1 Anatomy of the Median Nerve: Anatomic Variations and Anomalies

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Introduction

In this chapter, anatomic variations and anomalies of the median nerve in or adjacent to the carpal tunnel are described. Relevant branches of the median nerve in this region include the palmar cutaneous branch, thenar motor branch, recurrent motor branch, and common digital nerves. In addition, there may be an anomalous branching pattern and/or accessory branches of the median nerve in this region. Finally, an anastomosis between branches of the median and ulnar nerves may be present.

Intraoperative observations have provided data regarding the incidence and clinical relevance of median nerve anatomic variations. Lindley and Kleinert reported that the overall rate of median nerve anatomic variations or anomalies was 1% in their series of 526 carpal tunnel releases [1]. Tountas et al. reported a 9.8% rate of median nerve anomalies in a series of 821 carpal tunnel releases [2]. Beris et al. reported a 10% rate of median nerve anomalies in a series of 110 carpal tunnel releases [3]. However, it is important to note that clinical observations may be limited by selection bias since patients undergoing carpal tunnel release may not have an anatomy that is generalizable to the general population. For example, it has been hypothesized that clinical studies may overestimate the incidence of transligamentous branching of the thenar motor branch since this anomaly may predispose to nerve compression and consequent thenar atrophy [4]. In addition, clinical studies are restricted by more limited exposure and surgical technique, as compared to cadaveric studies. Not surprisingly, the incidence of median nerve anomalies in or adjacent to the carpal tunnel is higher in cadaveric studies—ranging from 18% in 92 specimens reported by Tountas et al. to 78% in 60 specimens reported by Alizadeh et al. [2, 5].

Palmer and Toivonen reported humbling survey results of American Society for Surgery of the Hand members performing open (616 respondents) or endoscopic (708 respondents) carpal tunnel release over a 5-year period. Among respondents performing open and endoscopic surgeries, there were 147 and 100 median nerve lacerations, 29 and 88 ulnar nerve lacerations, 54 and 77 digital nerve lacerations, 34 and 121 vessel lacerations, and 19 and 69 tendon lacerations, respectively [6]. Thus, understanding the anatomic variations and anomalies of the median nerve in proximity to the carpal tunnel is essential to minimizing risk of nerve injury (i.e., the most common complication) during open or endoscopic carpal tunnel release.

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Variable Branching of the Median Nerve in the Carpal Tunnel

Lanz comprehensively classified anatomic variations of the median nerve in the carpal tunnel based on intraoperative observations from 246 carpal tunnel releases performed during a 4-year period (Fig. 1.1) [7, 8]. Median nerve anomalies were subdivided into four groups depending on the location and type of anomaly: (I) variation in the course of the thenar motor branch, (II) accessory branch(es) at the distal carpal tunnel, (III) high division of the median nerve, and (IV) accessory branch(es) proximal to the carpal tunnel [8]. Groups I and III will be discussed in-depth later in this chapter.

Lanz reported that 7% had accessory branches of the median nerve at the distal portion of the carpal tunnel (i.e., group II) in a series of 246 hands [8]. In a study of ten cadaveric specimens, Falconer and Spinner reported that two had multiple thenar motor branches of the median nerve, and three had Riche-Cannieu anastomosis [9].

Lanz reported that 1.6% had accessory branches of the median nerve proximal to the carpal tunnel in a series of 246 hands [8].

Thenar Motor Branch

The normal origin of the thenar motor branch is distal to the flexor retinaculum (i.e., "extraligamentous") and from the volar/central or volar/

