THE CLINICAL SIGNIFICANCE OF THE ARM BONY LANDMARKS IN CORRELATION TO THE RADIAL NERVE COURSE: AN ANATOMICAL STUDY

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ABSTRACT

The radial nerve is one of the most commonly injured nerves in long bone fractures. Knowledge of the anatomy of the radial nerve is a key component for safety and successful surgical procedures about the arm and the elbow. This study aimed to identify the level of the points at which the radial nerve begins and ends its course on the posterior shaft of humerus in relation to the palpable anatomic bony landmarks of the arm. The upper limbs of twenty adult human cadavers, ten males and ten females, were used in this study. The specimens were obtained from the Anatomy Department, Faculty of Medicine, King Abdul Aziz University. The limbs were dissected and the radial nerve of each was exposed throughout its course within the arm. The distance between the points of both radial nerve entry and exit on the spiral groove was measured in relation to different bony landmarks. The values were measured in millimeters and in percentages in relation to the humeral length. The average humeral length (from the postero lateral angle of acromion to the centre of lateral epicondyle) was 316 mm ± 5.5 in male upper limbs and 286 mm ± 15.4 in female upper limbs. The mean distance from the point of radial nerve entry to the lateral angle of acromion, tip of the coracoid process, centre of lateral and medial epicondyles was 143.3 ± 14 mm (44.5%), 131.7 ± 14.9 mm (42.5%), 174.2 ±13.3 mm (55.5%) and 178.1± 15.2 mm(57.5%) in male upper limbs and they were 121.4 ± 10.4 mm (42.4%), 116.6 ± 12.3 mm (41.4%), 164.6 ± 1.9 mm (57.6%) & 166.3 ± 13.2 mm (58.6%) in female upper limbs respectively. However, the mean distances from the point of radial nerve exit to same bony landmarks were 214.2 ± 12.4 mm (67.7%), 205.6 ± 13.2 mm (66.4%), 102.5 ± 12.9 mm (32.3%), 104.7 ± 13 mm (33.8%) in male upper limbs and were 185.3 ± 14.6 mm(64.8%), 180.9 ± 13.4 mm (64.8%), 100.3 ± 8 mm (35.1%), 101.3 ± 7 mm (36%) and 23.8 ± 6 mm (8%) in female upper limbs respectively. Significant differences ($P < 0.01$) were reported between most of radial nerve measurements of both male and female upper limbs with exception of the mean distance from the point of radial nerve exit to the centre of both lateral and medial epicondyles. However, no significant differences were recorded between the measurements of right and left upper limbs of male or female cadavers. The palpable bony landmarks of arm provide an accurate data for the surgeon to determine the location and to avoid the iatrogenic injury of the radial nerve during the surgical interventions of the arm.

Key Words: Radial nerve, Bony landmarks, Humerus.

INTRODUCTION

The radial nerve is the continuation of the posterior cord of the brachial plexus. It passes downwards, backwards and laterally behind the insertion of teres major and in front of the long head of triceps to reach the radial (spiral) groove of humerus crossing the lower triangular space. Then, it spirals obliquely across the back of the humerus, lying posterior to the uppermost fibers of the medial head of triceps which separate the nerve from the bone in the first part of the spiral groove. On reaching the lateral side of the humerus it pierces the lateral intermuscular septum to enter the anterior compartment descending deep in a furrow between brachialis and brachioradialis muscles(1).

Knowledge of the anatomy of the radial nerve is a key component for safety and successful surgical procedures about the arm and the elbow(2) It is interesting to note that the radial nerve seems to be one of the most commonly injured nerves in long bone fractures(3). Fractures involving the middle and distal shaft of the humerus, such as Holstein Lewis fracture, are significantly more likely to give rise to radial nerve palsy. The overall prevalence of radial nerve injury is 11.8%, with much higher rates in the fractures of the middle (15.2%) and distal third (23.6%) of the humerus[4].

The radial nerve is at risk in both fractures of the humeral shaft and operative fixation of these fractures[5, 6]. The incidence of the radial nerve injury after operative fixation of fractures of the shaft of the humerus has been reported to be between 1.9% and 3.3% and as high as 11.5% after nonunion repair[7, 8, 9]. The intimate relationship of the radial nerve with the humerus has led to injuries associated with interfragmentary entrapment after fracture fixation as well as direct nerve injury related to the insertion of fixation devices along the middle third and distal third of the humerus [10, 11].

Previous studies have indicated that the radial nerve is at risk during operative exposure and fixation of the humerus at the location of the lateral intermuscular septum as the nerve passes from posterior to anterior compartment of the arm[12, 13, 14]. In a more recent study, 37.5% of fractures within the region of spiral groove had a radial nerve injury[15]. Although the incidence of radial nerve palsy after posterior approach for internal fixation reported to be 0-10% [16], permanent damage to the radial nerve either by traction or partial or complete traction, are considered to be in region of 0-3%[17].

Iatrogenic injuries to the radial nerve during surgical procedures can be minimized by utilizing palpable landmarks to predict the location of the radial nerve and its subsequent divisions. Poor anatomical knowledge or surgical technique may result in injury to the radial nerve during any of the surgical approaches. Surgeons must understand the anatomic relationships between the radial nerve and the bony landmarks of the humerus to avoid radial nerve injury during the fixation of the humeral shaft fracture[2].

The purpose of this study was to identify the level of the points at which the radial nerve begins and ends its course on the posterior shaft of humerus in relation to the palpable anatomic bony landmarks of the arm. As well as, determination the length and percentage of the safe zones and zone of danger around the humerus was done.

MATERIALS AND METHODS

Forty upper limbs of twenty adult human formalin preserved cadavers (ten males & ten females) were used in this study. These cadavers were obtained from the Anatomy Department, Faculty of Medicine, King Abdul Aziz University. The arms of cadavers with identifiable scarring or trauma were excluded from this study. The postero lateral angle of acromion & tip of coracoid processes of scapula, distal end of deltoid tuberosity and the centre of both lateral and medial epicondyles of the humerus were used as bony landmarks. The dissection was performed with the arm in 90° abduction and the forearm in full supination. The techniques described by Guse and Ostrum[18] were used as the bases for measurements of the radial nerve in relation to the surrounding bony landmarks. The humerus length for this study was measured and defined as the distance between the posterior lateral angle of the acromion process and the centre of the lateral epicondyle with the shoulder in adduction and neutral rotation.

The skin and the fascia of the arms were removed to expose the underlying muscles allowing blunt digital dissection to explore intermuscular planes. The deltoid muscle was further dissected to observe its attachments on the humeral bone. Deep dissection was performed by the triceps-splitting approach between the lateral and long heads of the triceps to expose the radial nerve from the triangular space to the point where the radial nerve pierced the lateral intermuscular septum (fig.1). The radial (spiral) groove was determined to be the short distance where the radial nerve lay directly on the posterior surface of the humerus (fig. 2).

A number of measurements were made to determine the course of the radial nerve relative to the previously reported bony landmarks (fig.3). The distances from (1) The point of radial nerve entry into the spiral groove to posterior lateral angle of acromion, centre of coracoid process, centre of both lateral and medial epicondyles; (2) The point of radial nerve exit from the spiral groove (where it pierces the lateral intermuscular septum) to the posterior lateral angle of acromion, centre of coracoid process, centre of lateral epicondyle, centre of medial epicondyle, and the distal aspect of the deltoid tuberosity were measured in millimeters with a standard tape and a Vernier Caliper accuracy 0.01mm. The mean, SD, and the range were calculated for all measurements, and the results were recorded as a percentage of the humeral length. An independent-sample t test was used to compare the mean data of male & female, right and left limbs of both male and female cadavers.

