

Title of Paper:

A comprehensive review of motor innervation of the Hand: Variations and Clinical significance

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Review of motor innervation of hand

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Abstract:

Purpose

The objective of the present review is to assemble the recognized anatomical variations, classifications and clinical evidence with regard to innervation of the hand and discuss the clinical significance of these variations.

Methods

The material for this review was obtained by exploring PubMed and Google Scholar (search terms: hand innervation, variations of ulnar nerve, variations of median nerve, variations of radial nerve) as well as from standard anatomy texts. This initial search returned approximately 300 articles, which was reduced by abstract or title review. Reviewing the reference lists of significant papers uncovered further studies missed in the initial search. A few standard anatomy texts were also consulted for normal anatomy.

Results

The Median and Ulnar nerves frequently display a number of significant deviations from the traditionally taught branching patterns. The traditionally taught innervation of the hand is also found to be highly variable. This is especially evident with regard to the motor innervation of thenar muscles. These variations may be explained by the often under-recognised anastomoses that exist in the hand, such as the motor Riche-Cannieu Anastomosis. Some of these variations are associated significant clinical consequences.

Conclusions

The Median and Ulnar nerves display many anatomical variations, often with significant clinical implications. Awareness about these variations is clinically important when interpreting clinical examination findings, electrophysiological and radiological investigation as well as during management of patients in terms of surgical and anaesthetic procedures.

Keywords:

Hand, Innervation, Variations, Median, Ulnar.

Introduction

Traditionally the innervation of the hand has been broken down into two clear rules: the Median nerve supplies the thenar eminence and the lateral two lumbricals, while the Ulnar nerve supplies all other intrinsic hand muscles [49, 56, 59]. However this is a huge oversimplification of a rather complex topic. Both nerves have numerous, common anatomical variations which can have significant clinical implications.

If the reader has no knowledge of aberrant connections, alternative innervation patterns or possible anastomosis, many peripheral nerve lesions will never be understood. Standard anatomical knowledge does not always explain the signs associated with nerve lesions [70], especially when anatomical variations are so common. For example, Rowntree found that the traditionally taught innervation pattern is found in only a third of the population, with one fifth of the population having significant variations of motor innervation [56].

The Median and Ulnar nerves have a “normal” anatomical arrangement in only 8.9% of dissected limbs [70]. The remaining limbs displayed a wide array of variations that can have significant clinical implications, especially for hand surgery, trauma and compressive lesions. Electrophysiological testing can detect only some of these variations before surgery [61], and thus an understanding of all possible nerve courses is vital.

Methods

An initial search of PubMed and Google Scholar was undertaken to gather material for this review, using the following search terms: hand innervation variations, ulnar nerve variations, median nerve variations, radial nerve variations, hand anastomosis. This produced approximately 300 articles, whose titles and abstracts were then reviewed for relevance to the research question. From this initial search approximately 100 articles were of relevance, and were reviewed. Additionally, the reference lists of significant papers were reviewed for studies missed in the initial search. From this, 18 additional articles were found for this review. Due to duplicate reporting, studies were only included in the final review article if they provided new, relevant information or a succinct summary of the known information at that date. A few standard anatomy texts were also used.

Results

The literature demonstrated that both the Median and Ulnar nerves display a number of significant deviations to the traditionally taught branching patterns. They rarely display a ‘normal’ anatomical arrangement, and some of the abnormal variations were found to be associated with clinical conditions. Useful classification systems exist to group

the variations, such as the Lanz classification for the Median nerve and the Murata classification for the Ulnar nerve. Additionally while the PCBM can be considered as an anatomical constant, there is rarely an Ulnar equivalent. The traditionally taught innervation of the hand is also highly variable. This is especially evident in the thenar eminence, where the Deep Branch of the Ulnar Nerve (DBUN) makes varying contributions that can have significant clinical impact. These variations may be explained by the often under-recognised anastomoses that exist in the hand, such as the MCA, RCA and Berettini anastomosis. Significantly the RCA has a reported prevalence of up to 77% and the Berettini anastomosis has a prevalence of up to 100%.

Median nerve - Normal Anatomy

The median nerve enters the hand through the carpal tunnel. Usually, the Palmar Cutaneous Branch of the Median nerve (PCBM) branches off just prior to the carpal tunnel [15].

