Original Research Article

BEYOND BONY LANDMARKS: THE TRICEPS APONEUROSIS CONFLUENCE AS A PREDICTIVE GUIDE FOR RADIAL NERVE PROTECTION

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ABSTRACT

Background: Iatrogenic radial nerve injury remains a persistent challenge in posterior humeral surgery, with reported rates up to 18% in complex fractures. Traditional reliance on bony landmarks is often unreliable due to fracture displacement, comminution, or anatomical variability. Soft-tissue landmarks that are consistently identifiable may offer a safer, more practical guide for nerve localization, yet their clinical utility remains underexplored. The aim is to prospectively quantify the anatomical relationship between the radial nerve and the triceps aponeurosis confluence, a soft-tissue landmark readily identifiable during posterior humeral approaches, and evaluate its potential to reduce iatrogenic injury.
Materials and Methods: Forty patients (18–60 years) with closed middle- or distal-third humeral shaft fractures underwent posterior open reduction and internal fixation. The confluence point of the triceps aponeurosis was marked intraoperatively, and the distance to the radial nerve in the spiral groove was measured. Arm length, laterality, and postoperative radial nerve function were recorded.
Results: The radial nerve was located a mean of 2.53 cm (range 2.3–2.8 cm) proximal to the aponeurosis confluence. No intraoperative or postoperative nerve injuries occurred. Distances were consistent across left- and right-sided fractures ($p > 0.05$), and all fractures achieved radiological union without complications.
Conclusion: The triceps aponeurosis confluence is a reliable, reproducible soft-tissue landmark for anticipating radial nerve location, offering a clinically relevant adjunct to bony references. Its use may enhance operative safety during posterior humeral approaches, particularly in complex or comminuted fractures. Prospective studies are warranted to validate its impact on surgical outcomes and nerve protection.
Keywords: Bony Landmarks, Triceps Aponeurosis, Radial Nerve.

INTRODUCTION

Iatrogenic injury to the radial nerve remains a persistent challenge in orthopaedic surgery, particularly during posterior approaches to the humeral shaft. The nerve's close anatomical relationship with the posterior humerus, its oblique course through the spiral groove, and proximity to musculotendinous structures render it vulnerable during fracture fixation, tumour excision, and reconstructive procedures. Despite advancements in surgical techniques, intraoperative imaging, and nerve monitoring, radial nerve palsy continues to be reported, underscoring the critical need for precise, reproducible anatomical guidance.

The triceps brachii, the principal extensor of the elbow, comprises three heads—long, lateral, and medial—that converge distally to form a common aponeurosis inserting onto the olecranon. The confluence point of this aponeurosis is consistently identifiable during posterior surgical exposure, even in complex trauma cases, making it a potentially reliable intraoperative landmark. Its proximity to the radial nerve offers an opportunity to improve nerve localization and minimize iatrogenic injury, yet this relationship has not been systematically quantified.

The radial nerve arises from the posterior cord of the brachial plexus and courses obliquely from medial to lateral within the spiral groove, passing between the lateral and medial heads of the triceps. Distally, it pierces the lateral intermuscular septum to enter the anterior compartment before bifurcating into superficial and deep branches near the lateral epicondyle. Considerable anatomical variability in its course, depth, and relation to surrounding structures increases the risk of inadvertent injury during surgical intervention.

Historically, safe zones for radial nerve exposure have been defined using bony landmarks such as the acromion, lateral epicondyle, or total humeral length. However, reliance solely on osseous references is limited by patient positioning, fracture displacement, and inter-individual variation. Soft-tissue landmarks that remain intact and easily identifiable, such as the triceps aponeurosis confluence, may provide superior intraoperative guidance.

Despite its potential clinical utility, few studies have precisely quantified the spatial relationship between the radial nerve and the triceps aponeurosis confluence. Addressing this gap is critical for improving operative safety, optimizing surgical approaches, and guiding educational training. This study aims to delineate the radial nerve's anatomical position relative to the triceps aponeurosis confluence, providing reproducible, clinically relevant data to enhance the safety and efficacy of posterior arm procedures.

MATERIALS AND METHODS

A prospective, hospital-based observational study was conducted at our institution involving patients with humeral shaft fractures who underwent surgical management. The study period extended from February 2023 to November 2025. Patients presenting with closed humeral shaft fractures classified as AO type 12-A or 12-B, involving the middle or lower third of the shaft, were screened for inclusion.

