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SURGICAL TECHNIQUE

A Method to Localize The Radial Nerve Using the 'Apex Of Triceps Aponeurosis' as a Landmark

Sumit Arora MS Ortho, DNB Ortho, Navneet Goel MS Ortho, Gursimrat Singh Cheema MS Ortho, Sumit Batra MS Ortho, DNB Ortho, Lalit Maini MS Ortho

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Abstract

Background The relationship of the radial nerve is described with various osseous landmarks, but such relationships may be disturbed in the setting of humerus shaft fractures. Alternative landmarks would be helpful to more consistently and reliably allow the surgeon to locate the radial nerve during the posterior approach to the arm.

Questions/purposes We investigated the relationship of the radial nerve with the apex of triceps aponeurosis, and describe a technique to locate the nerve.

Materials and Methods We performed dissections of 10 cadavers and gathered surgical details of 60 patients (30 patients and 30 control patients) during the posterior approach of the humerus. We measured the distance of the radial nerve from the apex of the triceps aponeurosis along the long axis of the humerus in cadaveric dissections and patients. This distance was correlated with the height and arm length. For all patients, we recorded time until first observation of the radial nerve, blood loss, and postoperative radial nerve function.

Results The mean distance of the radial nerve from the apex of the triceps aponeurosis was 2.5 cm, which correlated with the patients' height and arm length. The mean time until the first observation of the radial nerve from beginning the skin incision was 6 minutes, as compared with 16 minutes in the control group. Mean blood loss was 188 mL and 237 mL, respectively. With the numbers available, we observed no difference in the incidence of patients with postoperative nerve palsy: none in the study group and three in the control group.

Conclusion The apex of the triceps aponeurosis appears to be a useful anatomic landmark for localization of the radial nerve during the posterior approach to the humerus.

Each author certifies that he has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
Each author certifies that the work and all investigations were conducted in conformity with ethical principles of research. An approval from Institutional Review Board was granted.
This work was performed at Sushruta Trauma Centre and Safdarjung Hospital, New Delhi.

S. Arora (✉), G. S. Cheema, L. Maini
Department of Orthopaedic Surgery, The Maulana Azad Medical College & Associated Lok Nayak Hospital, Bahadur Shah Zafar Marg, 110002 New Delhi, India
e-mail: mamc_309@yahoo.co.in

S. Arora
C/o Mr. Sham Khanna, 2/2, Vijay Nagar, 110009 New Delhi, India

N. Goel
Department of Orthopaedics, Sushruta Trauma Centre, Delhi, India

S. Batra
Central Institute of Orthopaedics, Vardhman Mahavir Medical College & associated Safdarjung Hospital, New Delhi, India

Introduction

Owing to an increase in high-energy trauma cases, the incidence of fractures of the humerus diaphysis is increasing. Operative treatment of humeral fractures, especially the distal third region, chronic osteomyelitis of the distal third of the humerus requiring sequestrectomy and radial nerve palsy requiring exploration, usually requires a posterior approach to the humerus. This approach causes iatrogenic radial nerve injury in 0% to

10% of patients during operative fixation of fractures, and permanent nerve damage in 0% to 3% of patients [2, 9, 19].

The radial nerve arises from the posterior cord of the brachial plexus. The nerve, along with accompanying vessels, crosses medial to lateral obliquely over the posterior surface of the humerus in the spiral groove. It then penetrates the lateral intramuscular septum near the junction of the middle and distal thirds of the humerus [12, 23]. The brachial portion of the nerve is commonly encountered during the posterior approach to the humerus.

Some studies have established the anatomic relationship of the radial nerve with various bony landmarks, such as the lateral epicondyle, medial epicondyle, or angle of the acromion [1, 3–7, 12–14]. Based on cadaveric dissections, these studies show the distance of the lateral epicondyle from the point where the radial nerve leaves the spiral groove distally ranges from 6 cm to 16 cm, whereas the distance of the angle of the acromion from the point where the radial nerve enters the spiral groove ranges from 10 cm to 19 cm.

Considering the wide range of these proposed anatomic relationships, it may be difficult to localize the radial nerve during the posterior approach to the humerus. Moreover, such relationships with osseous landmarks may not hold true in clinical settings and are difficult for surgeons to access intraoperatively, especially with fractures of the distal third of the humerus [16]. Therefore, we believe another anatomic landmark is needed to consistently and reliably allow the surgeon to locate the radial nerve during the posterior approach to the humerus.