After exiting the carpal tunnel the Median nerve divides into medial and lateral branches. The medial branch then terminates as the first and second Palmar Common Digital Nerves (CDN), which usually supply motor innervation to the second lumbrical and sensory innervation to the distal palm and fingers. The lateral branch gives off the Recurrent Median nerve (RMN), i.e. the thenar Motor Branch. It then terminates as three palmar Proper Digital Nerves (PDN) which supply motor innervation to the first lumbrical (via the radial PDN to the index finger) and sensory innervation to thumb and radial side of the index finger. There is no CDN to the thumb; the lateral branch immediately branches into PDNs [29, 51]. This is shown in Figure 1. An anatomical variant of bifurcation within the carpal tunnel has also been described [2].

Lanz classified the variations in the course of the Median nerve at the wrist into five groups, as can be seen in Figure 2. He included Variations of the RMN previously classified by Poisel into Groups 0 and 1 [55]. Accordingly the group 0 has an extraligamentous RMN (considered standard anatomy) [29]. Group 1 contains the various RMN branching patterns, including, subligamentous, transligamentous, preligamentous and supraligamentous. Group 2 nerves comprise of a distal accessory thenar branch. Group 3 demonstrates a high division of the Median nerve, resulting in a bifid nerve. Finally, Group 4 nerves contain an accessory branch of the Median nerve branching proximal to the carpal tunnel [17, 29, 36]. Group 0 is sometimes considered to be a subgroup of Group 1. Group 0 and 1 are vastly the most common variations; Group 2 has prevalence of approximately 4.6%, group 3 a prevalence of 2.6% and group 4 a prevalence of 2.3% [29].

Clinical Implications

Possessing a Lanz group 3 variation of the Median nerve has been found to be associated with an increased rate of Carpal Tunnel Syndrome (CTS). In 2008 Bayrak et al found group 3 classification to be prevalent in 19% of patients with CTS as compared to 9% of healthy controls. The group is also associated with an increased risk of aberrant nerve branches [6] and the presence of persistent median artery [4]. The increased risk of CTS in Lanz group 3 maybe attributed to the increased cross sectional of the neural tissue [6] as well as the presence of the median artery reducing the space within this fibro-osseous channel. Further, this variation is one of the few that can be detected via ultrasound; a recent meta-analysis suggested ultrasound screening of patients before undergoing CTR surgery can help identify those at increased risk of iatrogenic nerve damage and allow for better surgical planning [29].

Recurrent Branch of the Median nerve (RMN)

Due to the clinical significance of the RMN, its variations have been extensively studied [3, 29, 54]. Poisel originally described a classification system of three main branching patterns: extraligamentous (type I), subligamentous (type II) and transligamentous (type III) [54].

In extraligamentous nerves the RMN arises distal to the TCL. It then takes a retrograde course to reach the thenar muscles. In the subligamentous class the RMN arises within the carpal tunnel, remaining deep to the TCL until it reaches the distal end of the ligament. At the distal end the nerve branch bends around the ligament to reach the thenar muscles. In transligamentous nerves, the RMN arises within the carpal tunnel. It then pierces the TCL and crosses superficially to the thenar eminence [29]. Extraligamentous is the most common group; a recent meta-analysis found that the pooled prevalence for extraligamentous nerves was 75.2%, 13.5 % for subligamentous and 11.3% for transligamentous [29]. Exact prevalence rates can vary among populations. For example, subligamentous RMN were found in 24.6% of Europeans, 12.6% of Asians and 7.1% of Americans, while the transligamentous group had a prevalence of 19.4% in Americans, 11.7% of Europeans and 8.7% in Asians [29].

Additionally, rare cases of a supraligamentous and preligamentous courses have also been described [29, 36]. The rare supraligamentous RMN remains deep to TCL before emerging at the distal edge of the TCL and take a recurrent course to run over the top of the TCL to reach the thenar muscles. Preligamentous RMNs arise proximal to the TCL, and run superficially over the ligament to reach their destination [29].

In approximately 2% of Median nerves the RMN has also been shown to arise from the ulnar side of the Median nerve [29].

Clinical Implications

Knowledge of RMN variations is vital, especially concerning operations such as carpal tunnel release (CTR). During CTR surgery the potential exists for iatrogenic damage to the main trunk of the Median nerve as well as the PCBM and the RMN [32]. RMN is known as the ‘million dollar nerve’ due to the significant functional deficits patients experience if it is damaged, and the subsequent litigation bill [29]. As discussed above there are numerous variations, such as transligamentous, preligamentous or ulnar branching RMN, which are at significant risk of iatrogenic harm. The traditional ulnar-based approach to CTR will not always ensure their safety, stressing the importance of careful layer by layer dissection.

