in distance between proximal and distal portals was less than 1mm for the brachial artery and less than 1.5mm for the median antebrachial cutaneous nerve (MABCN), whereas the ulnar nerve was 4.17mm further from the distal portal and the median nerve was 5.07mm further from the proximal portal. Across all studies, the median nerve ($18.05 \pm 3.67\text{mm}$) and MABCN ($5.34 \pm 2.33\text{mm}$) averaged the furthest distance from the proximal anteromedial portal. The ulnar nerve ($22.61 \pm 4.42\text{mm}$) and brachial artery ($20.1 \pm 4.24\text{mm}$) averaged the furthest distance from the distal portal. A standard deviation of 0mm occurred when only one study reported an average measurement for a certain portal distance to neurovascular structures (Table 2).

Effect of Joint Distention

High variability existed when measuring the distances from the anteromedial portal to neurovascular structures. This variability may be caused by differences in study design and direction of the surgeon's portal placement toward the joint capsule. One clear difference between these studies was the utilization or absence of joint distension. Four studies performed measurements without distending the joint capsule,^{3,4,8,12} Five studies utilized joint distension,^{5-9,11} and one study compared measurements between distended and non-distended joint capsules (Table 2).⁴ Verhaar et al⁶ did not utilize joint distension, however they produced measurements comparable to those in other studies with joint distension. Stothers et al⁸ did not identify differences in measurements between distended and non-distended joints, explicitly stating that distension had minimal effects compared to non-distension.

In a distended joint, the ulnar nerve ($21.81 \pm 5.05\text{mm}$) averaged the furthest distance from distal portals and the median nerve ($19.46 \pm 2.15\text{mm}$), brachial artery ($21.0 \pm 0\text{mm}$) and MABCN ($6.35 \pm 1.41\text{mm}$) averaged the furthest distance from proximal portals. In a non-distended joint, the ulnar nerve ($25 \pm 0\text{mm}$) averaged the furthest distance from distal portals and the median nerve ($12.4 \pm 0\text{mm}$), brachial artery ($18 \pm 0\text{mm}$) and MABCN ($2.3 \pm 0\text{mm}$) averaged the furthest distance from proximal portals (Table 2). When comparing measurements between distended and non-distended joints, all distal and proximal portal safety margins were largest in distended joints, except for the distance from the distal portal to the ulnar nerve. However, Verhaar et al⁶ was the only study to measure the distance between the distal portal and ulnar nerve without joint distension, measuring $>25\text{mm}$ from the distal portal site. Further studies are necessary to confirm these measurements for a more thorough understanding of the benefits of joint distension in ulnar nerve position.

Insertion with forearm in Extension vs. Flexion

Three studies, Unlu et al⁹, Chaware et al¹⁰, and Stothers et al⁸, determined the effects of flexion and extension on distal and proximal portal safety profile (Table 3). Flexion produced greater distances from portal site to neurovascular structures, with the exception of the Chaware study, which found the median nerve and MABCN to lie further from distal and proximal portals in extension. This difference is no greater than 2.7mm for any average measurement.

Miller et al¹⁵, a study not captured in any tables due to the uniqueness of their approach, measured distances from the humerus and joint capsule to nerves with and without joint distension. They measured seven pairs of insufflated and non-insufflated cadaveric elbows, one of which was arranged in extension and the other six in flexion. They reported greater distances from bone-to-nerve and capsule-to-nerve in a flexed, insufflated elbow compared to non-insufflated elbows and elbows in extension.

Insertion with forearm in Supination vs. Pronation

Unlu et al⁹ compared supination and pronation of the forearm. Table 3 indicates the differences in distance between pronation and supination of the forearm with the elbow flexed at 90-degrees. There was a slight increase in safety margins from the distal portal when the forearm was pronated. Supination and pronation had less of an effect on measurements from the proximal portal to neurovascular structures.

Discussion

The results reject our original hypothesis and strengthen the notion that the proximal anteromedial portal puts less neurovascular structures at risk compared to the distal portal. Additionally, distended elbows in a 90-degree flexed position have a reduced risk of neurovascular interference during placement of the arthroscope.