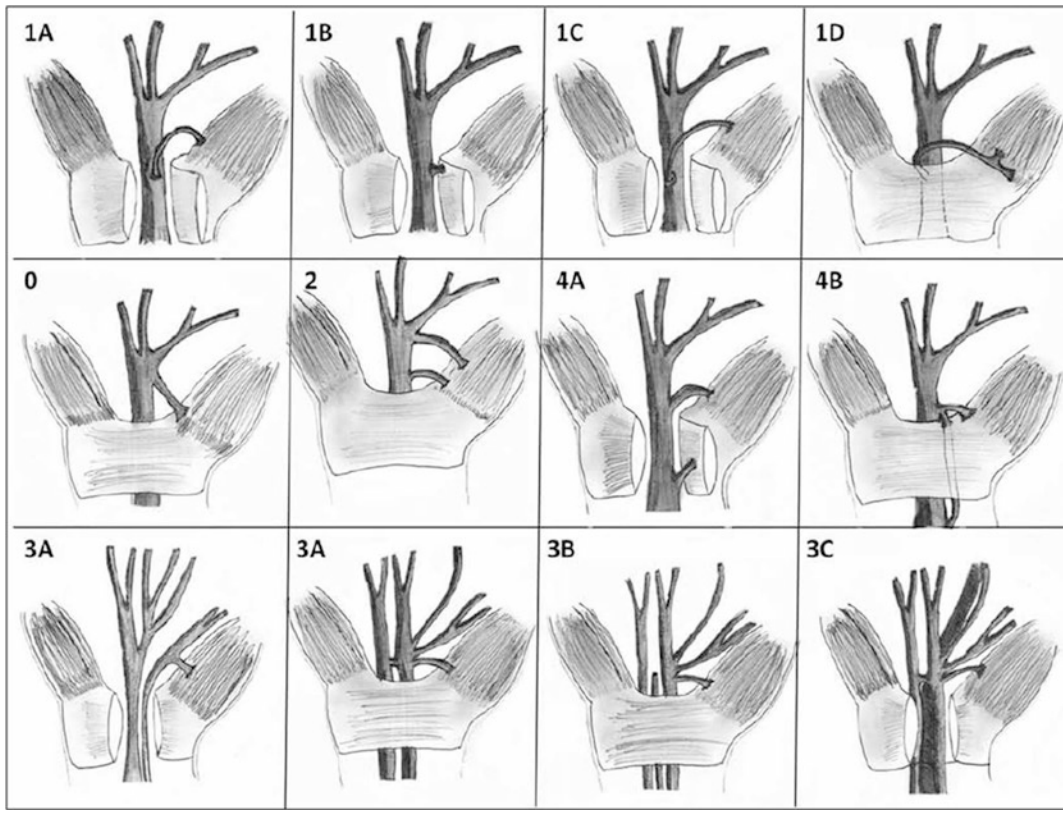

Fig. 1.1 Illustrations of median nerve anomalies in the carpal tunnel. Group 1 refers to thenar motor branch anomalies: (*A*) subligamentous, (*B*) transligamentous, (*C*) ulnar takeoff, or (*D*) supraligamentous. Group 0 refers to extraligamentous thenar motor branch. Group 2 refers to a distal accessory thenar branch. Group 3 refers to anomalies associated with high division of the median nerve: (*A*) without a persistent median artery or accessory muscle, (*B*) with a persistent median artery, or (*C*) with an accessory muscle. Group 4 refers to a proximal accessory thenar branch: (*A*) running directly into the thenar muscles or (*B*) joining another branch prior to reaching the thenar muscles. Figure and illustrations reproduced with permission from Demircay et al. [7]

radial aspect of the median nerve [10]. Variations in the origin and course of the thenar motor branch relative to the transverse carpal ligament were first described by Poisel [11]. In this original description, two anomalies were described: "subligamentous" (Fig. 1.1, 1A) in which the thenar motor branch originates beneath the transverse carpal ligament and "transligamentous" (Fig. 1.1, 1B) in which the thenar motor branch passes through the transverse carpal ligament. In his series of 100 specimens, Poisel reported that 46% were extraligamentous, 31% subligamentous, and 23% transligamentous [11].

This distribution of extraligamentous, subligamentous, and transligamentous branching patterns reported has been corroborated by other authors in both clinical and cadaveric series. Hurwitz published a series of 80 carpal tunnel releases in which the thenar motor branch was extraligamentous in 55%, subligamentous in 29%, and transligamentous in 16% [4]. In addition, 9% had an anomaly in which motor branch originated from the anterior aspect of the median nerve, coursed in an ulnar direction distally before coursing toward the thenar muscles superficial to the flexor retinaculum [4]. This anomaly was first described by Mannerfelt and Hybbinette and is associated with transversely oriented muscle fibers overlying the distal flexor retinaculum (most likely flexor pollicis brevis or abductor pollicis brevis) [4]. This "supraligamentous" course was included by Lanz in his classification (Fig. 1.1, 1D). In a cadaveric study of 60 specimens, Alizadeh et al. reported 47% of thenar motor branches were extraligamentous, 28% subligamentous, and 12% transligamentous [5]. Interestingly, the thenar branch originated from the ulnar aspect of the median nerve in 12% of specimens [5]. Lanz also included this anatomic variant in his classification (Fig. 1.1, 1C).

However, there has been debate in the literature regarding the incidence of these abnormalities—particularly the transligamentous and ulnar origin variants. The incidence of transligamentous branching has varied widely in the literature. Falconer and Spinner reported that 60% of ten cadaveric specimens had a transligamentous branching pattern [9]. On the other hand, Kozin reported that only 7% of 101 cadaveric specimens had a transligamentous branching pattern and concluded that previous studies had overestimated the incidence of transligamentous branching as a result of the close proximity of obliquely oriented fascia distally with the transverse carpal ligament [10]. Of note, Kozin did not observe any thenar motor branches originating from the ulnar aspect of the median nerve, and only 4% had multiple motor branches [10]. Similarly, in Lindley and Kleinert's clinical series of 526 carpal tunnel releases, only one patient had a thenar motor branch with an ulnar origin. Despite conflicting data on the incidence of the transligamentous and ulnar origin variants, awareness of all possible thenar motor branch anomalies is critical to prevent iatrogenic injury during carpal tunnel release.