Generally, “there are few, if any clinical or electrophysiological signs that anatomical variations of the Median nerve in the carpal tunnel are present in a patient”[29]. Ultrasound screening is usually unhelpful (except in the case of a Lanz Group 3 variation). Symmetry also cannot be relied upon; for example, only 72% of the population have the same course of the RMN bilaterally [29].

It has been suggested that the presence of hypertrophic thenar musculature may be indicative of an atypical RMN, especially a transligamentous RMN, and should be considered a warning sign during carpal tunnel surgeries [29].

Ulnar nerve -Normal Anatomy

The Ulnar nerve emerges from beneath the FCU tendon proximal to the wrist. It gives off the Dorsal Branch of the Ulnar Nerve (DorBUN) just prior to emergence. The DorBUN provides cutaneous innervation to dorsal medial surface of the hand and digits [49, 59]. At the wrist the main body of the Ulnar nerve gives off small variable palmar cutaneous branches, which supply the skin of the hypothenar eminence [12, 19, 49, 59].

The nerve enters the wrist via the Guyons canal, a tunnel between pisohamate and the palmar carpal ligaments on the ulnar boarder of the wrist [49, 50, 53, 59, 64]. Classical teaching states that the Ulnar nerve divides into the Superficial Sensory (SSBUN) and Deep Branch (DBUN) inside Guyon’s canal [8, 50, 59, 64]. This division can also occur proximal to the canal, in 13 – 16% of the population [53, 64].

Variations in Bifurcation

Not only does the exact position of the bifurcation of the nerve differ, but so does the entire branching pattern of the Ulnar nerve in the hand. Bonnel and Vila found the Ulnar nerve course could be classified as either Type 1 or Type 2 [10]. Type 1 reflects traditional anatomy teaching, as described above [10, 64]. Bonnel and Vila found this pattern present in 80% of specimens [10]. In Type 2 the Ulnar nerve trifurcates. There exists no Superficial Sensory branch; the Ulnar nerve splits into the DBUN, the third CDN and a PDN. This was present in 9% - 19.6% of specimens [10, 50, 64].

Murata et al. later extended on this classification system [50]. They added an additional 3 groups to Bonell and Vila's classification system. Type 3 Ulnar nerves bifurcates; however unlike Type 1 the Ulnar nerve bifurcated into an ulnar and radial trunk. The ulnar trunk further bifurcated into the DBUN and the ulnar PDN. The Radial trunk extended as the third CDN. In type 4 ulnar nerve trifurcates and there is an additional communicating superficial branch arising proximally. Type 5 demonstrates trifurcation with the DorBUN branching off distally, from the 5th PDN. The study found that Type 1, as described above, was present 77% of the time. Type 2 was present 9% of the time. Type 3 had a prevalence equal to Type 2, of 9%. Type 4 and Type 5 Ulnar nerves were both rare; each were found in 3% of specimens. [50]. This can be seen in figure 3.

There exist more possible variations of the Ulnar nerve not depicted in figure 3, however those depicted are the most common. Bonnell and Vila found one specimen where the Ulnar nerve divided into 4 branches inside Guyon's canal: the DBUN, third CDN, a PDN and a communicating branch to the second CDN of the Median nerve [10]. This communicating branch is likely a Berretini anastomosis, as described below.

Because of the many variations possible the branching of the Ulnar nerve is commonly grouped into 3 sets: bifurcated, trifurcated and anomalous [50]. Bifurcated Ulnar nerves are by far the most common (Groups 1 and 3), followed by trifurcated nerves (Groups 2, 4 and 5) with an incidence of 13% - 22% [10, 44, 50].

Superficial Sensory Branch of the Ulnar Nerve (SSBUN)

Where it exists most sources state the SSBUN exits Guyon's Canal, where it can be palpated on the hook of the hamate [59]. It then travels superficially to the hypothenar eminence, where it generally branches into the third CDN and the ulnar PDN of the small finger (Figure 1). These branches supply cutaneous innervation to the ulnar one and a half digits [50, 53, 64].

It has been reported that just prior to its bifurcation the SSBUN usually supplies motor innervation to the Palmaris Brevis [59].