The complexity of elbow arthroscopy is affected by the close proximity of major neurovascular structures near the capsule and operative field. Optimizing the portal site placement can minimize risks of nerve and vascular injury. In this review, we have categorized the anteromedial elbow portal site into two groups relative to their position around the medial epicondyle: the distal and proximal anteromedial portals. We identified the proximal anteromedial portal technique as the surgical approach with the greatest safety margin, specifically in a 90-degree flexed and distended elbow.

The anteromedial portal was first described by Andrews and Carlson³, who aimed to compare the anterolateral and anteromedial portal site. They described the anteromedial portal as 2cm distal and 2cm anterior to the medial epicondyle. Soon after, Poehling et al¹⁶ defined the first proximal anteromedial portal as 2cm proximal to the medial epicondyle. They placed their proximal portal directly anterior to the intermuscular septum, which served as a guide to avoid damage to the ulnar nerve. Lindenfield et al⁵ followed shortly after with another definition of the proximal anteromedial portal, which was placed 1cm proximal and 1cm anterior to the medial epicondyle. From then on, there have been five variations of the anteromedial portal investigated, owing to the discrepancy in expert opinion

on adequate portal placement. The senior authors have modified the proximal anterior medial portal, as originally described by Poehling et al¹⁶, to a more anterior location. This portal, 2.5cm proximal and almost 3cm anterior to the medial epicondyle, provides a complete view of the entire anterior compartment, including the medial side. The present review, although not specifically addressing this portal, does indeed show a satisfactory safety margin for proximal anteromedial portals and requires further evaluation in a cadaveric study.

Many authors have described caution in their approach of elbow arthroscopy as Andrews and Carson once described in their original review of elbow arthroscopy reporting transient median nerve palsy.¹⁷ Lynch et al reported a transient median nerve palsy, radial nerve palsy, and a neuroma of the MABCN using the distal anteromedial portal.⁴ A more recent study by Hilgersom et al looked at permanent ulnar and radial nerve injury following elbow arthroscopy, speculating that portal placement and use of motorized instrumentation could be avoidable causes to nerve damage.¹⁸ Kelly et al concluded in their review of 473 patients that temporary or minor complications from elbow arthroscopy, including ulnar and medial antebrachial cutaneous nerve palsies, could be more common than previously thought, which they reported as occurring 11% of the time. However, Kelly et al noted that there were no permanent complications seen in their review.¹⁹ Dumonski et al reported a case of ulnar nerve injury after arthroscopic debridement and drilling of the capitulum using a proximal medial portal (2 cm proximal to the medial epicondyle at the level of the medial intermuscular septum) in a patient with symptomatic osteochondritis dissecans. They concluded that extending this portal further proximally negates any protection of the ulnar nerve afforded by the intermuscular septum.²⁰ Under the assumption that larger distances from the portal to neurovascular structures would decrease risk of injury, it appears imperative to choose a portal technique that would maximize these distances and safety profiles.

Joint distension significantly improved the safety profile of the anteromedial portals (Table 2). Carson agrees with the trend seen here that joint distension should precede puncture of the joint capsule because it pushes soft tissues anteriorly, increasing the clearance between neurovascular structures and the arthroscope.^{9,12,21} Furthermore, Lindenfield et al⁵ preferred the proximal anteromedial portal in a distended joint due to the dense, tendinous nature of the flexor/pronator group, which reduces fluid extravasation from the capsule. Lindenfield et al⁵ compared this reduction in fluid extravasation to the softer, thinner radial capsule when using the anterolateral portal, which has less of an ability to maintain joint distension. Because of its superior fluid control, the proximal anteromedial portal maintains a predictable safety margin for a longer period of time.⁵