RESULTS

The mean length of the male arm from the posterior lateral angle of the acromion to the centre of lateral epicondyle (fig. 4) was 316.9 mm ± 5.5. The radial nerve was found to be in direct contact with the posterior humeral shaft (fig. 2) from 141.1mm ±14 to 214.4 mm ± 12.4 distal to lateral angle of the acromion, from 131.3 mm ±14.9 to 204.6 mm ± 13.2 distal to the coracoid process, from 175.8 mm ± 13.3 to 102.5 mm ± 12.9 proximal to the central aspect of the lateral epicondyle and it passed from 178.1 mm ± 15.2 to 104.8 m ± 13.5 proximal to the centre of medial epicondyle. The mean distance from the lower margin of spiral groove (exit of radial nerve from lateral intermuscular septa) to the lower end of deltoid tuberosity was 30.9 ± 7.9 mm (table, 1& fig. 8).

Because of large variation in limb length amongst the general population, the results were expressed as a percentage of overall arm length in addition to the exact measurement in millimeters. Thus, in male limbs, the radial nerve traversed the spiral groove at an average of 44.5% distal to the acromion and 55.5% proximal to the lateral epicondyle of humeral length respectively. As well as, the radial nerve pierced the lateral intermuscular septum at an average of 32.3% proximal to lateral epicondyle and 9.8% distal to the distal end of the deltoid tuberosity of humeral length. The mean of the inter-epicondylar distance was equal to 20.4% ± 1.4% (table, 2).

The humeral length measured 286 mm ± 15.4 in female limbs (fig. 6). Moreover, the mean distance from the point of radial nerve entry into the spiral groove to posterior lateral angle of acromion, centre of coracoid process, centre of lateral epicondyle and the centre of medial epicondyle was 121.4 mm ± 10.4 & 117.5 mm ± 12.3, 164.6 mm ± 11.9 and 166.2 mm ± 13.2 respectively. As well as, the mean distance from the radial nerve exit to the previous bony landmarks and lower end of deltoid tuberosity was 185.4 mm ± 14.6, 181.5 mm ± 13.4, 100.6 mm ± 7.7, 102.2 mm ±7.04 and 23.8 mm ± 6 respectively (table, 1& fig. 8).

When the results of female limbs were expressed as a percentage of overall arm length, the average length of the distance from the acromion to the entry point of radial nerve measured 42.4% ± 1.04 and the mean distance of from acromion to the exit point of radial nerve measured 64.8% ± 5.1%. Moreover, the distance from the points of radial nerve entry and exit to the centre of the lateral epicondyle was 57.6% ± 4.2% and 35.1% ± 2.7%. The radial nerve exit at a mean distance measured 8% ± 2.1% distal to the lower end of deltoid tuberosity. However, the mean distance from the entry and exit points of radial nerve to the centre of medial epicondyle was 58.6% ± 4.6% and 36% ±2.46%. Lastly, the inter-epicondylar distance measured 20.6% ±1.2% of the humeral length (table, 2). There were significance differences ($P<0.05$) in all parameters defining the distribution of radial nerve around the humerus between male and female limbs with exception of the mean distance from the radial nerve exit to the centre of both lateral and medial epicondyles.

As the fracture of the humerus commonly occurring in one limb, side-dependent measurements were done in right and left limbs of both male and female cadavers to give the clinicians more details about radial nerve measurements. Comparing the measurements of right and left limbs of male cadavers, minimal or no differences were recorded. In right male limbs, the mean humerus length (fig.4) was 318.3 mm ± 5.0 and it was 315.6 mm ± 5.8 in left limbs. The mean distance from the radial nerve entry to posterior lateral angle of acromion, centre of coracoid process, centre of lateral epicondyle and centre of medial epicondyle was 143.9 mm ± 11.1, 135.6 mm ± 14.4, 174.4 mm ± 12.1, 174.4 mm± 14.2 in right limbs and 137.8 mm ± 15, 127.7 mm ± 14.4, 177.8 mm ± 14.2 and 181.7 mm ± 16.01 in left limbs. Moreover, the mean distance from the radial nerve exit to the posterior lateral angle of acromion, centre of coracoid process, centre of lateral epicondyle, centre of medial epicondyle and the lower end of the deltoid tuberosity (fig. 5) was 214.4 mm ± 14.5, 206.1 mm ± 14.7, 103.9 mm ± 16, 103.9 mm ± 15.2 and 31.2 mm ± 7.9 (15-40) in right male limbs and 213.9 mm ± 10.8, 203.8 mm ± 9.8, 101.7 mm ± 9.7, 105.6 mm ± 11.3 and 30.4 mm ± 9.3 in left male limbs respectively (table, 1 & fig. 8). There were no significance differences in the parameters defining the distribution around the humerus between right and left male limbs.

In female limbs, the mean humeral length was 286.5 mm ±16.2 and 285.5 mm ± 15.4 in right (fig. 6) and left limbs respectively. The main distances from the radial nerve entry to posterior lateral angle of the acromion (fig. 6), centre of the coracoid process, centre of lateral epicondyle and the centre of the medial epicondyle were 121mm ± 10.7, 118 mm ± 14.1, 165.5 mm±13 and 166 mm ± 14.9 in the right limbs and 121 mm ± 10.7, 115.7 mm ± 10.8, 164.5 mm ± 11.3 and 167.5 mm ± 12 in the left limbs. Moreover, the mean distances from the exit point of the radial nerve to the posterior lateral angle of the acromion, centre of the coracoid process, centre of the lateral epicondyle (fig.7), centre of the medial epicondyle and the lower end of the deltoid tuberosity were 186 mm ± 15.2, 183 mm ± 14.2, 100.5 mm 9, 101 mm ± 5.8 and 22.5 mm ± 4.2 in the right limbs and 184 mm ± 14.8, 178.7 mm ± 12.7, 101.5 mm ± 7.4, 104.5 mm ± 8.2 and 25.1 mm ± 7.4 in the left limbs (table, 1 & fig. 8). No significant differences were recorded between the measurements of right and left female limbs.

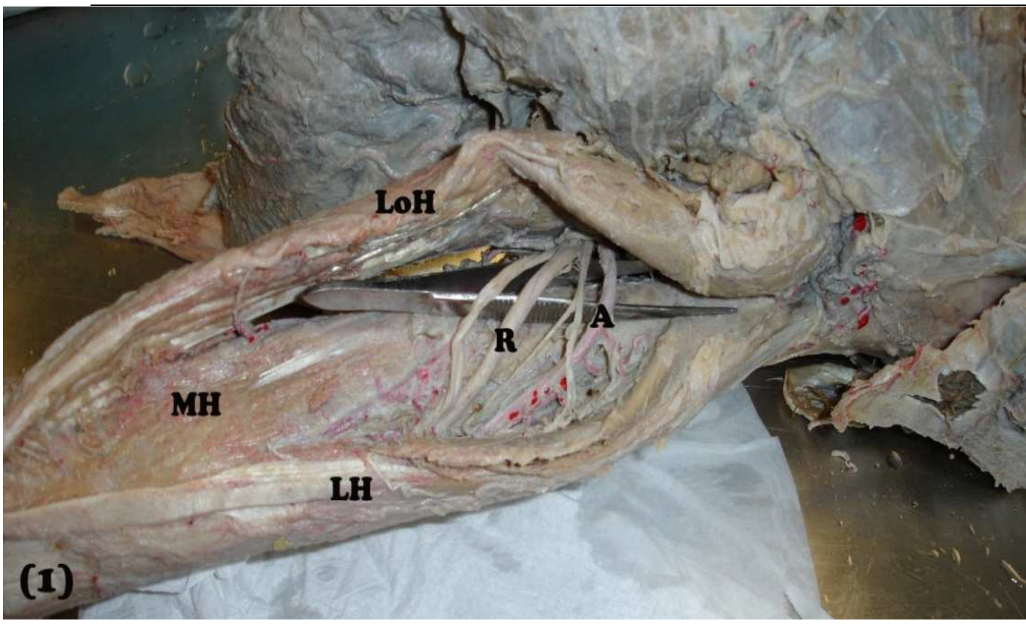

Fig. (1): A photograph of a right female upper limb showing the muscular splitting approach of radial nerve (R) within the spiral groove between the long head (LoH) and lateral head (LH) of triceps muscle. The nerve descends above the origin of medial head of triceps (MH) accompying with the profunda brachii artery (A) descends within the spiral groove