A total of 40 patients met the inclusion criteria and were enrolled in the study. Inclusion criteria comprised patients aged between 18 and 60 years with closed humeral shaft fractures, intact preoperative radial nerve function, and no distal fracture extension. Patients with open fractures, proximal or distal humerus involvement, grossly comminuted fractures, pre-existing muscle atrophy, pathological fractures, associated neuromuscular disorders, or preoperative radial nerve injury were excluded.

Institutional Ethics Committee approval was obtained prior to initiation of the study, and informed written consent was obtained from all participants. Preoperative evaluation included a detailed clinical examination to classify the fracture pattern, assess soft-tissue condition, rule out associated injuries, and document baseline radial nerve function. Temporary fracture stabilization was achieved using a U- or J-shaped plaster slab until definitive surgery. Routine preoperative investigations included complete blood counts, serum biochemistry, electrocardiography, chest radiography, and radiographs of the injured arm including the shoulder and elbow joints.

All patients underwent surgery under general and were positioned in the standard lateral decubitus position. Procedures were performed under fluoroscopic guidance to confirm appropriate plate positioning and screw length. After standard skin preparation and sterile draping, a midline posterior approach to the humeral shaft centered over the fracture site was utilized. A longitudinal skin incision measuring approximately 10–12 cm was made [Figure 1a]. The subcutaneous tissue and deep fascia were dissected, and the confluence point of the triceps aponeurosis was identified and marked using a sterile skin marker [Figure 1b, c].

Dissection was continued through the triceps muscle fibres until the radial nerve was visualized in the radial groove. A sterile metallic ruler was aligned along the longitudinal axis of the humeral shaft, and the distance between the previously marked confluence point of the triceps aponeurosis and the nearest point of the radial nerve was measured and recorded [Figure 2a,b]. Following nerve identification and protection, the fracture site was exposed, fracture ends were reduced, and internal fixation was performed using a locking compression plate (3.5 mm or 4.5 mm, narrow or broad as appropriate).

Following fixation, thorough wound irrigation was performed was closed in layers. All patients were advised to use an arm pouch. Intravenous antibiotics were administered for three postoperative days. Wound dressings were performed on the 2nd, 5th, and 8th postoperative days, and sutures were removed on the 10th postoperative day.

Rehabilitation was initiated on the second postoperative day and included pendulum shoulder exercises and elbow range-of-motion exercises for the first two weeks. Shoulder abduction exercises were commenced in the third postoperative week and gradually progressed to full range of motion over the subsequent three weeks. Weight-bearing activities were permitted after three months, following clinical and radiological confirmation of fracture union. Return to sports and strenuous activities was restricted for six months. Patients were followed up clinically and radiologically for a minimum duration of one year.

Statistical analysis was performed using SPSS software (IBM SPSS version 30). Descriptive statistics, including mean, range, and standard deviation, were calculated for all measured parameters. A paired t-test was used to compare parameters between left- and right-sided fractures, with statistical significance set at $p < 0.05$.

RESULTS

A total of 40 patients with closed humeral shaft fractures underwent open reduction and internal fixation using locking compression plates through a standard posterior approach. The study cohort comprised 28 males (70%) and 12 females (30%). The left humerus was involved in 27 patients (67.5%), while the right side was affected in 13 patients (32.5%). The mean age of the patients was 47 years (range: 18–60 years).

Road traffic accidents constituted the most common mechanism of injury, followed by self-fall and fall from height. Patients presented to the hospital at a mean of two days following injury. All patients had intact preoperative radial nerve function, and no intraoperative or postoperative radial nerve palsy was observed.

The mean distance of the radial nerve from the confluence point of the triceps aponeurosis was 2.53 cm, with a range of 2.3 cm to 2.8 cm. The mean arm length measured was 31.72 cm, ranging from 26 cm to 37 cm. No statistically significant difference was observed in measured distances between left- and right-sided fractures ($p > 0.05$).

All fractures achieved radiological union within the follow-up period. No cases of implant failure, deep infection, or reoperation were recorded during the study duration.

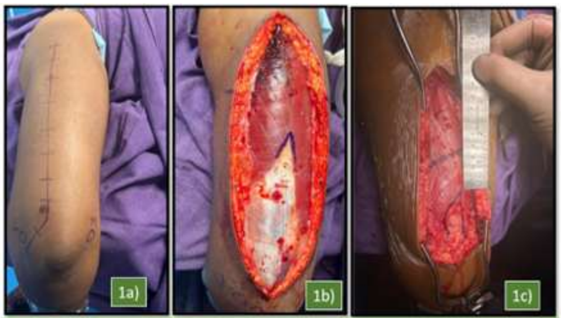

Fig 1a) Skin incision for posterior midline approach to humerus shaft marked with sterile maker b) triceps confluent point marked and expected level of radial nerve marked using a metal ruler.