In a distended joint, the ulnar nerve was furthest from the distal portal and the median nerve, brachial artery and MABCN were furthest from the proximal portal (Table 2). Many authors prefer the proximal anteromedial portal because it provides greater visualization of the radial head and it provides better accessibility to the radio-ulnar joint.^{6,7,21} Stothers et al⁸ reported that the proximal portal provides complete assessment of the anterior elbow joint. Lindenfield et al⁵ reported versatility of the proximal portal (1cm proximal, 1cm anterior) over the distal portal used by Lynch et al⁴ (2cm distal, 2cm anterior) because proximal portal

placement can be angled in more ways than the distal portal, providing more options for joint visualization. Lindenfield et al⁵ further concluded that the distal portal is close to the distal aspect of the elbow capsule and a cannula can only be advanced straight medially in a direction toward the median nerve, putting it at an increased risk of injury. A proximal portal allows the cannula to be directed distally, parallel to the median nerve with less risk of nerve injury.⁵ Trauma and previous surgery to the elbow is an important part of patient history before plans for portal placement can be done. Potential anatomic changes to neurovascular structures, such as ulnar nerve transposition or previous trauma, can affect nerve mobility and deviate from typical anatomy.^{5,8,11} Park et al studied the use of proximal anteromedial portals in patients with prior transposition of the ulnar nerve and concluded that it was a safe portal technique based on a degree of certainty with which the nerve can be localized by clinical palpation.²²

When comparing the safety profile of each of the studies included in this review to the collective mean, a few studies provided the most accurate measurements from the anteromedial portal to neurovascular structures. Adolfsson et al⁷ reported the closest measurement to the mean from the distal anteromedial portal to the ulnar nerve, median nerve, MABCN and from the proximal anteromedial portal to the median nerve. Unlu et al⁹ reported the closest measurement to the mean from the distal anteromedial portal to the brachial artery and from the proximal anteromedial portal to the ulnar nerve and brachial artery. Chaware et al¹⁰ reported the closest measurement to the mean from the proximal anteromedial portal to the MABCN. Of all of these studies that reported measurements closest to the mean distances from portal to neurovascular structures, Adolfsson et al⁷ had the greatest number of measurements closest to the mean distances. One important reason that could have led to the accuracy of the Adolfsson et al⁷ measurements over the other studies, is that Adolfsson et al⁷ and Zonno et al¹¹ were the only two studies that incorporated a 2.7mm arthroscope rather than a 4mm arthroscope. Adolfsson et al⁷ alludes to the fact that a smaller arthroscope could be one of the reasons they reported the specific distances they measured. Additionally, it is important to note that Zonno et al¹¹ reported the second closest measurement to the mean from the proximal anteromedial portal to the ulnar nerve, which was the only measurement they reported in their study. These results indicate that the use of smaller arthroscopes may allow for more accurate measurements when conducting a study of this nature. Although, the majority of arthroscopy is performed with the 4mm arthroscope and the utility of these measurements may be limited. Investigation of pressure on the neurovascular structures needs to be investigated based on arthroscope size to further evaluate these differences.

Future studies should investigate the increased safety profile of the proximal anteromedial portal with every aspect analyzed, including but not limited to cannula size, flexion/extension, joint distension/non-distension, and supination/pronation. Potential new studies include analyses of portal distances to neurovascular structures in post-traumatic elbows compared to healthy elbows and the use of technological advancements and their effect on safety.