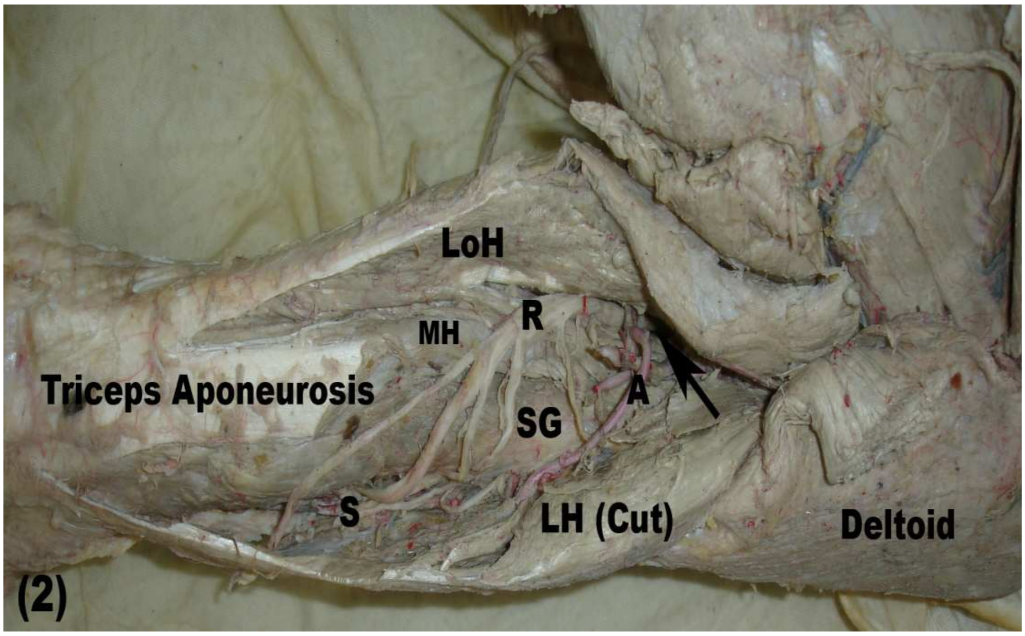

Fig. (2): A photograph of a right male upper limb showing the passage of radial nerve (R) within the spiral groove (SG) between lateral (LH) and medial (MH) heads of triceps muscle and anterior to the long head (LoH) of triceps. The radial nerve crosses the back of the arm within the spiral groove from its entry point (arrow) to the piercing point of the lateral intermuscular septum (S) reaching the lateral side of the arm. The profunda brachii artery (A) crosses the spiral groove with the radial nerve.

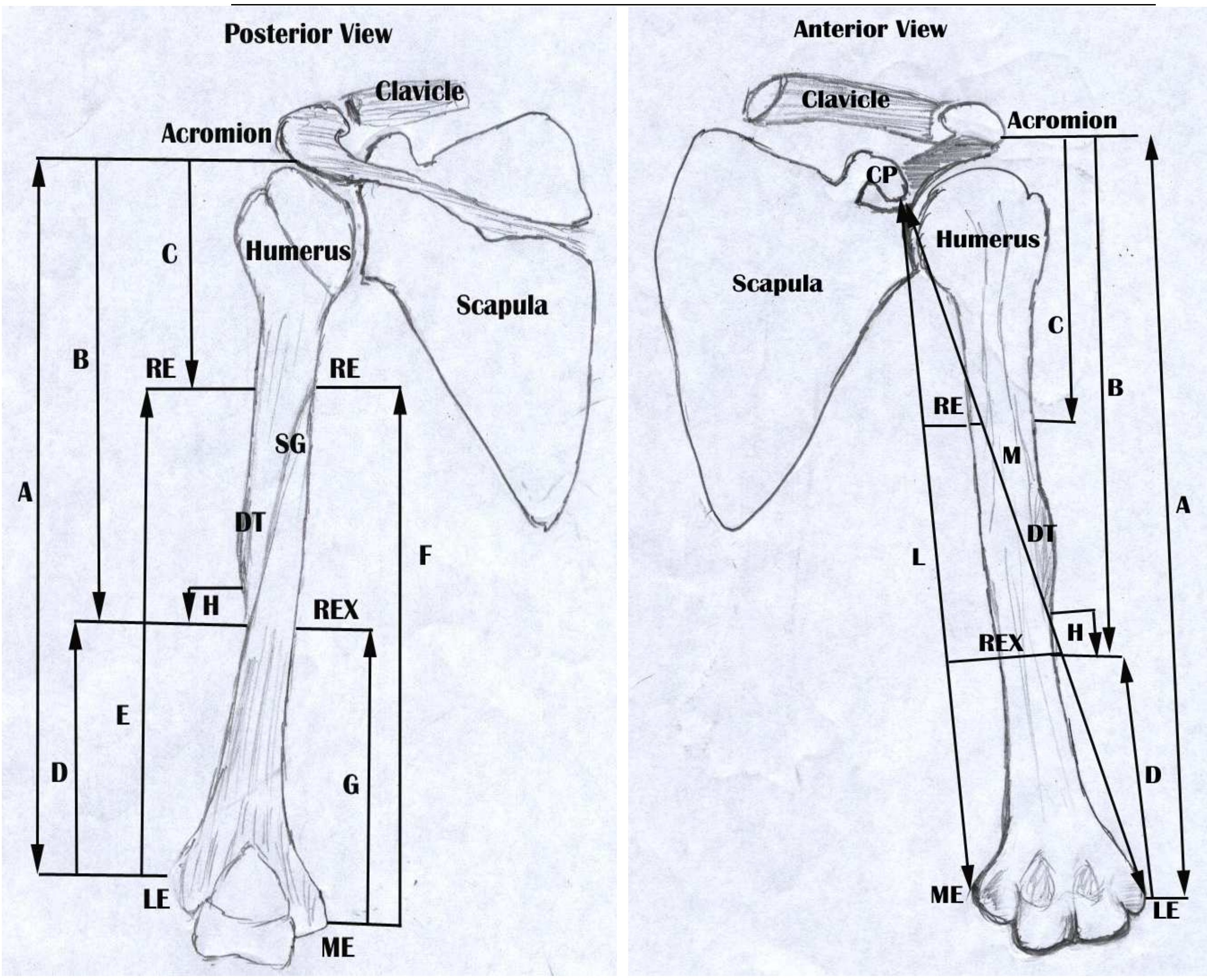

Fig. (3): A Diagram showing the points and lines of the radial nerve measurements in relation to the arm bony landmarks. RE: entry point of radial nerve onto the spiral groove, REX: the exit point of radial nerve at the lateral intermuscular septum, LE: lateral epicondyle of humerus, ME: medial epicondyle of humerus, SG: spiral (radial) groove, DT: deltoid tuberosity, CP: coracoid process. Line (A): the humeral length, Line (B): the distance from the acromion angle to the entry point of radial nerve, Line (C): the distance from the acromion to the exit point of radial nerve, Line (D): the distance from the centre of lateral epicondyle to the exit point of radial nerve from spiral groove at its piercing level to the lateral intermuscular septum, Line (E) measures the distance from lateral epicondyle to the point of radial nerve entry onto the spiral groove. Line (F) constitutes the distance from the centre of medial epicondyle to the entry point of radial nerve. Line (G) represents the distance from medial epicondyle to the exit point of radial nerve. Line (H) measures the distance from the lower end of deltoid tuberosity to the exit point of radial nerve. Line (L): represents the distance from the tip of coracoid process to that of medial epicondyle. Line (M): measures the distance between the tip of coracoid process to the centre of lateral epicondyle.