The purposes of our study were to: (1) compare the distance of the radial nerve from the apex of the triceps aponeurosis among cadavers (having an intact humerus) and patients treated with open reduction and internal fixation for distal third humerus fractures; (2) correlate the distance of the radial nerve from the apex of the triceps aponeurosis during operative exposure of the posterior arm with arm length and body height of the patients; and (3) compare operative details and complications of the procedure with those of a conventional method of exposing the radial nerve.

Materials and Methods

We performed cadaveric dissections and gathered surgical details of patients during the posterior approach to the humerus. Ten cadaveric specimens were obtained at autopsy within 72 hours after death. No specimen had any evidence of prior injury or surgery to the arm. Eight of the specimens were from men and two were from women. Only right upper extremities were used. The body height and arm length (from the angle of the acromion to the lateral epicondyle) of each specimen were measured. The arm was dissected using the posterior approach with the body kept in the lateral position, duplicating the position used in theatre. During dissection, we noted the shape of the triceps aponeurosis (Fig. 1A) and placed sutures on either side of the deep fascia at the level of the apex of the triceps aponeurosis. We then made the plane between the long and lateral head of the triceps, approximately 2.5 cm proximal to the apex of the triceps aponeurosis (Fig. 1B) and exposed the radial nerve (Fig. 1C). We measured the distance of the radial nerve from the apex of the triceps aponeurosis.

Between August 2008 and July 2010, we prospectively studied all 169 patients treated for humerus shaft fractures. All underwent adequate orthogonal radiographs and received standard primary care. We examined the patients and radiographs and made a decision regarding possible inclusion in the study, considering the following criteria: (1) closed fractures, (2) skeletally mature patients of either gender, (3) injury less than 2 weeks old, (4) distal third fractures requiring operative fixation with the posterior approach of the humerus, and (5) fractures without radial nerve injury. We excluded all patients with severely comminuted fractures or fractures having large butterfly fragments (involving greater than 50% of the circumference). We also excluded all patients with pathologic fractures and fractures associated with other life-threatening conditions, and those with a history of previous surgery to the region. This left 60 patients for our study. We obtained written informed consent from each patient, authorizing treatment, radiographic examination, and photographic documentation. Approval from the Institutional Review Board was granted.

We randomized the selected patients into two groups using an odd-even numbering, consisting of 30 patients in each group. In the first group (patients), we performed exposure of the humerus with a posterior approach, considering our method to localize the radial nerve. In the other group (control patients), we exposed and explored the radial nerve by making the plane between the long and lateral head of the triceps, along the whole length, in a conventional manner [15]. In the first group, we placed two sutures on either side of the deep fascia at the level of the apex of the aponeurosis to facilitate measurements. We measured the distance of the radial nerve along the long axis of the humerus from a point, where the long and lateral heads of the triceps fused to form the apex of the triceps aponeurosis (Fig. 2), and the patients' height and contralateral arm length (cm). We then divided the patients into four subgroups: (A) patients' height 150 cm or less and arm length less than 26 cm (n = 3), (B) patients' height between 151 cm and 165 cm and arm length between 26 cm to 32.5 cm (n = 9), (C) patients' height between

Fig. 1A–C Photographs of the cadaveric dissection (right arm) show (**A**) the apex of the triceps aponeurosis and anatomic details of the triceps aponeurosis, (**B**) the point 2.5 cm proximal to the apex of the triceps aponeurosis (exploration of that point will locate the radial nerve), and (**C**) the radial nerve on exploring the point in depth.

166 cm and 180 cm and arm length between 32.6 cm to 36 cm (n = 15), and (D) patients' height greater than 180 cm and arm length greater than 36 cm (n = 3) (Table 1).

