Frohse’s arcade is not the exclusive compression site of the radial nerve in its tunnel

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Summary
Introduction. — The radial tunnel is a musculo-aponeurotic furrow which extends from the lateral epicondyle of humerus to the distal edge of the supinator muscle. The superficial head of the supinator muscle forms a fibrous arch, the arcade of Frohse (AF), which is the most common site of compression of the radial nerve motor branch. The latter is less commonly compressed by the adjacent muscular structures. This tunnel syndrome might be worsened with repeated pronation and supination of the forearm. The double object of that work was: (1) to define the radial nerve anatomic landmarks, (2) to determine the anatomical relationship of the radial nerve main trunk and branches to the peripheral osseous and muscular structures in the anterior aspect of the elbow joint in order to identify which of these conflicting elements are likely to cause a compressive neuropathy.

Material and methods. — The study design involved the dissection of 30 embalmed cadaveric upper limbs. Anatomic and morphometric investigations of the radial nerve, its terminal and motor branches were carried out. The presence of adhesions between radial nerve and joint capsule, tendons and aponeurotic expansions of epicondylar muscles and supinator arch was investigated. All measurements were taken in both pronation and supination of the forearm.

Results. — Neither macroscopic radial compressive neuropathy at the level of the supinator arch nor adhesions between the radial nerve and the joint capsule were found. In four cases (13%), dense fibrous tissue surrounded the radial nerve supply to extensor carpi radialis brevis (ECRB). The fibrous arch of the supinator muscle arose in a semi-circular manner and was noted to be tendinous in 87% of the extremities and of membranous consistency in the remaining 13%. The length of the AF averaged 25.9 mm. The angle formed by the radial shaft and the supinator arch was 23°. Neither fibrous structures nor adhesions of the deep branch of the radial nerve (DBRN) along its course through the supinator muscle were observed.
Introduction

While entrapment of the sensory branch of the radial nerve at the elbow joint is fairly uncommon, the deep branch (DBRN) is particularly vulnerable to chronic compressive injury which may result in two distinct clinical presentations: radial tunnel syndrome results in sensory deficits whereas posterior interosseous nerve (PIN) syndrome results in paralysis.

The radial tunnel is a musculo-aponeurotic furrow extending from the lateral epicondyle of humerus to the distal edge of the supinator muscle [1]. Proximally, the radial nerve [2] runs between the brachioradialis and the extensor carpi radialis longus posteriorly and between brachialis and biceps brachii muscles anteriorly. In a deep plane, it lies against the elbow joint capsule and the deep head of the supinator muscle. The superficial head of the supinator muscle, the aponeurotic expansions stretching from the lateral epicondyle, and insertion of the extensor carpi radialis brevis (ECRB) constitute the roof of the tunnel [1,3–5]. The deep motor branch of the radial nerve passes through the supinator muscle between its superficial and deep heads [1,4,6–10]. The proximal edge of the superficial head of the supinator muscle may form a fibrous arch of variable thickness and length also known as the "arcade of Frohse" (AF) [11–13]. The AF is reported to be the most common site of PIN entrapment [4,14–20].

PIN is less frequently compressed by the adjacent vascular or muscular structures [3,13], whether by the supero-medial edge of ECRB or the deep head of the supinator muscle. Clinical symptoms of radial tunnel syndrome might be intensified with repeated pronation and supination of the forearm. Repetitive pronation and supination of the forearm induces compression of the radial nerve and its branches between two inextensible structures. The fibrous AF and the proximal end of the radius (radial head and radial tubercle). This condition is aggravated by the supinator muscle repeated activity. Repetitive compression might then promote histological changes in radial tunnel content and progressive development of a local fibrous zone. We also observed that the radial nerve supply to ECRB could be entrapped between the superolateral aspect of the ECRB and the superior edge of the supinator muscle.

Material and methods

Thirty upper limbs (14 men and 16 women; 14 right and 16 left limbs) obtained from embalmed cadavers after donation to the Institut d’Anatomie Normale of Strasbourg were dissected. All subjects were adults and mean age at death was 79.8 years. All of the upper-limbs were scar-free, both in arms and forearms. None of the limbs were injected and for that reason, the presence of any vascular arcade responsible for compressive neuropathy was not investigated.

Dissection was performed under visual control and with magnifying glasses (× 2.5). Limbs were maintained in an anatomical position (supination) during dissection. The skin was incised longitudinally from the lower third of the anterior face of the arm to the lower third of the anterior aspect of the forearm. Two transverse incisions were made subsequently, facing the anterior aspect of the elbow joint thus allowing four cutaneous and subcutaneous flaps to be performed. Brachioradialis, ECRB, extensor carpi radialis longus and supinator muscles were then separated from their fascia. The supinator arch was identified. Muscles were tenotomized proximal to their insertion on the humerus. The radial nerve was dissected and released from its perineurium from the site where it pierces the lateral intermuscular septum in the arm up to the passage of the deep branch beneath the AF. Presence of a thick fibrous structure was investigated at any stage of the procedure.