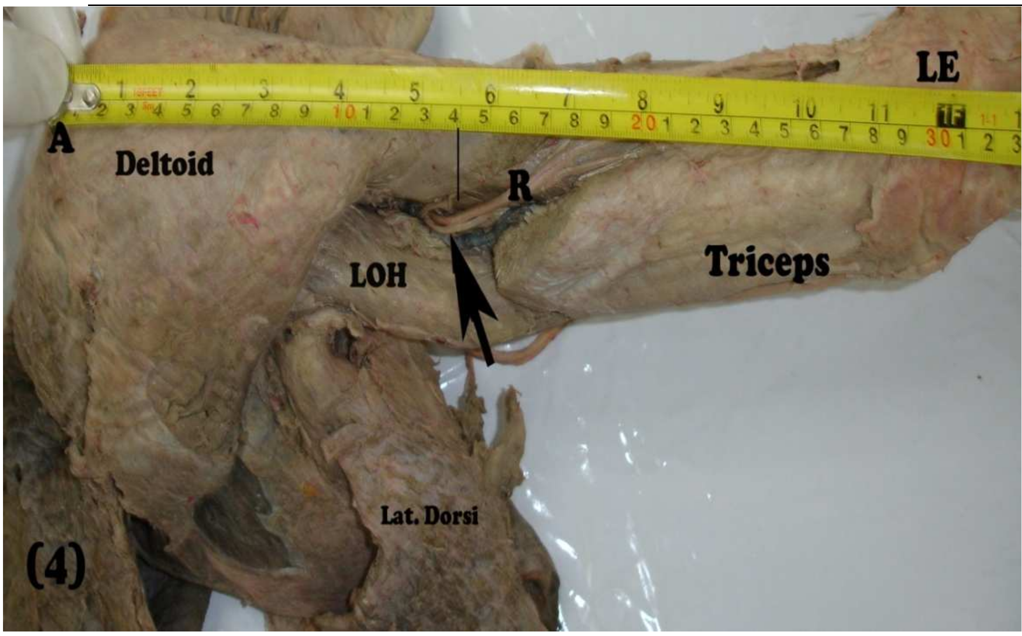

Fig. (4): A photograph of a right male upper limb showing the crossing of radial nerve (R) through the triangular space (arrow) lateral to the long head of triceps (LoH) to entre the spiral groove onto the back of the arm. The arm length is the distance from the lateral angle of acromion (A) to the centre of the lateral epicondyle (LE).

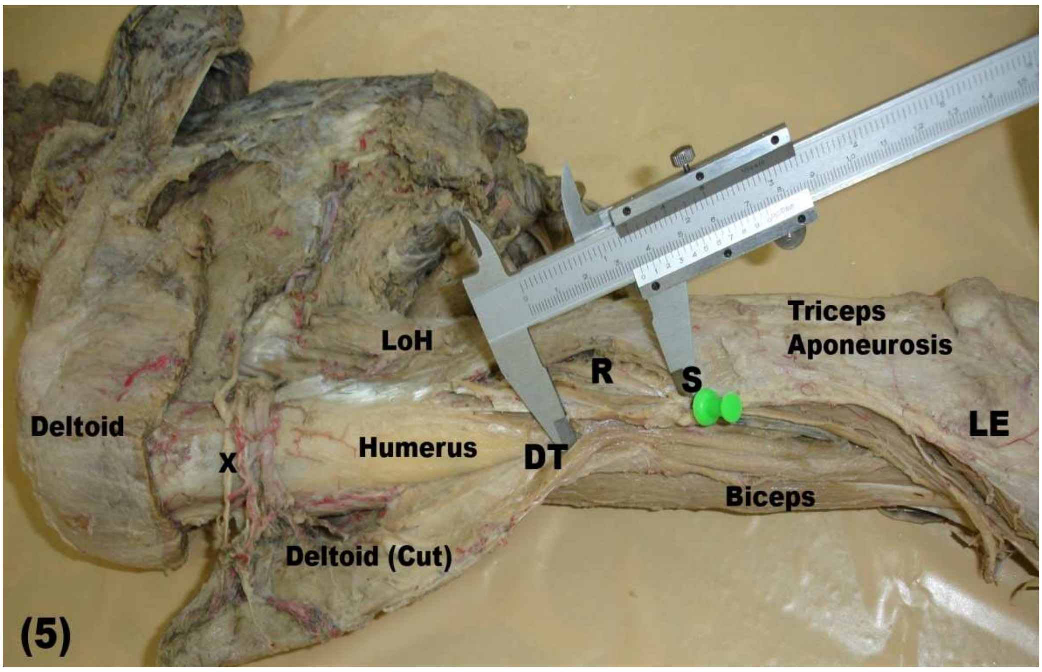

Fig. (5): A photograph of a left male upper limb showing the measure of the distance from the lower end of deltoid tuberosity (DT) to the exit point (S) of the radial nerve (R) from the spiral groove. LE: lateral epicondyle, X: Axillary nerve.