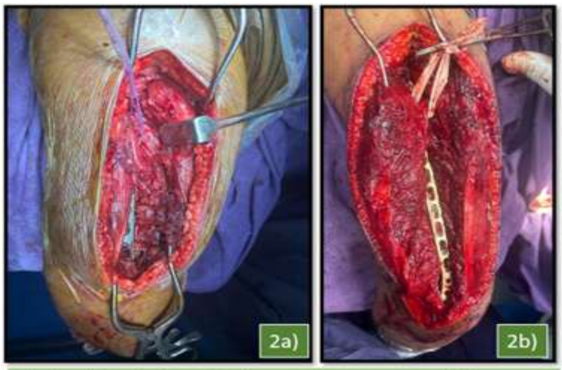

Fig 2 a, b) soft tissue is dissected to secure radial nerve which is protected using a loop during fixation of humerus shaft using plate

DISCUSSION

Iatrogenic injury to the radial nerve remains a major concern during surgical procedures involving the posterior aspect of the arm, particularly during fixation of humeral shaft fractures and posterior approaches to the humerus. Despite advances in surgical techniques, instrumentation, and intraoperative imaging, radial nerve palsy continues to be reported at clinically meaningful rates, underscoring the importance of precise anatomical localization of the nerve.[1,2] Traditional reliance on osseous landmarks to estimate the course of the radial nerve is frequently undermined by fracture displacement, comminution, and post-traumatic distortion of anatomy, limiting their reliability in many operative scenarios.[3] These limitations have driven interest in dependable soft-tissue landmarks, among which the confluence point of the triceps aponeurosis has emerged as a potentially reliable reference.

The triceps brachii muscle forms the principal muscular mass of the posterior compartment of the arm, with its long, lateral, and medial heads converging distally into a common aponeurosis inserting onto the olecranon. The confluence of the long and lateral heads, forming the apex of the triceps aponeurosis, is a distinct and readily identifiable structure during posterior surgical exposure.[4] In contrast to bony landmarks, which may be fractured, displaced, or obscured, this soft-tissue landmark tends to remain relatively preserved even in comminuted fractures, thereby offering potential advantages in complex operative settings.[5]

The radial nerve courses through the posterior compartment of the arm in close proximity to this aponeurotic convergence as it traverses the spiral groove of the humerus before penetrating the lateral intermuscular septum. This consistent anatomical relationship provides a sound anatomical rationale for using the confluence point of the triceps aponeurosis as a reference landmark for nerve localization.[6] Identification of a predictable soft-tissue guide may facilitate safer dissection and reduce the risk of inadvertent nerve injury during posterior exposure.

The majority of evidence supporting this landmark originates from cadaveric studies. Seigerman et al. demonstrated a relatively constant distance between the apex of the triceps aponeurosis and the radial nerve, reporting a mean distance of approximately 39 mm with minimal interspecimen variability during posterior humeral exposure.[7] These findings suggested that the radial nerve could be reliably anticipated at a predictable distance proximal to the aponeurotic convergence.

Comparable results were reported by Prasad et al., who identified a mean distance of approximately 40 mm between the triceps aponeurosis confluence and the radial nerve in adult cadaveric specimens.[8] Although greater variability was observed, the overall findings reinforced the utility of this landmark as a reasonable estimator of nerve location. Gupta et al. further substantiated these observations, emphasizing that soft-tissue landmarks exhibited less variability than distances measured from traditional bony reference points such as the lateral epicondyle or acromion.[9]

Arora et al. extended these anatomical observations by describing a surgical technique based on identification of the apex of the triceps aponeurosis, noting that the radial nerve could be consistently identified approximately 2.5–4 cm proximal to this point along the lateral border of the triceps muscle.[10] Importantly, this study provided both quantitative anatomical data and a practical intraoperative strategy, bridging the gap between cadaveric research and surgical application.

Taken together, these cadaveric investigations suggest that the confluence point of the triceps aponeurosis represents one of the more consistent soft-tissue landmarks for predicting the location of the radial nerve in the posterior arm. However, cadaveric data must be interpreted with caution. Post-mortem tissue changes, absence of muscle tone, and lack of physiological dynamics limit the direct translation of these measurements to live surgical conditions, where limb positioning, retraction, and tissue elasticity may alter spatial relationships.