We placed the patient, under anesthesia, in the lateral decubitus position with the shoulder at 90° flexion, full internal rotation, and neutral abduction. The elbow was flexed with the forearm draped across the body. We centered the standard longitudinal midline posterior skin incision over the fracture site [15]. The subcutaneous tissue and deep fascia were incised in the line of the skin incision, exposing the triceps muscle. The long and lateral heads of the triceps converged and fused to form the triceps aponeurosis, the proximal-most point of which was identified and termed the apex of the triceps aponeurosis. We observed that the shape of the proximal part of the aponeurosis is triangular with the apex lying proximally and the base distally (Fig. 3). The medial border of the aponeurosis (along the long head of the triceps) was almost straight, and the lateral border of the aponeurosis (along the lateral head of the triceps) initially was placed obliquely and became almost straight distally. We placed two sutures on either side of the deep fascia, at the level of the apex of the triceps aponeurosis, to facilitate measurements (Fig. 4A). We developed the intramuscular plane between the long and lateral head of the triceps, approximately 2.5 cm proximal to the apex of the aponeurosis. As we split the two heads of the triceps, we could easily roll the radial nerve between the palpating finger and bone. With further exploration, we observed the radial nerve, along with the accompanying vessels, in the tunnel made by this technique (Fig. 4B). We then further extended the plane proximally and distally as desired, obviating the chances of radial nerve injury. We internally fixed the exposed fracture with a compression plate, deep to the radial nerve. Using the conventional manner, we closed the wound in layers. In both groups, we recorded the time from skin incision to first observation, and blood loss. The surgeons performing surgery on the patients and control patients had comparable levels of experience, however, the surgeons operating on the patients in the

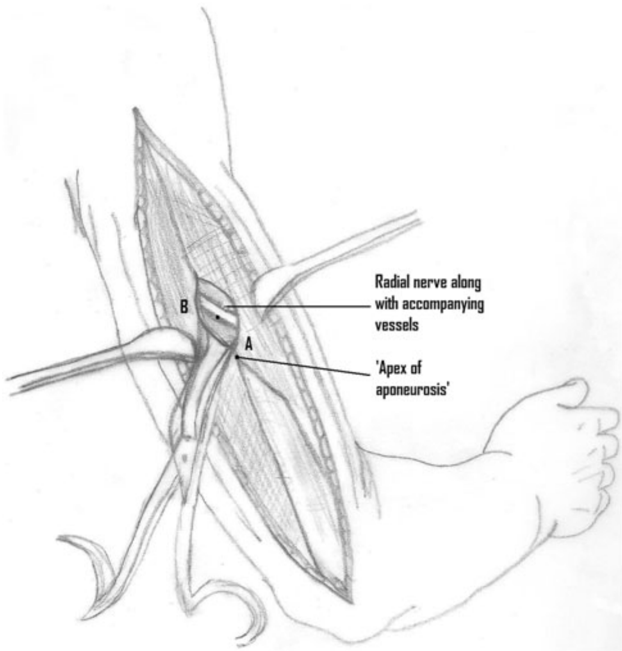

Fig. 2 A diagram shows how, during the posterior approach to the humerus, the radial nerve and accompanying vessels can be seen in the tunnel made approximately 2.5 cm proximal to the apex of the triceps aponeurosis. Point "A" denotes the apex of the aponeurosis, whereas point "B" denotes the most distal extent of the radial nerve along the long axis of the humerus in the plane between the long and lateral heads of the triceps.

Table 1. Mean distance of radial nerve from the apex of triceps aponeurosis

Number of patients (N = 30)	Body height (cm)	Arm length (cm)	Mean distance of the radial nerve from the apex of the triceps aponeurosis (cm)
3	$\leq$ 150	< 26	2.27
9	151–165	26–32.5	2.48
15	166–180	32.6–36	2.57
3	> 180	> 36	2.73
			$p < 0.001$

control group were unaware of the relationship of the radial nerve with the apex of the triceps aponeurosis.

Postoperatively, we assessed the radial nerve function by clinical examination. We considered active and full dorsiflexion of the wrist and metacarpophalangeal joints and sensory preservation in the autonomous zone as indicators of normal radial nerve function. We did not routinely use electrophysiologic or nerve conduction studies. Early mobilization was begun.

The patients were followed up weekly during the first month, and bimonthly for the next 2 months. At each visit, we clinically assessed the radial nerve function and ensured adequate physiotherapy. All the patients and control patients underwent repeat radiographs monthly.