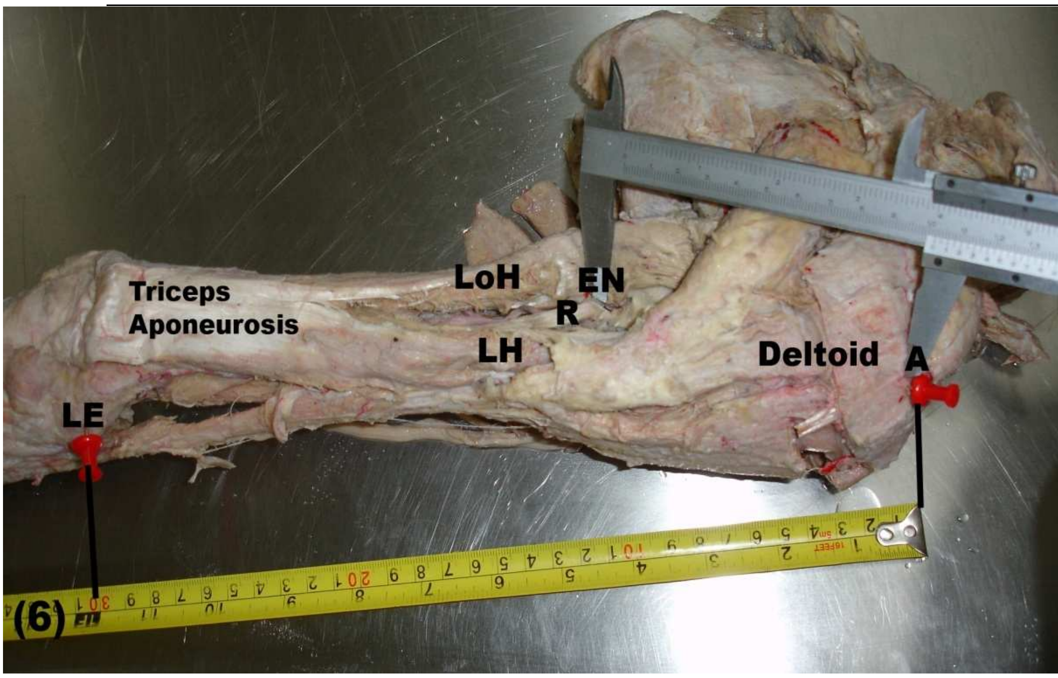

Fig. (6): A photograph of a right female upper limb showing the measuring method of the arm length from the lateral angle of the acromion (A) to the centre of the lateral epicondyle (LE), as well as, the length of the distance between the entry point(EN) of radial nerve (R) and the lateral angle of the acromion (A). The radial nerve passes anterior to the long head of triceps (LoH) and deep to its lateral head(LH).

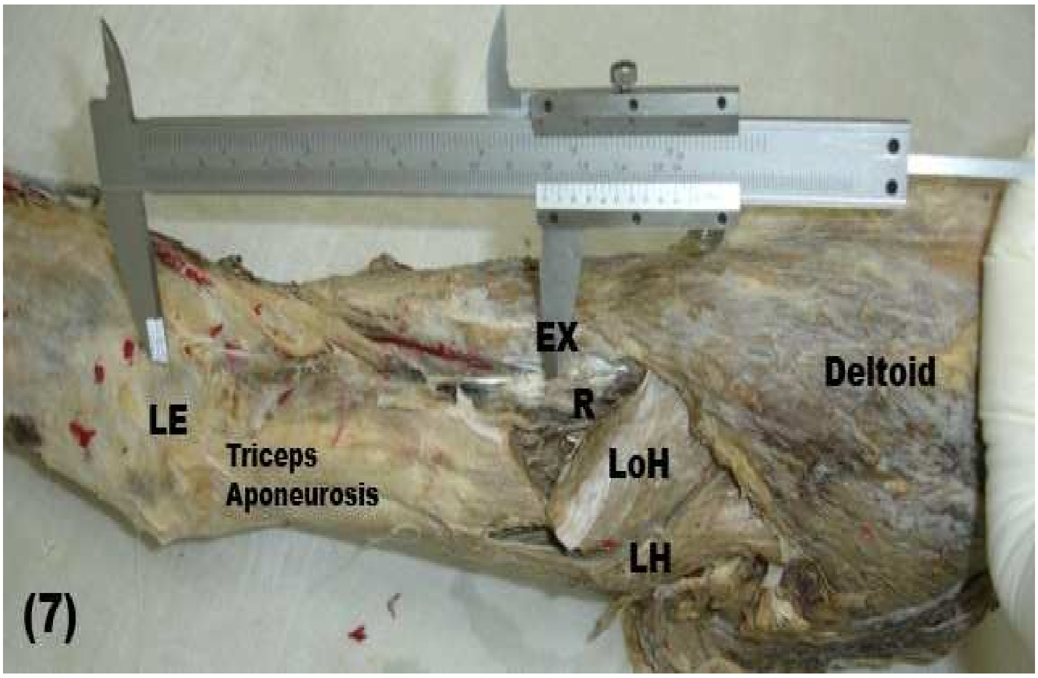

Fig. (7): A photograph of a left female upper limb showing measuring method of the distance from the exit point (EX) of the radial nerve (R) from the spiral groove to the centre of lateral epicondyle (LE).. LH: lateral head of triceps, LoH: long head of triceps.

Table (1): Measurements (mean ± SD) of Radial nerve

Mean ± SD	A-LE	A-EN	A-EX	C-EN	C-EX	LE-EN	LE-EX	ME-EN	ME-EX	DT-EX	BCD
Male	316.9 ± 5.5	141.1 ± 14	214.4 ± 12.4	131.3 ± 14.9	204.6 ± 13.2	175.8 ± 13.3	102.5 12.9	178.1 ± 15.2	104.8 ± 13.5	30.9 ± 7.9	64.7 ± 4.5
Female	286 ± 15.4	121.4 ± 10.4	185.4 ± 14.6	117.5 ± 12.3	181.5 ± 13.4	164.6 ± 11.9	100.6 ± 7.7	166.2 ± 13.2	102.2 ± 7	23.8 ± 6	59 ± 3.4
Rt. Male	318.3 ± 5	143.9 ± 11	214.4 ± 14.5	135.6 ± 14.4	206.1 ± 14.7	174.4 ± 12.1	103.9 ± 16	174.4 ± 14.2	103.9 ± 15.2	31.2 ± 7.9	66 ± 4.4
Lt. Male	315.6 ± 5.8	137.8 ± 15	213.9 ± 10.8	127.7 ± 14.4	203.8 ± 9.8	177.8 ± 14.2	101.7 ± 9.7	181.7 ±16	105.6 ±11.3	30.4 ± 9.3	63.4 ± 4.5
Rt. Female	286.5 ± 16.2	121 ± 10.7	186 ± 15.2	118 ± 14.1	183 ± 14.2	165.5 ± 13	100.5 ± 9	166 ± 14.9	101 ± 5.8	22.5 ± 4.2	58.8 ± 3.2
Lt. Female	285.5 ± 15.4	121 ± 10.7	184 ± 14.8	115.7 ± 10.8	178.7 ± 12.7	164.5 ± 11.3	101.5 ± 7.4	167.5 ± 12	104.5 ± 8.2	25.1 ± 7.4	25.1 ± 3.8

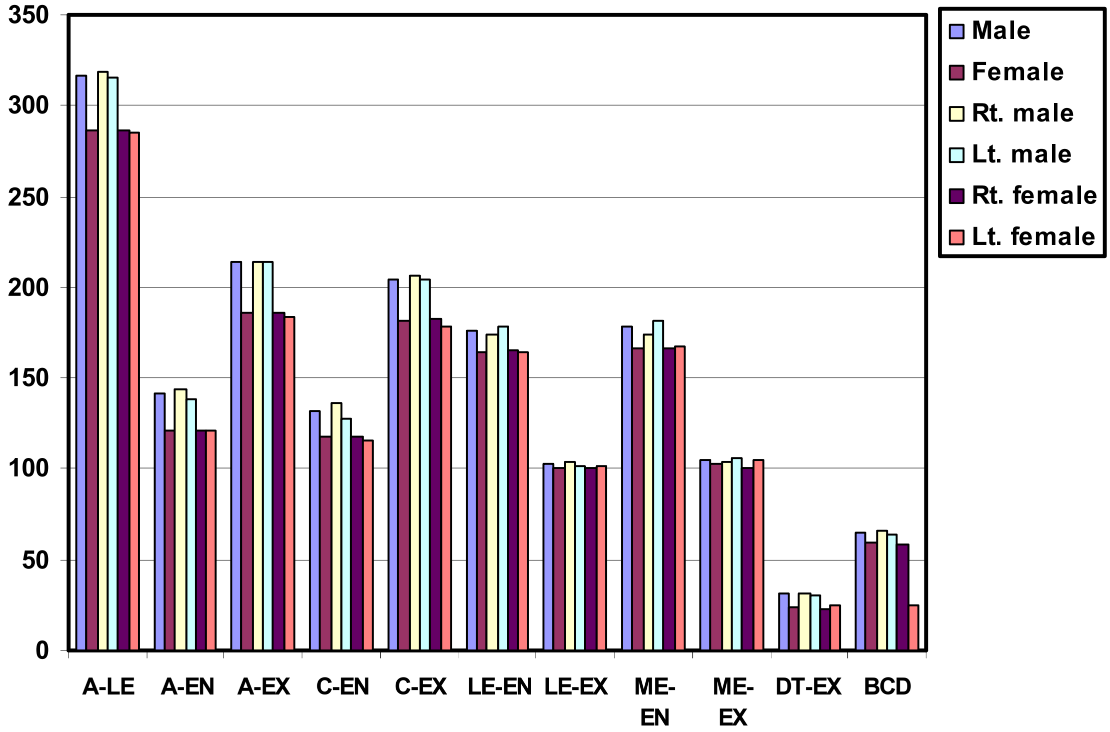

Fig. (8): A Histogram showing the means of the different radial nerve measurements in relation to the bony landmarks of the arm bones of male and female, right and left, upper limbs.