Limitations

Our review has several limitations. The medial epicondyle is an indiscrete ridge rather than a focused point and the included studies did not identify a specific point on the medial epicondyle for reference. This could provide a source of error when measuring the placement of the distal and proximal portals as well as measuring distances from the portal to neurovascular structures.⁵ Though many anteromedial portal techniques were described in this review, many practitioners have modified their anteromedial approach as previously described. Because of this distinction, there may be other anteromedial portals used throughout the orthopedic surgery community that have not been evaluated for safety in this review. Cadaveric studies are limited by changes in tissue characteristics compared to *in vivo* and there was a significant distinction in preservation technique between the 4 studies that compared the distal and proximal portals.^{7–10} Chaware et al¹⁰ used formalin-fixed cadavers whereas the other three studies used fresh, frozen cadavers^{7–9}, even noting their use within 36 hours of reception.⁹ Regarding the cadaver preservation techniques of the 6 other studies in this review, all used fresh, frozen cadavers except for Andrews and Carlson et al³ and Marshall et al¹², in which there was no mention of cadaver preservation technique. There were only three studies^{9,10,11} that included accuracy metrics of their technique. Unlu et al⁹ reported accuracy to 1mm, Chaware et al¹⁰ reported accuracy of their digital Vernier calipers of $\pm 0.02\text{mm}$, and Zonno et al¹¹ reported precision of their Optotrack 3020 measurement system of 0.29mm. Because seven studies did not report measurement accuracy, we may be limited by the potential magnitude of deviation from the reported distances in those studies. Chaware et al¹⁰ alludes to the fact that fresh cadavers would have been preferable and asserted that formalin-fixed specimens limit the extent of joint distension and neurovascular mobility due to a reduction in elasticity of embalmed tissue. These limitations were not reported in studies using fresh cadavers.

There were two cadaveric studies that were excluded from this review because they did not meet eligibility and did not contain valuable information needed in order to be a significant contributor to this review. Drescher et al²³ was a cadaveric study conducted in German that found the mean distance of the median nerve to the arthroscope of the anteromedial portal was 15.5mm (range 8–27mm) when elbow joint position was optimized in 90-degree flexion and distended. This study did not meet inclusion because the large majority of it was non-English and the small amount that was written in English did not indicate whether the anteromedial portal was made distally or proximally. Claessen et al²⁴ was another cadaveric study that measured the proximity of the anteromedial arthroscope to neurovascular structures. This study was excluded because all of the surgeons were inexperienced in elbow arthroscopy and their training for the procedure came solely from a 2-hour introductory course given before cadaveric dissection took place. The inexperience has potential to confound our measurement analysis from errant portal placement.

Conclusion

The results show proximal anteromedial portals puts less structures at risk compared to the distal portal. Elbows in 90-degrees flexion with joint distension carry a lower risk of

neurovascular injury during portal placement. These findings suggest the proximal anteromedial portal to be the safer technique in anteromedial arthroscopy of the elbow.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1:
Flow diagram illustrating the literature search process

Figure 2:

Image illustrating the 5 different anteromedial portal locations identified during literature review. A, two versions identified of the 2cm proximal portal. B, 2cm proximal and 1cm anterior portal. C, 2cm distal and 2cm anterior portal. D, 2cm distal and 1cm anterior portal.

Table 1:

Information for each included study, neurovascular structures and portals investigated, elbow position variations and use of distention. QUACS scores for all included studies determined by two independent raters, with individual scores listed for each of the 13 QUACS criteria.¹⁸

Authors, Year	Number of Elbows Dissected	Neurovascular Structures Investigated	Elbow Position Variations	Distension (Y/N/Both)	Type of Portal Investigated (Distal, Proximal, or Both)		Total QUACS Score:	Maximum Possible QUACS Score:	QUACS (%)
Unlu et al., ⁹ 2006	20	Ulnar n., Median n., Brachial a., MABCN	Y	Y	Both	Rater 1	11	13	84.62
						Rater 2	12	13	92.31
Lynch et al., ⁴ 1986	5	Median n., Brachial a., MABCN	N	Both	Distal	Rater 1	9	12	75.00
						Rater 2	9	12	75.00
Zonno et al., ¹¹ 2010	8	Ulnar n.	N	Y	Proximal	Rater 1	11	12	91.67
						Rater 2	11	12	91.67
Marshall et al., ¹² 1992	20	Median n.	N	N	Distal	Rater 1	6	12	50.00
						Rater 2	6	12	50.00
Stothers et al., ⁸ 1995	12	Ulnar n., Median n., Brachial a., MABCN	Y	N	Both	Rater 1	8	12	66.67
						Rater 2	8	12	66.67
Lindenfeld et al., ⁵ 1990	6	Ulnar n., Brachial a.	N	Y	Proximal	Rater 1	8	12	66.67
						Rater 2	8	12	66.67
Adolfsson et al., ⁷ 1994	14	Ulnar n., Median n., Brachial a., MABCN	N	Y	Both	Rater 1	9	12	75.00
						Rater 2	8	12	66.67
Verhaar et al., ⁶ 1991	5	Ulnar n., Median n., Brachial A.	N	N	Distal	Rater 1	7	12	58.33
						Rater 2	7	12	58.33