Deep Branch of the Ulnar Nerve (DBUN)

Traditionally it is thought that the DBUN travels through the Guyon's canal and curves around the medial wall of the hook of the hamate, deep to the hypothenar muscles [2, 8, 50, 53, 64]. It passes deep into the palm between the heads of the Flexor Digiti Minimi (FDM) and Abductor Digiti Minimi (ADM) and courses between the superficial and deep layers of the Opponens Digiti Minimi (ODM) [50, 53, 59, 64]. This pathway is not consistent however. In about 20% of the population the DBUN enters the intermuscular space between the ADM and ODM [8, 50]. Rarely the DBUN courses between the 2 origins of the FDM [50].

As the nerve passes through the hypothenar muscles, motor branches are given off [8, 50, 53]. This branching pattern demonstrates incredible variability. Either one large main motor branch is given off to the hypothenar muscles, or up to four small main branches [8, 53]. Two main motor branches is the most common pattern, with a prevalence of 66% [8]. The main body of the DBUN then continues down to the deep plane of the interossei muscles and “arches deeply in the palm within the concavity of the deep palmar arch” [59]. Murata et al studied the motor branch to the ADM, and found a wide array of variation. For example, in 29% of hands they found the motor branch to the ADM originated from the Ulnar nerve prior to Guyon’s canal [50].

Palmar Cutaneous Branch of the Ulnar Nerve (PCBUN)

The PCBUN is highly variable when compared to its median counterpart [19, 44, 46]. It is commonly absent; one study failed to find it in 40 dissected hands [46]. In a another study it was present in only 16% of hands [19, 44]. Where present it originates an average of 4.6cm proximal to the pisiform from the main Ulnar nerve body. It then travels into the palm superficial to the TCL [44].

Where the PCBUN is not present, the hand appears to receive cutaneous sensation via the Nerve of Henle, a forearm branch of the Ulnar nerve that provides sympathetic innervation to the ulnar artery. It has been suggested that the Nerve of Henle is actually a proximal variant of the PCBUN [5, 44, 47].

Innervation of the intrinsic hand muscles

Motor innervation of the hand is also not as simple as is traditionally taught. Classical teaching states the Median nerve supplies the thenar eminence and the lateral two lumbricals. The Ulnar nerve supplies all other intrinsic hand muscles [49, 56, 59]. However this innervation pattern is only found in roughly one third of the population, with one fifth off the population having ‘significant’ variations of motor innervation [2, 56].

Thenar Muscles and the Adductor Pollicis

The thenar eminence is composed of the Abductor Pollicis Brevis (APB), the Flexor Pollicis Brevis (FBP) and the Opponens Pollicis (OP) [27, 49]. The Adductor Pollicis (ADD) also acts on the thumb, and will be discussed here. The innervation of these muscles displays significant variation in the population, as can be seen in Table 1. Quantifying the exact percentage of each pattern of innervation is difficult due to the vast differences between studies, and the added complexity of dual innervation.

The majority of the Thenar muscles are innervated by RMN, however the DBUN makes varying contributions. Some of this variation is thought to be due to connections between the Median and Ulnar nerves, such as the Riche - Cannieu anastomosis discussed below. In approximately 2% of hands the Ulnar nerve was found to innervate all the thenar

muscles, and the Adductor Pollicis [2, 56, 70]. One author found that the median nerve solely innervated the thenar muscles in roughly one quarter of the population [22].

Of all of the muscles of the thenar eminence the FPB demonstrated some of the highest variability. As seen in Table 1, the Superficial Head of the FPB is generally innervated by the Median nerve. A significant outlier to this however is Belson et al's 1976 study [7]. They found that the Superficial Head was only innervated strictly by the Median nerve in 14.3% of the population. Occasionally the Deep head of the FPB muscle is absent. In these hands, Ajmani et al found the whole belly of the FPB was always innervated by the Ulnar nerve [2].

Lumbricals

The four lumbrical Muscles assist in metacarpophalangeal joint flexion and are the main contributor to interphalangeal joint extension. [51] Their innervation is generally constant, as can be seen in Table 2. The innervation of the first two lateral lumbricals is commonly via Digital Nerves branching from the Median nerve. It is important to keep this in mind, and to recognize that the Digital Nerves are not purely sensory [37, 51]. A recent study found that lumbrical innervation was 'normal' in 92% of hands [33]. The third lumbrical undoubtedly has the highest rate of variable innervation; a recent study suggested that it receives dual innervation 64% of the time [30].