Table (2): Percentages of Radial nerve Measurements in relation to humeral length

	Male Limbs				Female Limbs			
Variable	**Mean**	**SD**	**Minimum**	**Maximum**	**Mean**	**SD**	**Minimum**	**Maximum**
A-EN	44.5%	2.55%	33.9%	49.2%	42.4%	1.04%	38.5%	45.2%
A-EX	67.7%	2.55%	61.3%	73.8%	64.8%	5.1%	61.5%	64.5%
C-EN	42.5%	2.14%	33.9%	50%	41.4%	4.3%	38.5%	45.9%
C-EX	66.4%	1.9%	64.4%	75%	64%	4.7%	61.5%	65.6%
LE-EN	55.5%	2.41%	51.6%	63.1%	57.6%	4.16%	55.8%	58.1%
LE-EX	32.3%	2.35%	25.8%	40%	35.1%	2.7%	32.7%	37.1%
ME-EN	57.5%	2.18%	52.5%	65.6%	58.6%	4.6%	55.8%	62.3%
ME-EX	33.8%	1.86%	27.1%	39.1%	36%	2.46%	34.6%	37.7%
DT-EX	9.8%	2.5%	4.3%	15%	8.04%	2.1%	4.5%	12.6%
BCD	20.4%	1.4%	17.04%	24%	20.6%	1.2%	18.2%	18.5%

DISCUSSION

Without sex or side differentiation, the results of the present study were similar to those of Guse and Ostrum and Chou et al.[18, 19] who reported that, the mean of the length of humerus was 302 mm. However regarding the sex, the measurement of the humeral length was different in male from that of female cadavers. Where, it measured 316.9 mm ± 5.5 (310-325 mm) in male limbs and 286 mm ± 15.4 (260-310 mm) mm in female limbs. Moreover, by comparing the mean of male and female humeral length, a high significance was recorded (P value < 0.001) but no significant difference was seen between right and left humeral length in male or female cadavers in the present study. However, in disagreement with the results of the present study, no sex or side differences were recorded regarding the measurements of radial nerve and the humeral length[18, 19,20].

Regardless the sex or side of the limbs, in the present study, the mean distances from the posterior lateral angle of the acromion to the entry and exit points of radial nerve were 132 ± 16.9 mm (100-160) and 199 ± 19.4 mm (160-240) respectively. These findings were similar to those of Chou et al.,[19] and differed from the 124 ±12 mm (97-142mm) and 176 ± 17 mm (140-210 mm), respectively, reported by Guse and Ostrum[18]. In addition, the mean distances from the centre of the medial epicondyle to the entry and exit points of the radial nerve were 171 ± 14.2 (145-210 mm) and 104 ± 11.2 mm (80-125 mm) respectively in the present study. These observations were similar to 161 ±20 (121-200) mm and 111± 21 mm (75-155 mm) reported by Chou et al.[19] and differed from 181± 11mm (158-200 mm) and 131± 10 mm (108-151mm) mentioned by Guse and Ostrum,[18]). Moreover, the mean distance from the centre of lateral epicondyle to the point of radial nerve exit was 102 ±10.5 mm (80-130 mm). This finding was similar to 104 ±25 mm (60-156 mm) and 111 ±1.2 mm (74-138mm) reported by Chou et al. and Chaudhry et al.[19,20] however, it differed from those of Guse and Ostrum,[18] who reported that its value was 126 ±11 (101-148 mm). The distance from the centre of lateral epicondyle to the entry point of radial nerve measured 169 ± 13.5 mm (80-130 mm), which were similar to the 156 ± 1.3 mm (118-186 mm) reported by Chaudhry et al., [20]. The variations might be due to the low position of the radial nerve within the spiral groove.

Similar to the results of previous literatures that described the surgical anatomy of the radial nerve on the posterior aspect of the humerus related to the posterior tip of the acromion and the lateral epicondyle[18], the results of the present study revealed that the radial nerve crossed onto the posterior shaft of the humerus, never closer than 100 mm, and never within 80 mm above the medial or lateral condyle. The authors added that, the danger zone for the radial nerve lies between the proximal and distal third of the humeral length and the zone in which the radial nerve can be injured on the posterior shaft of the humerus.

Understanding the safe zones and the zone of danger of the humerus provides more safety during the surgical interference of the humerus. To do this, the radial nerve must be identified and protected[21, 22]. The proximal and distal safe zones as defined by Guse and Ostrum,[18] are the length of humerus proximal and distal to the point at which the radial nerve respectively begins and ends its course on the posterior shaft of the humerus. The authors found the proximal safe zone ended at an average 124 mm (41% of humeral length) from the tip of the acromion and the distal safe zone began at 176 mm (58% of humeral length) from the same landmark. Ay et al. [23] found similar results with longer lengths accounted for by longer humeri.

Cox et al.,[2] added that, the radial nerve traversed the spiral groove at an average of 14.7 cm (range, 10.3-20.8) distal to the tip of greater tuberosity of humerus. These values represented an average of 48% of humeral length (range, 36%-63%). Right limb measurements averaged 46.8%, and left limb measurements averaged 48.6%. Comparison of right versus left sides revealed a P-value of 0.289. However, regardless the sex or side of the limbs, the results of the present study revealed that, the radial nerve entered the spiral groove at an average distance 132 mm ± 16.4 (range, 100-160) distal to the posterior lateral angle of the acromion. These values represented 43.9% (range, 38.5%-49.2%) of the humerus length. However, right limb measurements was 143.9 mm ±11.1 (130-160 mm) representing a percentage 45.2% (range, 41.9%-49.2%) in male and 121 mm ± 10.7 (100-140 mm) that was equivalent to 42.2% (38.5%-45.2%) in female limbs. In addition, the left limb measurements averaged 137.8 mm ± 15(range, 125-155 mm) that represented 43.7% (range, 40.3% - 47.7%) in male limbs and 121 mm ± 10.7 (range, 105-140 mm) that represented 42.4% (range, 40.4%-45.9%) in female limbs. The disagreement of the results of the present study with those of Cox et al. [2] might be due to the difference in the bony landmarks that were used as a guide for radial nerve measurement in each or due to racial factor.