Common Digital Nerves

Terminal branches of the median nerve include common digital nerves to the second and third web spaces. Engineer et al. described three variations of the third common digital nerve based on dissection of 20 cadaveric specimens (Fig. 1.2) [12, 13]. Type I originates proximal to the distal edge of the transverse carpal ligament and found in 15% of specimens. Type II originates distal to transverse carpal ligament, but proximal to the superficial palmar arch, and was found in 70% of specimens. Type III originates distal to the transverse carpal ligament and at (or distal to) the superficial palmar arch and was found in 15% of specimens [12]. Knowledge of type I third common digital nerve anatomy is critical to prevent iatrogenic injury during carpal tunnel release [12].

Palmar Cutaneous Branch

The palmar cutaneous branch arises from the volar/radial aspect of the median nerve 4.6 cm proximal to the distal transverse volar wrist crease [14]. Lindley and Kleinert noted two palmar cutaneous branch anomalies in their series of 526 open carpal tunnel releases. In one patient, the nerve pierced the flexor retinaculum and traveled with the median nerve, and in the second, the nerve originated ulnarly [1].

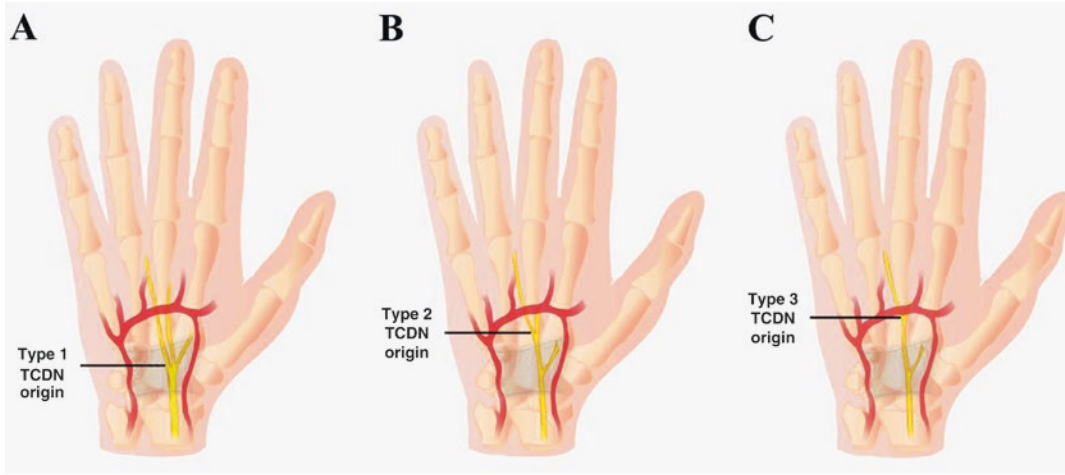

Fig. 1.2 Illustrations of variations in the origin of the third common digital nerve. (**a**) Type I originates from the median nerve within the carpal tunnel. (**b**) Type II originates distal to the transverse carpal ligament, but proximal to the superficial palmar arch. (**c**) Type III originates distal to the transverse carpal ligament and at/distal to the superficial palmar arch. Figure and illustrations reproduced with permission from Engineer et al. [12]

Median and Ulnar Nerve Anastomosis

The Martin-Gruber anastomosis consists of a branch of the median nerve crossing over to the ulnar nerve and has a variable incidence (10–23%) [15, 16]. Communicating branches between the ulnar and median sensory nerves distally have been described and are an important consideration during carpal tunnel release.

High Division of the Median Nerve

High division of the median nerve has been associated with separation by a persistent median artery, muscle belly of the flexor digitorum superficialis to the long or index finger, accessory palmaris longus tendon, and accessory lumbrical muscle [1, 2, 7, 8]. A subset of these anomalies was described by Lanz and compiled into Demircay et al.'s classification scheme (Fig. 1.1, 3). Lanz reported that 2.8% of 246 hands had a high division of the median nerve [8]. Lindley and Kleinert reported that 1% of median nerves exposed during 526 open carpal tunnel releases had a high division of the median nerve, which was frequently associated with a persistent median artery [1]. Amadio reported that 3.3% of median nerves had a high division [17].

Variable Course of the Median Nerve in the Carpal Tunnel

The course of the median nerve within the carpal tunnel is variable [7, 18]. The median nerve has either a straight or curved path within the carpal tunnel. If straight, the median nerve can either be in the middle of the flexor retinaculum (21.7%), deviated radially (43.3%), or deviated ulnarly (1.7%) [18]. If curved, the median nerve can either diverge in a radial (21.6%) or ulnar (11.7%) direction [18].

Summary

Hand surgeons need to be aware of the numerous anatomic variations that exist during carpal tunnel surgery. These variations can be responsible for inadvertent injury during routine surgical procedures.

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