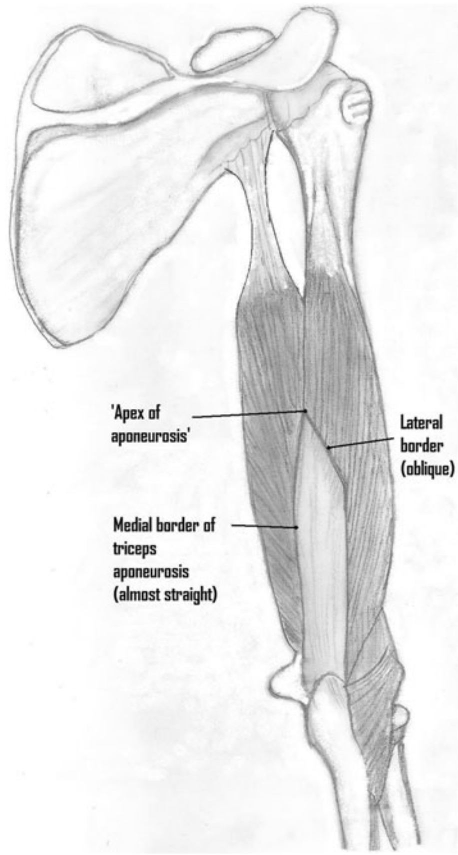

Fig. 3 A diagram shows the anatomy of the triceps aponeurosis, the medial head of which is almost straight and the lateral border is curved proximally. The long and lateral heads of the triceps fuse to form the apex of the aponeurosis.

We calculated mean, standard deviation, and standard error of the mean separately for the distance of the radial nerve from the apex of the triceps aponeurosis in the cadaveric series (intact humeri group) (n = 10) and clinical series (fracture cases) operated on using our technique to localize the radial nerve (n = 30). Using the Student t-test, we determined the difference of means for the distance of the radial nerve from the apex of the triceps aponeurosis among these groups. We also used the Student t-test to analyze the difference in means for the time until first observation of the radial nerve and blood loss during surgery, and Fisher's exact test to evaluate differences of radial nerve function postoperatively among patients (n = 30) and control patients (n = 30). ANOVA was used to analyze the distance of the radial nerve from the apex of the triceps aponeurosis in different height subgroups (A-D) among patients; we constructed the 95% confidence interval around the proportions with the normal approximation method. Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS, version 16, Chicago, IL, USA) for Windows.

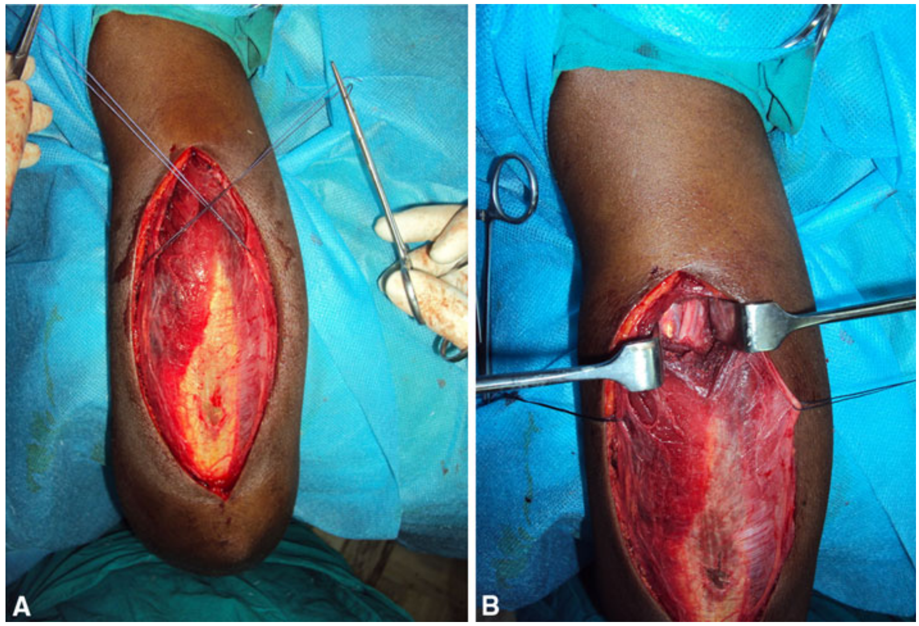

Fig. 4A–B Perioperative clinical photographs of a patient with a distal third humerus fracture (left arm) show (**A**) anatomic details: two sutures placed in the deep fascia at the level of the apex of the triceps aponeurosis converge approximately 2.5 cm proximal to the apex; and (**B**) the radial nerve and accompanying vessels observed when exploring the point in depth.

Table 2. Comparison between patient and control groups

Variables	Patient group (N = 30)	Control group (N = 30)	p Value
Mean time (minutes) since first observation of the radial nerve (with standard deviation)	6 ± 1.5	16.3 ± 3.9	< 0.001
Mean blood loss (mL with standard deviation)	188 ± 13	237 ± 18	0.0007
Number of patients with postoperative radial nerve palsy	0	3	0.237

Results

The mean distance and standard deviation of the radial nerve from the apex of the triceps aponeurosis were similar ($p = 0.753$) in the cadaveric and patient groups (2.51 ± 0.2 cm in the cadaveric series versus 2.53 ± 0.4 cm in the patient group).