Regardless the sex or side of limbs, the results of the present study revealed that the mean length of the proximal safe zone from the posterior lateral angle of the acromion ended at an average 132 mm that measured 43.9% of humeral length and the distal safe zone began at 199 mm (66.1% of humeral length) from the same point of the acromion. Moreover, the length of proximal safe zone ended at an approximate distance from both lateral and medial epicondyle (56.1%) and at a distance 42.2% of humeral length distal to the coracoid process. While, the distal safe zone began at an average distance 34% and 64.9% proximal to the centre of both epicondyles and distal to the tip of coracoid process respectively. Regarding the sex, the proximal safe zone measured 44.5% (33.9%-49.2%) and 42.5% (33.9%-50%) in male limbs and it was 42.4% (38.5%-45.2%) and 41.4% (38.5%-45.9%) in female limbs from the lateral angle of the acromion and the centre of coracoid process respectively. While, the distal safe zone measured 32.3% (25.8%-40%) and 33.8% (27.1%-39.1%) in male limbs and it was 35.1% (32.7%-37.1%) and 36% (34.6%-37.7%) in female limbs from the centre of lateral and medial epicondyle respectively. Moreover, no significance was determined between the measurements of right and left limbs in both sexes in the present study.

Similar observations were reported by Guse and Ostrum,[18]; Ay et al.[23], and Carlan et al.[24] who stated that, the lateral (distal) safe zone, extending from the lateral epicondyle to the point of radial nerve exit, ranged from 109 mm to 126 mm (33%-42% of humeral length). These data could be applied clinically when placing an external fixator or bicortical screws in a medial to lateral direction, where it is imperative to stay approximately 10 cm proximal to the lateral epicondyle. However, these findings were in disagreement with the results of Chou et al.,[19] who reported that the distal safe zone measured 60 – 165 mm representing 19% - 49% of humeral length from the lateral epicondyle. In the present study, the mean length of the distal safe zone was 80-130 mm (30.8%-40% of humeral length) proximal to the centre of the lateral epicondyle. However, no one reported the differences between the male and female measurements or between the right and left sided-limb measurements [18, 19, 25].

A simple method of defining the zone of danger was described by Carlan et al.[24], who found that the radial nerve was in contact with bare bone for an average length of 6.3 ± 1.7 centered on the distal border of deltoid tuberosity. These findings were similar to 67 mm (range, 60-85 mm) reported in the present study and did not similar to those of Chaudhry et al,[20] who revealed that the mean length of radial nerve groove was 48 mm (range, 29-56 mm). In addition, the authors added that, the length of radial groove varied between the left and the right limbs of single cadavers and ranged widely between cadavers from 29 ± 5 to 56 ± 4 mm. Similarly, in the present study, significant differences of the danger zone measurement were seen between male and female limbs but without obvious differences were recorded between the right- and left-sided limbs of male or female cadavers. Where, its measurement was 73.3 mm (75-90 mm) in male, 64 mm (55-75) in female limbs, 70.5 mm (60-80mm) in right male limbs, 76.1 mm (65-90 mm) in left male limbs, 65 mm (55-80 mm) in right female limbs and 63 mm (55-65 mm) in left female limbs.

In disagreement with the results of the present study, the radial nerve crossed the posterior aspect of the humerus from an average of 20.7 ± 1.2 cm proximal to the medial epicondyle to 14.2 ± 0.6 cm proximal to the lateral epicondyle[13]. The mean length of the radial nerve in the spiral groove varied from 4.26 cm[10] to 6.5 cm[18]. In this area, the radial nerve could be injured by the screw inserted from anterior to posterior.

Bono et al.[14] described anatomical considerations for humeral fixation of the radial nerves. The average humeral length measured from the proximal articular surface to the most distal aspect of the trochlea was 35 ± 5.7 cm, and the length from the proximal articular surface to the olacranon fossa was 33 ± 0.28 cm. They recommended inserting the antero-posterior pin or screws in the distal 30% of the humerus to decrease the risk of radial nerve injury. However, these bony landmarks cannot be palpated during surgery or may require wide exposure. In the present study, the humeral length measured from the posterior lateral angle of the acromion process to the centre of lateral epicondyle, which are easily palpated and can be used as anatomical landmarks during surgery.

Apivatthakakul et al.,[25] stated that, on the posterior aspect of humerus, the fixation of the radial nerve injury averaged 10.8-17.59 cm (36.35%-59.2%) of the humeral length from the lateral epicondyle and the most dangerous screws that penetrated or touched the radial nerve were in the sixth and seventh holes, which lie 14.03-15.8 cm (42.22%-53.21%) of the humeral length from the lateral epicondyle. Moreover, when the humeral length was divided into eight parts, the danger zone for radial nerve was approximately 3/8 to 5/8 (37.5%-62.5%) of the humeral length measured from the tip of the acromion process to the lateral epicondyle. In this danger zone, bicortical screw insertion from anterior to posterior should be avoided. Thus, the unicortical screw was recommended if the screw placement was needed. Similar observations were recorded in the present study where the danger zone measured from 33.9% - 56.2% proximal to the lateral epicondyle and from 43.4%-66.1% distal to the posterior lateral angle of acromion process of the humeral length.

Gerwin et al.[13] concluded that a safe exposure could be performed 15.4 cm from the lateral epicondyle posteriorly, 20 cm proximal to the medial epicondyle, and 14 cm proximal to lateral epicondyle. However, Mazurek and Shin[26](2001) reported a mean safe distance of 7.5-10 cm from lateral epicondyle to the radial nerve crossing point. The radial nerve pierced the lateral intermuscular septum at 122 mm (range, 88-152 mm) from the lateral epicondyle. When normalization of the data to patient height was attempted, no statistical correlation was found to exist. The results of the present study were in agreement with those of Kamineni et al.[27] who concluded that, the average radial nerve height was 102 ± 10 mm (range, 75-129 mm) and the trans-epicondylar distance was 62 ± 6 mm (rang, 52 -78 mm). The ratio of the lateral nerve height to the trans-epicondylar distance was an average 1.7 ± 0.2 (range, 1.4-2.0).

Protection of radial nerve could be achieved by identifying the piercing point of radial nerve to the lateral intermuscular septum. The nerve might not be completely safe and care could be taken when placing bicortical screws in an anterior posterior direction to avoid the radial nerve in the zone of danger[24]. The crossing point of the radial nerve to the lateral intermuscular septum was considered as a critical point of the radial nerve course. This sepal point was recognized to be an area where the radial nerve was relatively tethered and liable to injury due to its restricted excursion. Thus, various cadaveric studies have reported the risk of radial nerve injury from lateral to medial inserted distal interlocking screws with intramedullary humeral nail[28,29].

Various authors have attempted to landmark the radial nerve at the septal tether point in different way. Uhl et al,[12] measured where the radial nerve pierced the lateral intermuscular septum. The authors recorded that, the radial nerve was laterally located at an average of 10 cm from the articular surface in men and 9.4 cm in women with minimal distance 7.5 cm and its posterior distance from the articular surface was 15.8 cm in men and 15.2 cm in women with minimal distance 13 cm. Thus, it was concluded that when proximal humeral dissection beyond 7.5 cm laterally or 13.0 cm posteriorly from the articular surfaces is required, care should be taken to isolate and protect the radial nerve.