Anatomical variability further complicates reliance on any single landmark. Variations in the branching pattern and course of the radial nerve, differences in muscle bulk, and morphological diversity of the triceps aponeurosis have been well documented.[11] Recent morphometric studies have classified distinct patterns of aponeurotic morphology, each with potential implications for the relative position of the radial nerve.[12] These variations reinforce the principle that the triceps aponeurosis confluence should be regarded as a guiding reference rather than an absolute determinant of nerve location.

Accordingly, landmark-based localization must be complemented by meticulous dissection and direct visualization of the nerve. This combined approach is particularly important in complex cases such as revision surgery, high-energy trauma, and nonunion, where both osseous and soft-tissue anatomy may be distorted.

Numerous studies have examined the relationship of the radial nerve to traditional bony landmarks, including the lateral epicondyle, medial epicondyle, and acromion.[13,14] While these landmarks may be useful in intact anatomy, their reliability diminishes substantially in the presence of fractures, malunions, or deformities. Several authors have reported wide interindividual variability in measurements based on bony reference points, occasionally exceeding clinically acceptable margins of error.[9,13] In comparison, soft-tissue landmarks such as the triceps aponeurosis appear to demonstrate comparatively less variability, particularly during posterior approaches where the muscle is directly visualized.

An additional advantage of utilizing the aponeurotic confluence is the potential for earlier identification of the radial nerve during surgical exposure. Early nerve identification may reduce the risk of inadvertent injury during deeper dissection and instrumentation, especially in posterior approaches where the nerve is vulnerable during muscle splitting and retraction.

Despite these theoretical and anatomical advantages, a major limitation of the current literature is the paucity of robust clinical studies evaluating the effectiveness of the triceps aponeurosis confluence as a landmark in live surgical settings. Most published data remain confined to cadaveric analyses, with only limited incorporation of intraoperative observations.[10] Although Arora et al. reported favorable intraoperative experiences, their study lacked a comparative control group and was not designed to assess postoperative nerve function or complication rates.[10]

To date, no large-scale prospective clinical trials have directly compared landmark-guided radial nerve localization using the triceps aponeurosis with conventional techniques based on bony landmarks. This absence of outcome-based clinical evidence represents a critical gap in the literature. Without such validation, it remains uncertain whether use of this landmark leads to reduced rates of iatrogenic radial nerve injury, shorter operative duration, or improved functional outcomes.

From a practical perspective, the triceps aponeurosis confluence offers several advantages: it is readily identifiable during posterior exposure, independent of bony integrity, and provides a reproducible reference point for anticipating the location of the radial nerve.[7-10] These attributes are particularly valuable in comminuted fractures, revision procedures, and non-union, where conventional landmarks may be unreliable.

However, patient-specific factors such as obesity, prior surgery, scarring, and soft-tissue trauma may obscure the aponeurosis or alter its morphology. Additionally, intraoperative retraction and limb positioning may influence tissue relationships, potentially reducing the precision of landmark-based estimates. Consequently, while the triceps aponeurosis confluence represents a valuable adjunct, it should be incorporated into a comprehensive surgical strategy emphasizing careful dissection, awareness of anatomical variability, and direct nerve visualization before definitive fixation.

Future research should prioritize prospective clinical studies evaluating the safety and efficacy of using the triceps aponeurosis confluence as a primary landmark for radial nerve localization. Comparative trials assessing nerve injury rates, operative time, and functional outcomes are needed to determine its true clinical value. Imaging-based studies using ultrasound or magnetic resonance imaging may further enhance understanding by correlating surface anatomy with intraoperative findings, thereby facilitating improved preoperative planning and individualized risk assessment.[15]

CONCLUSION

The confluence point of the triceps aponeurosis represents a consistent and readily identifiable soft-tissue landmark for predicting the location of the radial nerve in the posterior arm. Cadaveric evidence supports a relatively stable anatomical relationship between this landmark and the radial nerve, suggesting potential advantages over traditional bony reference points, particularly in the setting of fracture comminution or altered osseous anatomy. However, reliance on this landmark should be tempered by awareness of anatomical variability and the limitations inherent to cadaveric data. The absence of robust clinical outcome studies remains a significant gap in the literature. Until validated by prospective clinical investigations, the triceps aponeurosis confluence should be used as an adjunct to meticulous dissection and direct nerve visualization rather than as a sole determinant of nerve location.

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