The mean distance of the radial nerve from the apex of the triceps aponeurosis differed ($p < 0.001$) among the four subgroups: 2.27 cm in A, 2.48 cm in B, 2.57 cm in C, and 2.73 cm in D (Table 1).

The mean time to first observation of the radial nerve from skin incision was less ($p < 0.001$) in the patient group compared with the control group (6 ± 1.5 minutes in the patient versus 16.3 ± 3.9 minutes in the control group). Similarly, the mean blood loss was less ($p = 0.0007$) in the patient group than in the control group (188 ± 13 mL in the patient group versus 237 ± 18 mL in the control group) (Table 2).

With the numbers available, we observed no difference ($p = 0.237$) in the incidence of patients with postoperative radial nerve palsy (none in the patient group versus three in the control group) (Table 2).

Discussion

A posterior approach is commonly used in surgery of the arm although the radial nerve is at a risk of iatrogenic injury with this approach. Therefore, a comprehensive evaluation of distribution of the radial nerve in the region is essential. Knowledge of the location of the radial nerve during the posterior approach to the humerus, and its relationship with a consistent and reliable anatomic landmark, are major concerns for treating surgeons. Another anatomic landmark is needed to consistently and reliably allow the surgeon to locate the radial nerve during this approach, as described relationships [1, 3–7, 12–14] of the radial nerve with various osseous landmarks rarely hold true in the clinical setting. Therefore, we compared the distance of the radial nerve from the apex of the triceps aponeurosis among cadavers (having an intact humerus) and patients treated with open reduction and internal fixation for distal third humerus fractures. We correlated the distance of the radial nerve from the apex of the triceps aponeurosis during operative exposure of the posterior arm with arm length and body height of the patients, and compared operative details and complications of the procedure with those of the conventional method of exposing the radial nerve.

There are some limitations to our study. First, our subjects were all inhabitants of the Indian subcontinent.

The measurements may differ slightly among patients of different race and ethnicity, as Chou et al. [6] reported the courses of the radial nerve differ between Chinese and Caucasians subjects. Future studies may evaluate such relationships in patients of other ethnicities. Second, we had a limited number of subjects. A larger study size may further enhance our anatomic understanding. Third, we did not routinely use electrophysiologic or nerve conduction studies to detect the radial nerve injuries, as some cases might be missed on clinical examination. Nevertheless, we describe the relationship of the radial nerve with a proposed soft tissue landmark.

Numerous anatomic studies have attempted to establish the relationship of the radial nerve with bony points (lateral epicondyle, medial epicondyle, and angle of acromion) [1, 3–7, 12–14]. In an anatomic study, Guse and Ostrum [14] reported that the proximal extent of the radial nerve in the spiral groove was 18.1 cm (± 1.1 cm) proximal to the medial epicondyle, whereas the distal extent of the radial nerve in the spiral groove was 12.6 cm (± 1.1 cm) proximal to the lateral epicondyle of the humerus. In a similar study, Gerwin et al. [13] reported that the radial nerve ran along the posterior aspect of the humerus from 20.7 cm (± 1.2 cm) proximal to the medial epicondyle to 14.2 cm (± 0.6 cm) proximal to the lateral epicondyle of the humerus. Based on these observations, they suggested a modified posterior approach to the humerus. They concluded that the knowledge of specific location of the radial nerve in relation to the lateral epicondyle can assist in decision-making. Kamineni et al. [16] reported that the distance of the lateral epicondyle from a point where the radial nerve crosses the humerus in the midlateral plane was 1.4 to 2.0 times the transepicondylar distance. On this basis, they proposed a safe zone for external fixator pin entry into the lateral distal humerus. All studies observing such relationships were conducted in cadaveric specimens having intact humeri; therefore, such anatomic relationships may not hold true in clinical situations. The relationships of the radial nerve with various osseous landmarks did not have any correlative value, with wide interobserver variability, and are difficult for surgeons to access intraoperatively [16]. Based on cadaveric dissections, these studies show that the distance of the lateral epicondyle from the point where the radial nerve leaves the spiral groove distally ranges from 6 cm to 16 cm, whereas the distance of the angle of the acromion from the point where the radial nerve enters the spiral groove ranges from 10 cm to 19 cm [1, 3–7, 12–14]. Considering the wide range of these proposed anatomic relationships, it may be difficult to localize the radial nerve during the posterior approach to the humerus. Moreover, a surgeon is more interested in the relationship of the radial nerve along the plane of surgical dissection (ie, the intramuscular plane between the long and lateral head of triceps) rather than its relationship with the point where the radial nerve enters or leaves the spiral groove. The exact localization of the radial nerve using these bony points therefore seems to be questionable, and it may be imprudent for a surgeon to expect the existence of such relationships during operative fixation of fractures. During surgery, we have observed the anatomy of the triceps aponeurosis and its relationship to the radial nerve. We performed this study to ascertain whether the relationship between the radial nerve and the apex of the triceps aponeurosis exists, which remains unchanged regardless whether the humerus is fractured.