Hypothenar Muscles

The hypothenar eminence is comprised of the Abductor Digiti Minimi (ADM), the Flexor Digiti Minimi (FDM) and the Opponens Digiti Minimi (ODM) [49]. As can be seen in Table 3 the Ulnar nerve usually solely innervates the hypothenar eminence, however there have been reports of Median nerve contribution through either Martin- Gruber anastomosis or a hypothenar motor branch from the Median nerve [53, 56].

The Palmaris Brevis lies superficial to the base of the hypothenar eminence. It is usually innervated by the SSBUN, though occasionally receives innervation from the DBUN [44, 59].

Interosseous Muscles

The 7 interosseous muscles, three palmar and four dorsal, are vital for hand function (especially grip and pinch strength) [40]. It is classically taught that they are innervated by the DBUN [40, 64]. The literature agrees generally, though it does acknowledge that anastomoses between the Ulnar and Median nerve could potentially alter the innervation pattern [8, 40, 60, 64]. Sunderland has demonstrated median innervation of first dorsal interosseous in 3 out of 100 consecutive autopsy specimens [65].

Clinical Implications

It is important to acknowledge the wide array of variation that exists in the innervation of the hand. Whether this is due to abnormal branching of the nerves, or anastomoses as discussed below, the hand is more likely to demonstrate

abnormal innervation patterns than it is to reflect the ‘classical’ teachings [56]. This is important to recognize not only for the evaluation of any nerve injury itself, but for the planning of possible reconstructive surgery [2].

While some of these anatomical variations may only be minor, there are numerous reports of significant deviations that could have serious clinical implications if not recognized. For example several authors have described the possibility of a totally ulnar innervated hand [2, 9, 23, 56, 57]. In the study performed by Sachs et al they found “4 out of 102 Median nerve transections spared all intrinsic hand muscles, including the Abductor Pollicis Brevis” [57]. Uncini et al have reported a case with ulnar nerve injury at elbow sparing the first dorsal interosseous. Electrophysiological studies in this patient revealed an anastomosis between Ulnar and Median nerves near the elbow [68]. Without knowledge of the possible variations of innervation possible these type of scenarios would confuse the clinician.

Neural Anastomoses

Not only can the course of the Median and Ulnar nerve be extraordinarily varied, but numerous anastomoses can exist between the two nerves to complicate matters. An understanding of the possible anastomoses is vital for understanding the innervation of the hand and correct evaluation of peripheral nerve lesions.

Martin Gruber Anastomosis (MGA)

The Martin Gruber Anastomosis (MGA) is perhaps the most well described anastomosis between the Median and Ulnar nerve. As it occurs in the forearm, the MGA will not be discussed in detail in this report. However, it is important to acknowledge its existence, as it can alter the innervation of the hand.

The MGA is formed in the forearm by an anastomosis between either the Anterior Interosseous Nerve or the main body of the Median nerve, to the Ulnar nerve [12, 13, 26, 45, 53, 70]. The nerve axons start in the proximal Median nerve and cross the forearm to join the distal Ulnar nerve [70]. This anastomosis often carries motor fibers and has been shown to alter the innervation of the hand [12, 20, 42]. For example, one study explicitly demonstrated it would variably innervate the first dorsal interosseous, the ADM and the Adductor Pollicis [42]. Reported prevalence varies from 10% - 39% [20, 26, 34, 38, 42, 45, 58, 67, 70].

The MGA is not the only anastomosis of note in the forearm; the Marinacii communication also exists. The Marinacci communication can be thought of as a reverse, rare MGA. It is a connection between the proximal Ulnar nerve and the distal Median nerve [43, 62, 70]. It has a prevalence of 1.3 - 4% [35, 48]. While rare, this anastomosis also deserves recognition. It was first proposed by Marinacci, who presented a case study of a patient with trauma to the Median nerve at the forearm. The patient had denervation of their forearm flexors, with preserved median innervation of the hand muscles [43].

Riche - Cannieu Anastomosis (RCA)

The Riches-Cannieu Anastomosis (RCA – figure 4) is a clinically significant anastomosis in the hand, formed between the RMN and the DBUN [12, 21, 27]. It is also known as the Thenar Ansa [27]. The RCA is a motor anastomosis, and facilitates the Ulnar nerve innervation of the thenar muscles [9, 11, 25, 69, 70]. It has a reported prevalence of 19 – 77% [2, 28, 57, 70]. Yang et al recently noted an incidence of bilateral RCAs in 31% of dissected hands, and a unilateral RCA in 38%. It is more common in the right hand (62%) than the left hand (28%) [70].