An anatomic and morphometric study of the radial nerve was conducted and measurements were taken manually and macroscopically with a caliper square (max. length 15 cm, 0.01 mm precision and max. error of 0.02 mm). Measurements were carried out with forearms in an anatomical and prone position. Thirteen measurements were recorded throughout the study (Fig. 1):

- distance from the radial nerve to the radial head, corresponding to the supinator muscle thickness;

Discussion. — Anatomic studies have revealed a variable rate of occurrence of a tendinous AF, which range from 30 to 80% (87% in our study) according to authors. It is reported to be a pre-disposing factor to the development of chronic entrapment neuropathy of the DBRN, especially if it is thick and provides a narrow opening for passage of the DBRN. The tendinous consistency of the supinator arch is believed to develop in adults, in response to repeated rotary movements of the forearm. Repetitive pronation and supination of the forearm induces compression of the radial nerve and its branches between two inextensible structures. The fibrous AF and the proximal end of the radius (radial head and radial tubercle). This condition is aggravated by the supinator muscle repeated activity. Repetitive compression might then promote histological changes in radial tunnel content and progressive development of a local fibrous zone. We also observed that the radial nerve supply to ECRB could be entrapped between the superolateral aspect of the ECRB and the superior edge of the supinator muscle.

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Figure 1  Summary diagram of all measurements. (d) is the angle formed by the radial shaft and the deep branch of the radial nerve. (g) is the distance from the lateral intermuscular septum (St) to the radial nerve bifurcation into superficial and deep branches; (h) is the distance between the bifurcation of the radial nerve and the anterior edge of the radial head. (i) is the distance from the radial nerve bifurcation and the fibrous supinator arch (St). (j) is the distance from the lateral intermuscular septum (St) to the joint line. (k) is the distance from the lateral intermuscular septum (St) to the fibrous supinator arch (S). (L) is the length of the fibrous supinator arch (S).

- distance from the radial tubercle (bicipital tubercle) to the deep branch, in supination;
- distance from the radial tubercle to the DBRN, in pronation;
- angle formed by the radial shaft and the DBRN;
- distance from the radial tubercle to the superficial branch, in pronation;
- distance from the bicipital tubercle of the radius to the superficial branch, in supination;
- distance between the lateral intermuscular septum and the radial nerve bifurcation into superficial and deep branches;
- distance between the radial nerve bifurcation and the joint line (measurement taken at the anterior edge of the radial head)*;
- distance from the radial nerve bifurcation to the supinator fibrous arch;
- distance from the lateral intermuscular septum to the joint line;
- distance from the lateral intermuscular septum to the supinator arch;
- length of the supinator arch;
- angle formed by the radial shaft and the supinator arch.

The (*) symbol means measurements were noted positive when bifurcation of the radial nerve was distal to the joint line and noted negative when bifurcation was proximal.

Figure 2  Branches originating from the radial nerve trunk (1) — (2) Superficial branch — (3) Deep branch — BR: brachioradialis muscle, previously divided — ECRB: extensor carpi radialis brevis — ECRL: extensor carpi radialis longus — BRA: brachialis muscle — SUP: supinator muscle — FDP: flexor digitalis profundus (flexor digitalis superficialis was resected).

Data were collected in an Excel spreadsheet (Microsoft Corporation, version 11.3, United States) and subjected to statistical analysis through mean, median and standard deviation.

Results

No anatomic variants were noted throughout the study regarding the location of the radial nerve, its two terminal branches, the supinator muscle and both extensor muscles (Fig. 2).

Anatomical study of the radial nerve

The average distance from the septum to the joint line was 12.77 cm (range from 10.05 to 15.48 cm, S.D. = 1.75). The radial nerve bifurcation into superficial and deep branches was measured to be 11.76 cm (from 8.66 to 14.89 cm, S.D. = 1.88) from where the nerve pierces the lateral intermuscular septum and 3.75 cm (from 2.01 to 5.48 cm, S.D. = 0.98) from the AF. In other words, mean distance from the radial nerve bifurcation to the joint line was −0.87 cm (from 1.29 to −2.53 cm, in one case radial nerve bifurcation was distal to the joint line). The average distance from the radial nerve to the radial head was 4.8 mm (from 4 to 7.6 mm, S.D. = 0.098). The distance from the radial tubercle to the DBRN, in pronation averaged 2.67 cm (from 2 to 4.3 cm, S.D. = 0.76). This measurement decreased to 2.17 cm in supination (from 1.5 to 3.36 cm, S.D. = 0.57). The angle formed by the radial nerve and the radial shaft averaged 12.8° (from 0 to 27°, S.D. = 7).
Analysis of fibrous structures and supinator arch

No adhesions between radial nerve and joint capsule were noted; fat-body sheath and perineurium surrounded the radial nerve in all cases. However, a dense fatty fibrous structure was found around the nerve supply to the ECRB in four cases (13%), when innervation of this muscle arose from the PIN (17 cases; 57%). Innervation of the ECRB muscle was found to arise from the radial nerve trunk in 13 cases (43%). In that case, no evidence of fibrous adhesions between the nerve and adjacent structures was found. The same pattern was observed regarding the radial nerve innervation of the extensor carpi radialis longus (in 26.7% of specimens). In that case, the presence of fibrous adhesions were noted around the nerve, stretching from the most superior part of the supinator muscle to the deep and postero-lateral aspect of the ECRB.