Authors, Year	Number of Elbows Dissected	Neurovascular Structures Investigated	Elbow Position Variations	Distension (Y/N/ Both)	Type of Portal Investigated (Distal, Proximal, or Both)		Total QUACS Score:	Maximum Possible QUACS Score:	QUACS (%)
Chaware et al., ¹⁰ 2016	12	Ulnar n., Median n., MABCN	Y	Y	Both	Rater 1	12	13	92.31
						Rater 2	12	13	92.31
Andrews et al., ³ 1985	Unknown	Median n.	N	N	Distal	Rater 1	4	12	33.33

QUACS, Quality Appraisal for Cadaveric Studies; MABCN, medial antebrachial cutaneous nerve; n., nerve; a., artery

Table 2:

The average measured distances to the ulnar nerve, median nerve, brachial artery and median antebrachial cutaneous nerve (MABCN) reported at each portal site for each study. The average distances and associated standard deviations from neurovascular structure to portal site between all studies, studies that only included joint distension, and studies that did not include joint distension. Standard deviations (reported in table as $\pm$ standard deviation) and ranges of measurements reported in each study were included, if available. Of note, the values reported in the table are with the elbow in 90-degrees of flexion wherever applicable to standardize comparison. w/o = measured without joint distention; w = measured with joint distention. There was no standard deviation or range to report from the Andrews and Carlson³ study.

Study	Average Distance to Ulnar N. (if reported) (mm)		Average Distance to Median N. (if reported) (mm)		Average Distance to Brachial A. (if reported) (mm)		Average Distance to MABCN (if reported) (mm)	
	Distal	Proximal	Distal	Proximal	Distal	Proximal	Distal	Proximal
Andrews and Carson (w/o)			6					
Lynch et al (w and w/o)			4 (range 3–10mm) (w/o), 14 (w)		9 (range 8–13mm) (w/o), 17 (w)		1 (range 1–9mm) (w)	
Lindenfeld (w)		23.7 $\pm$ 1.63		22.3 $\pm$ 1.63				
Verhaar et al (w/o)	> 25		18 (range 12–25mm)		26 (range 21–32mm)			
Adolfsson et al (w)	24 (range 19–26mm)	21 (range 19–24mm)	14 (range 11–18mm)	19 (range 16–22mm)	22 **		4 (range 2–11mm)	6 (range 3–12mm)
Stothers et al (w/o)		12 (range 7–18mm)	7 (range 5–13mm)	12.4 (range 7–20mm)	15.2 (8–20mm)	18 (12–25mm)	1 (range 0–5mm)	2.3 (range 0–9mm)
Unlu et al * (w)	25.4 $\pm$ 1.7	20 $\pm$ 2.2	16.2 $\pm$ 4.4	17.1 $\pm$ 2.8	20.3 $\pm$ 3.4	21.1 $\pm$ 3.3	9.2 $\pm$ 3.9	7.9 $\pm$ 2.5
Chaware et al (w)	16.03 $\pm$ 4.86	13.16 $\pm$ 3.73	22.12 $\pm$ 6.64	19.45 $\pm$ 7.42			4.99 $\pm$ 5.03	5.14 $\pm$ 5.08
Marshall et al (w/o)			6.5 $\pm$ 3.3					
Zonno et al (w)		20.8 (range 14.4–25.1mm)						
Average Distance and Standard Deviation (All Studies)	22.61 $\pm$ 4.42	18.44 $\pm$ 4.72	12.98 $\pm$ 5.95	18.05 $\pm$ 3.67	20.1 $\pm$ 4.24	19.55 $\pm$ 2.19	4.04 $\pm$ 3.39	5.34 $\pm$ 2.33
Average Distance and Standard Deviation (w/ joint distension)	21.81 $\pm$ 5.05	19.73 $\pm$ 4.28	16.58 $\pm$ 3.84	19.46 $\pm$ 2.15	19.77 $\pm$ 2.54	21.1 $\pm$ 0	4.8 $\pm$ 3.39	6.35 $\pm$ 1.41
Average Distance (w/o joint distension)	25 $\pm$ 0	12 $\pm$ 0	8.3 $\pm$ 5.54	12.4 $\pm$ 0	16.73 $\pm$ 8.6	18 $\pm$ 0	1 $\pm$ 0	2.3 $\pm$ 0