Knowledge of a potential RCA is vital when evaluating the innervation of the hand. For example Bolukbasi et al. reported a case where the RCA facilitated ulnar innervation of both the thenar and hypothenar muscles [9]. Another recent case report supported Bolukbasi's finding: Rovers et al. described a patient with atrophy of the thenar and first dorsal interosseous muscles of the hand due to compression of the ulnar nerve in the piso-hamate hiatus. They determined that this was due to a RCA, which was visible on an MRI [55]. It is highly likely that a RCA may help explain the 2% of hands that have ulnar innervation of both thenar and hypothenar muscles [56, 69].

It is also interesting to note that the innervation of the Superficial Head of the FPB by the Ulnar nerve occurs significantly more frequently in hands where a RCA was present; 78% compared to the 22% in those without the anastomosis [70].

Berrettini Anastomosis

The Berettini Anastomosis (BA) is a poorly discussed, though very common anatomical variation [61, 66]. While rarely discussed in the literature the anastomosis has been known since the 18th century, where it appeared in Berettini's anatomic drawings [18, 66]. The BA is a purely sensory anastomosis between the second palmar CDN (from the Median nerve) and the third palmar CDN (from the Ulnar nerve), resulting in alteration to the sensibility of the middle and ring finger [21, 61, 66]. Specifically it alters the innervation to the ulnar side of the middle finger and the radial side of the ring finger [61]. The BA is widely recognized as being extremely common, with a prevalence of 60 - 100% [21, 61, 66]. Some authors even suggested that it should be considered an anatomical constant, not variant, due to this [61, 66].

Ferrari and Gilbert classified the course of the BA into 4 main groups, as can be seen in figure 5 [21]. In Group 1 the distance between the origin of the anastomosis and the distal end of the TCL was more than 4mm. The BA typically took an oblique course, running from the proximal Ulnar nerve branch to the distal Median nerve branch. In Group 2 the distance before the origin of the BA and the distal end of the TCL was less than 4mm. Typically the BA branched off at the distal end of the TCL at a right angle, and ran parallel to the distal margin of the TCL. Group 3 BAs branched off below the distal margin of the TCL and traversed the palm at an acute angle to reach the second CDN at its distal

limit. Finally a BA belongs to Group 4 if it is atypical or plexiform. [21]. The incidence of each group is variable between studies, though Group 3 and Group 1 appear to be the most prevalent [21, 61, 66].

The BA is clinically significant. Due to its common and under recognized existence it is at significant risk of iatrogenic harm. When injured it produces an “uncomfortable tingling sensation or hyperesthesia” in the area of altered distribution [61].

Combinations of Anastomoses

Yang et al. observed the most common combinations of variations. In 10% of limbs dissected they found the coexistence of a contribution from the lateral cord of the brachial plexus to the proximal Ulnar nerve, a Berrettini anastomosis, a Riche-Canneiu communication and ulnar innervation of the Superficial Head of the FPB [70].

Kaplan Anastomosis

The Kaplan Anastomosis (KA) is not an anastomosis between the Median and Ulnar nerve; it is formed by a connection between the Dorsal Branch of the Ulnar nerve and “any level of the Ulnar nerve (main) in the palm.” Classically it joins the ulnar sensory nerves in the palm and has been found in 2 – 4% of hands [63]. Though rare in the literature, it has been described by numerous authors as passing around the pisiform bone before joining with the Ulnar nerve, placing the connection at risk if there is any surgery or trauma to this region [10, 50, 52, 63]. The connection lies subcutaneously and usually does not pass through Guyon’s canal [63]. A recent case study by Paraskevas et al however did demonstrate the KA passing through Guyon’s canal, implying its course is very variable [52].

Clinical Significance

An understanding of possible anastomoses is important for correct evaluation of peripheral nerve lesions. For example, a complete lesion of the Median nerve at the forearm might be interpreted as a partial lesion of said nerve in the presence of a MGA [9]. As discussed above Sachs et al found 4 out of 102 Median nerve transections spared all intrinsic hand muscles, including the Abductor Pollicis Brevis [57]. This clinical scenario could partially be accounted for by some of the anastomoses discussed here [23]. Additionally, Sraj et al described a patient who presented with paraesthesia resembling CTS, however Tinel and Phalen’s tests were negative. The patient did have clear signs of Ulnar nerve compression at the elbow, demonstrating the transfer of “sensitive nerve fascicles of the Ulnar nerve to the Median nerve” [60]. Some authors have called for anastomosis to be “excluded electrophysiologically before any surgical intervention” in patients with focal neuropathy [9].