Our observations prompted us to extensively search the literature for a detailed anatomy of the triceps aponeurosis or triceps tendon, but we found the anatomy has not been described in detail [8, 10, 11, 15, 17, 18, 20–24]. The terms 'triceps tendon' and 'triceps aponeurosis' are used interchangeably. By definition, aponeuroses are layers of flat, broad tendons with a shiny pearly-white color, and are supplied sparingly with blood vessels [8, 10, 23]. We suggest that the term 'triceps aponeurosis' is appropriate in describing the insertion of the triceps muscle. We observed that the triceps aponeurosis, where the long and lateral heads of the triceps fuse, is triangular proximally, and its medial border (along the long head of the triceps) is almost straight and parallel to the long axis of the arm, whereas its lateral border (along the lateral head of the triceps) is obliquely placed initially and runs straighter distally, almost parallel to the long axis of the arm, thus giving it a trapezoid shape. We termed the most proximal point of it as the apex of the triceps aponeurosis (Fig. 1A). We also noticed that the apex is best defined in subjects with well-developed musculature, especially in dominant extremities, and in manual laborers and men.

In another anatomic study on 55 formalin-preserved cadavers, Chaudhry et al. [5] analyzed the radial nerve in relation to the lateral epicondyle and lateral margin of the triceps aponeurosis. In their dissections, the radial nerve was 11.1 (± 1.2) cm away from the lateral epicondyle at the inferior margin of the spiral groove, and ran a course parallel and 22 mm to 27 mm (± 2 mm) lateral to the lateral margin of the triceps aponeurosis. Our data show the radial nerve is encountered 2.5 cm proximal to the apex of the triceps aponeurosis, along the long axis of the humerus; therefore, surgeons should meticulously explore this point (Fig. 4A) to find the radial nerve (Fig. 4B). We also observed the mean distance of the radial nerve from the apex of the triceps aponeurosis is similar in the cadaveric and patient groups (2.51 ± 0.2 cm in the cadaveric series versus 2.53 ± 0.4 cm in the patient group). We suggest this relationship will not be disturbed in the presence of a fracture in the middle or distal third shaft of the humerus (except with severely displaced, comminuted fractures or high-energy trauma) because the long and lateral heads of the triceps converge and fuse to form the aponeurosis (the long head of the triceps originates from the infraglenoid tubercle of the scapula, whereas the lateral head of the triceps originates from an oblique ridge corresponding to the lateral lip of the spiral groove) (Fig. 3). The origins of both heads of the triceps are well above the fracture site; therefore, such a constant relationship will remain undisturbed with bony discontinuity distal to it, although the landmark may change with severely displaced or comminuted fractures owing to high-energy trauma.

We found the nerve between 2 to 3 cm proximal to the apex of the triceps aponeurosis in our dissections and the distance correlated with the arm length and body height of the patients included in the study. One must record the arm length and body height of the patients judiciously, as these are the important variables in localization of the radial nerve. As 90% of patients in our study were less than 6 feet tall, the relationship may be further developed in taller patients. The time until first observation of the radial nerve reduced with the understanding of this anatomic relationship. Such an early observation of the radial nerve also may reduce blood loss during surgery, as the surgeon can safely perform electrocoagulation of bleeding vessels. We observed no difference in the incidence of patients with postoperative radial nerve palsy with the numbers available (none in patient group versus three patients in the control group).

We have described the soft tissue point over the triceps, which is 2.5 cm proximal to the apex of the triceps aponeurosis, along the long axis of the humerus, which may help with easy localization of the radial nerve during the posterior approach to the arm.

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