* best results from the study in full flexion and neutral pronation/supination rotation⁹

** reported as 8mm further from the mean median nerve distance (14mm) to the distal portal, which therefore was assumed to equal 22mm⁷

MABCN, median antebrachial cutaneous nerve; n., nerve; a., artery; w/o, measured without joint distention; w, measured with joint distention.

Table 3:

Three studies that reported measurements from the distal and proximal anteromedial portal to neurovascular structures under settings of various flexion/extension and pronation/supination positions.^{8–10}

Distal Portal (mm)					
Unlu et al					
	90 flex+neutral	extension+neutral	full flexion+neutral	90 flex+supination	90 flex+pronation
median n.	12.9 ± 4.6	7.9 ± 4.6	16.2 ± 4.4	13.9 ± 4.3	15.1 ± 4.4
ulnar n.	22.1 ± 2.0	17.7 ± 1.6	25.4 ± 1.7	22.5 ± 1.9	22.6 ± 1.9
MABCN	8.9 ± 3.8	8.8 ± 3.4	9.2 ± 3.9	9.1 ± 3.6	9.2 ± 3.8
brachial a.	16.6 ± 3.6	11.5 ± 3.4	20.3 ± 3.4	17 ± 3.5	18.4 ± 3.9
Chaware et al					
	90 flex+neutral	extension+neutral	full flexion+neutral	90 flex+supination	90 flex+pronation
median n.	22.12 ± 6.64	24.77 ± 6.56			
ulnar n.	16.03 ± 4.86	14.56 ± 5.49			
MABCN	4.99 ± 5.03	5.35 ± 4.94			
Stothers et al					
	90 flex+neutral	extension+neutral	full flexion+neutral	90 flex+supination	90 flex+pronation
median n.	7	2.1			
brachial a.	15.2	9.6			
Proximal Portal (mm)					
Unlu et al					
	90 flex +neutral	extension+neutral	full flexion+neutral	90 flex+supination	90 flex+pronation
median n.	13.8 ± 2.6	8.9 ± 2.8	17.1 ± 2.8	13.8 ± 2.6	14.1 ± 2.5
ulnar n.	16.2 ± 2.2	12.2 ± 2.1	20 ± 2.2	16.2 ± 2.2	16.2 ± 2.4
MABCN	7 ± 2.6	2.9 ± 1.8	7.9 ± 2.5	7 ± 2.6	6.7 ± 2.3
brachial a.	17.6 ± 3.3	12.3 ± 3.3	21.1 ± 3.3	17.6 ± 3.3	17.9 ± 3.1
Chaware et al					
	90 flex +neutral	extension+neutral	full flexion+neutral	90 flex+supination	90 flex+pronation
median n.	19.45 ± 7.42	20.69 ± 7.16			
ulnar n.	13.16 ± 3.73	12.84 ± 4.60			
MABCN	5.14 ± 5.08	5.54 ± 5.68			
Stothers et al					
	90 flex +neutral	extension+neutral	full flexion+neutral	90 flex+supination	90 flex+pronation
median n.	12.4	7.6			
brachial a.	18	16.6			

flex, flexion; MABCN, medial antebrachial cutaneous nerve; n., nerve; a., artery; 90, 90 degrees