The supinator arch arose in a semi-circular manner in all cases. According to the Prasartritha et al. classification [4], the AF was tendinous and movable in 87% (26 cases out of 30) and of membranous consistency, thickened and unyielding with tissue forceps in 13% (4 cases out of 30) (Fig. 3). The average length of the arcade was 26 mm (from 16.9 to 32.4 mm, S.D. = 5). The angle formed by the radial shaft and the supinator arch was 23° (from 7 to 49°, S.D. = 11). The fibrous arch was located 13.52 cm (from 11.2 to 16 cm, S.D. = 1.59) from the lateral intermuscular septum.

Neither fibrous structures nor adhesions of the deep radial nerve, along its course through the supinator muscle, were observed.

Discussion

This study was undertaken to define the radial nerve relationship to the musculo-aponeurotic structures at the elbow joint, in order to determine the most common sites likely to promote compression syndrome of the radial nerve and its branches. Although the AF has been widely described in the literature, little data is available regarding other anatomical sites responsible for radial tunnel syndrome [22]. Knowledge of the anatomical structures and their relationship in this region could provide better understanding of radial tunnel syndrome physiopathology [22] and aid in the decompression of the radial nerve [1].

The presence of a normal tendinous anatomic arch was initially reported by Frohse and Frankle in 1908 [11]. In 1968, Spinner [12] conducted an anatomical study of the upper limbs in 25 adults and 10 newborn full-term foetuses and did not find evidence of a tendinous arcade at the level of the superficial head of the supinator in the newborn full-term foetus. This led to the suggestion that the semi-circular arch did probably form in adults, in response to repeated rotary movement of the forearm.

Anatomic studies have revealed a variable rate of occurrence of a tendinous AF, which ranges from 30 to 80% [3,4,9,10,12,23–25].

In our study, the arcade was of a tendinous nature in most individuals (87%), which corroborates the results reported by Ozturk et al. [13]. Lister et al. [18] have reported an incidence of 100%.

According to Spinner [12], the arcade tendinous consistency is a predisposing factor for chronic compressive neuropathy of the DBRN, particularly when it is thick and provides a narrow opening for passage of the deep branch. Measurements were thus undertaken to determine the length of the arcade and its location relative to the axis of radius and find if any relationship exists between compressive neuropathy and forearm positioning. The results of Ebraheim et al. [24], Ozturk et al. [13] and Konjengham et al. [26] were published in the literature regarding length and thickness of the arcade but regardless of its position relative to the axis of radius. The average length of the arcade was 16.8 mm in the former, identical in both men and women,
10.13 mm in the second one and 41 mm in the third one. In our study, the average length of the arcade is 25.9 mm, which appears to be significantly greater. However, these measurements do not clearly appear as contradictory since precise macroscopic assessment of the AF remain difficult due to the very progressive anatomical transition between the tendinous structure of the superior part of the supinator and the muscular elements.

The present study supports the hypothesis [12,15,26,27] that repetitive pronation and supination of the forearm promotes compression of the radial nerve and its two branches between two inextensible structures: the fibrous AF and the proximal end of the radius (radial head and radial tubercle). This condition is aggravated by the repeated activity of the supinator muscle which increases perineurial pressure by five during sustained supination as shown by Bonnel [28]. These repetitive compressions might then promote histological changes in radial tunnel content and progressive development of a local fibrous structure.

Besides these findings, we could observe, as pointed out by many authors [16,26,29], that the radial nerve innervation to ECRB could be entrapped between the superolateral aspect of the ECRB and the superior edge of the supinator muscle. In case of epicondyilitis, this condition might be less due to the thickening of the proximal tendon of ECRB.

This study demonstrates that the distance between the radial nerve and the radial head as well as the length of the supinator arch show no significant variation. The radial nerve bifurcation is classically noted to be proximal to the radiohumeral joint line in 97% of the cases (only one case beyond that point). However, some of the parameters demonstrate significant interindividual variations such as the angle formed by the radial shaft and the axis of the deep radial nerve on the one hand and the angle between the radial shaft and the supinator arch on the other hand. The distance from the radial nerve branches to the radial tubercle naturally varies depending on whether the arm is in pronation or supination. That distance is decreased by approximately 5 mm for the deep branch and 6 mm for the superficial branch in supination.

References