The radial nerve pierced the lateral intermuscular septum at a distance average 47% of humeral length proximal to the distal humeral articular surface[14], 11.8 cm ± 2.1, proximal to the lateral epicondyle (38.3% of the humeral length which measured 30.8 cm ± 2.2 from the tip of the greater tuberosity of humerus to the lateral epicondyle[2] and at a location 2/3 of the distance from the lateral edge of the acromion to the lateral epicondyle[30]. The results of the present study revealed that the lateral intermuscular septum was pierced by the radial nerve at an average distance 102 ± 10.5 mm (80-130) proximal to the lateral epicondyle. This distance represented 33.9% of the humeral length. Regarding the sex, the radial nerve pierces the lateral intermuscular septum at a mean distance 102.5 mm ± 12.9 (80-130mm) in male limbs and 100.6mm ± 7.7 (85-115 mm) in female limbs. These distances represented 32.3% ±2.4% (25.8%-40%) and 35.1% ±2.7% (32.7%-37.1%) in male and female limbs respectively. No significant differences were recorded between right and left limb measurements in male or female cadavers. These results were in accordance with those of Fleming et al.,[30] who add that, localizing the position of the radial nerve might facilitate the performance of the different invasive techniques for the fixation of fractures and insertion of the percutaneous wires which could be safely carried out with an accurate pre-operative prediction of the site of the radial nerve.

In the present study, the measurement of the inter-epicondylar distance was 61.8 ± 4.9 mm similar to those reported by Van Sint Jan et al.[31] who added that, the mean of the vertical distance from radial nerve exit point at the lateral intermuscular septum to the lower tip of the deltoid tuberosity was 47.6 ± 18.5 mm. However, it measured 30.9 mm ± 7.9 (15-48 mm) in male and 23.8 mm ± 6 (13-36 mm) in female limbs respectively in the present study. Moreover, Klepps et al.[32] found the distances between proximal and distal deltoid tuberosity and radial nerve was 2.4 cm and 1.6 cm respectively. The distances between the radial nerve exit and both epicondyles found in the present study were lower than those reported by Van Sint Jan et al. and Guse and Ostrum[31, 18]. This might be due to the discrepancies between the levels of the two reference points used in each. On the other hand, all these studies reported similar results regarding the mean distance between the point of radial nerve entry and the posterior lateral angle of the acromion. In the region of the readily palpable deltoid tuberosity, the radial nerve in jury might be avoided by knowledge of the direct posterior location of the radial nerve at the level of the distal deltoid tuberosity.

Because of large variation in limb length amongst the general population, the results were expressed as a percentage of overall bone length in addition to the exact measurement in millimeters. This allows the surgeon to normalize the findings to patients of varying heights and increase accuracy when planning approaches. These approximated values can serve as a general rule during surgical approaches when identifying and dissecting out the radial nerve. No previous report encountered the differences between male and female cadavers as well as the right and left limbs. The previous literatures considered the data of both sides (right & left) and both sex (male & female) independent [18, 19, 20].

Gerwin et al.,[13] found that the radial nerve crossed the posterior humerus without muscle or fascial interposition. Moreover, No evidence of a structural spiral groove in humerus was found, despite previous reports of a humeral groove or shallow groove and no interposed triceps muscle between nerve and periosteum in this region was reported[24]. However, in all dissections, the radial nerve lay within a fibrous sheath as it passed through the muscle layers. Veins and arteries were frequently encountered running alongside the nerve within this sheath, but their exact number and position variable[20]. The radial nerve is separated from the humeral shaft by the medial head of triceps[1, 18]. The findings of the present study confirmed no muscle interposed between the redial nerve and the humeral periosteum within the spiral groove. The intimate relationship of the radial nerve with the posterior humerus renders the nerve susceptible to injury with mid-shaft fractures and with bicortical fixation of humerus from an anterior approach.

CONCLUSION

Understanding the correlation between the radial nerve within the arm and its surrounding bony landmarks provide good knowledge for surgeons to minimize the iatrogenic injury of the radial nerve during any surgical interventions of the humerus.

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الأهمية السريرية للعلامات العظمية للعضد بالإرتباط مع مسار العصب الكعبرى: دراسة تشريحية

إن العصب الكعبرى هو واحد من الأعصاب الأكثر عرضة للإصابة فى كسور العظام الطويلة. ومعرفة تشريح العصب الكعبرى يكون مفتاح لحماية ونجاح التدخلات الجراحية فى العضد والساعد. تهدف هذة الدراسة الى تعريف مستوى نقاط بداية ونهاية مسار العصب الكعبرى على خلف قصبة عظمة العضد بالنسبة للعلامات العظمية التشريحية المحسوسة للعضد. وقد أستخدم الأطراف العلوية لعدد عشرين جثة (عشر رجال وعشر نساء) فى هذا البحث. وقد أخذت هذة العينات من قسم التشريح بكلية الطب جامعة الملك عبد العزيز. وقد تم تشريح تلك الأطراف. وتم إظهار العصب الكعبرى لكل طرف خلال مسارة فى العضد. وقد تم قياس المسافة بين مدخل ومخرج العصب الكعبرى فى التجويف الحلزونى بالنسبة الى عدد من العلامات العظمية وقد تم قياس هذة القيم بالميليمتر وبحسابها كنسبة مئوية بالنسبة لطول عظمة العضد. وقد كان طول عظمة العضد (من الزاوية الخلفية الوحشية للنتوء الأخرومى الى مركز النتوء مافوق البكرى الوحشى) هو ٣١٦ ± ٥,٥ مم فى الأطراف العلوية لجثث الرجال وكانت ٢٨٦ ± ١٥,٤ مم للأطراف العلوية لجثث النساء. متوسط المسافة من نقطة مدخل العصب الكعبرى الى الزاوية الوحشية للنتوء الأخرومى ، طرف النتوء الغرابى، ومركز النتوء ما فوق البكرى الوحشى والأنسى كانت ١٤٣,٣ ± ١٤ مم (٤٤,٥ %)، ١٣١,٧ ± ١٤,٩ مم (٤٢,٥%)، ١٧٤,٢ ± ١٣,٣ مم (٥٥,٥%)، ١٧٨,١ ± ١٥,٢ مم (٥٧,٥%) فى الأطراف العلوية للرجال وكانت ١٢١,٤ ± ١٠,٤ مم (٤٢,٢%)، ١١٦,٦ ± ١٢,٣ مم (٤١,٤%)، ١٦٤,٦ ± ١٠,٩ مم (٥٧,٦%)، ١٦٦,٣ ± ١٣,٢ مم (٥٨,٦%) فى الأطراف العلوية للنساء على التوالى. ولكن متوسط المسافة من نقطة مخرج العصب الكعبرى الى نفس العلامات العظمية كانت ٢١٤,٢ ± ١٢,٤ مم (٦٧,٧%)، ٢٠٥,٦ ± ١٣,٢ مم (٦٦,٤%)، ١٠٢,٥ ± ١٢,٩ مم (٣٢,٣%)، ١٠٤,٧ ± ١٣ مم (٣٣,٨%)، فى أطراف الرجال العليا وكانت ١٨٥,٣ ± ١٤,٦ مم (٦٤,٨%)، ١٨٠,٩ ± ١٣,٤ مم (٦٤,٨%)، ١٠٠,٣ ± ٨ مم (٣٥,١%)، ١٠١,٣ ± ٧ مم (٣٦%)، ٢٣,٨ ± ٦ مم (٨%) فى أطراف العليا للنساء على التوالى. وقد سجلت إختلافات هامة ($P < 0.01$) بين معظم قياسات العصب الكعبرى فى الأطراف العلوية للرجال والنساء بإستثناء متوسط المسافة من نقطة مخرج العصب الكعبرى الى مركز كلا من ما فوق النتوء البكرى الوحشى والأنسى. ولكن لم يوجد إختلافات مهمة بين قياسات الأطراف اليمنى واليسرى لجثث الرجال والنساء. تعطى العلامات العظمية المحسوسة للعضد تعطى معلومة واضحة للجراح لكى يحدد مكان العصب الكعبرى ويتجنب إصابتة أثناء التدخل الجراحى فى العضد.