The physical position of these connections is also important knowledge. Due to their variable pathways, and under-recognized existence many of these anatomic variations are prone to iatrogenic injury [62]

Conclusion

Like most of human anatomy the Median and Ulnar nerves are rarely consistent. They both display unusual branching patterns and pathways, variable innervation and occasional anastomoses like many other anatomical structures.

However these variations possess a unique clinical importance due to their possible effects on the hand, arguably one of the most important anatomical systems. If the reader has no knowledge of aberrant connections, innervation or possible anastomosis this complex system can never be correctly evaluated.

Conflict of Interest:

The authors declare that they have no conflict of interest.

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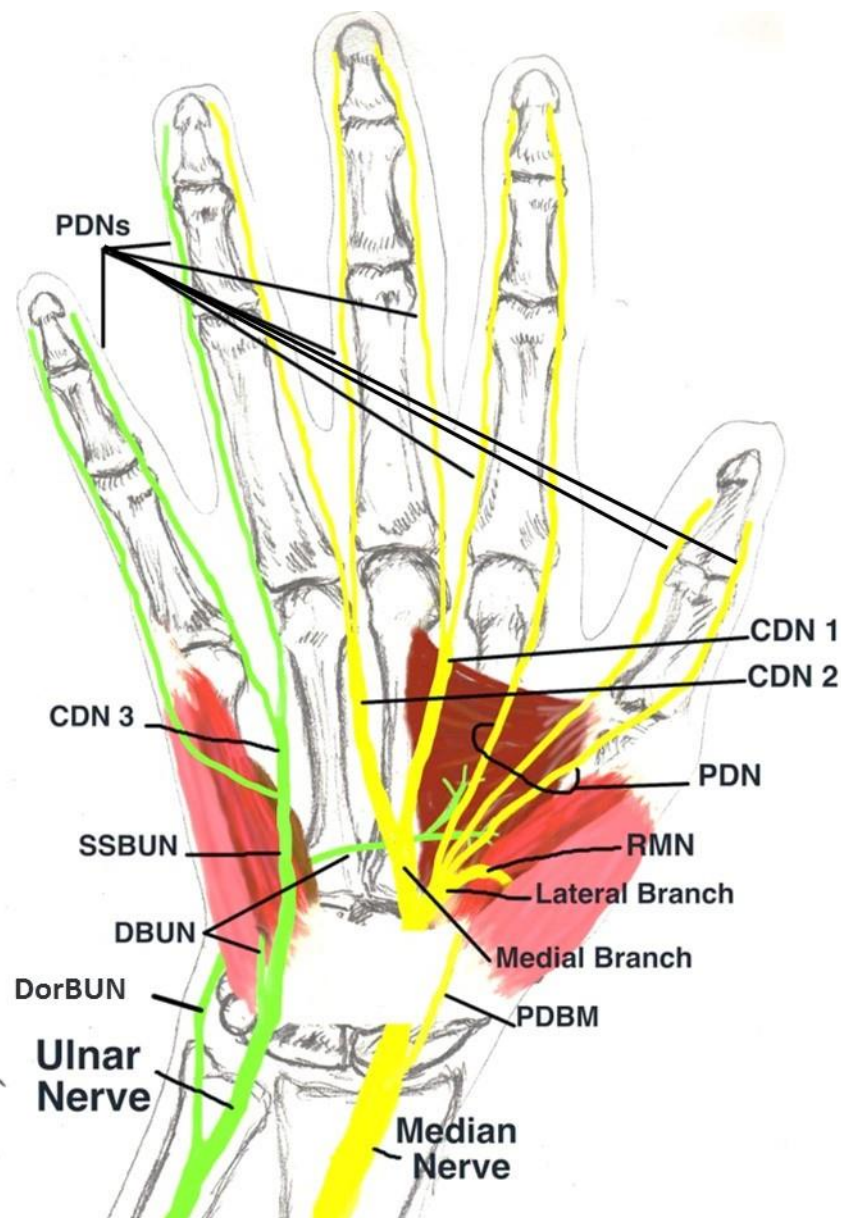
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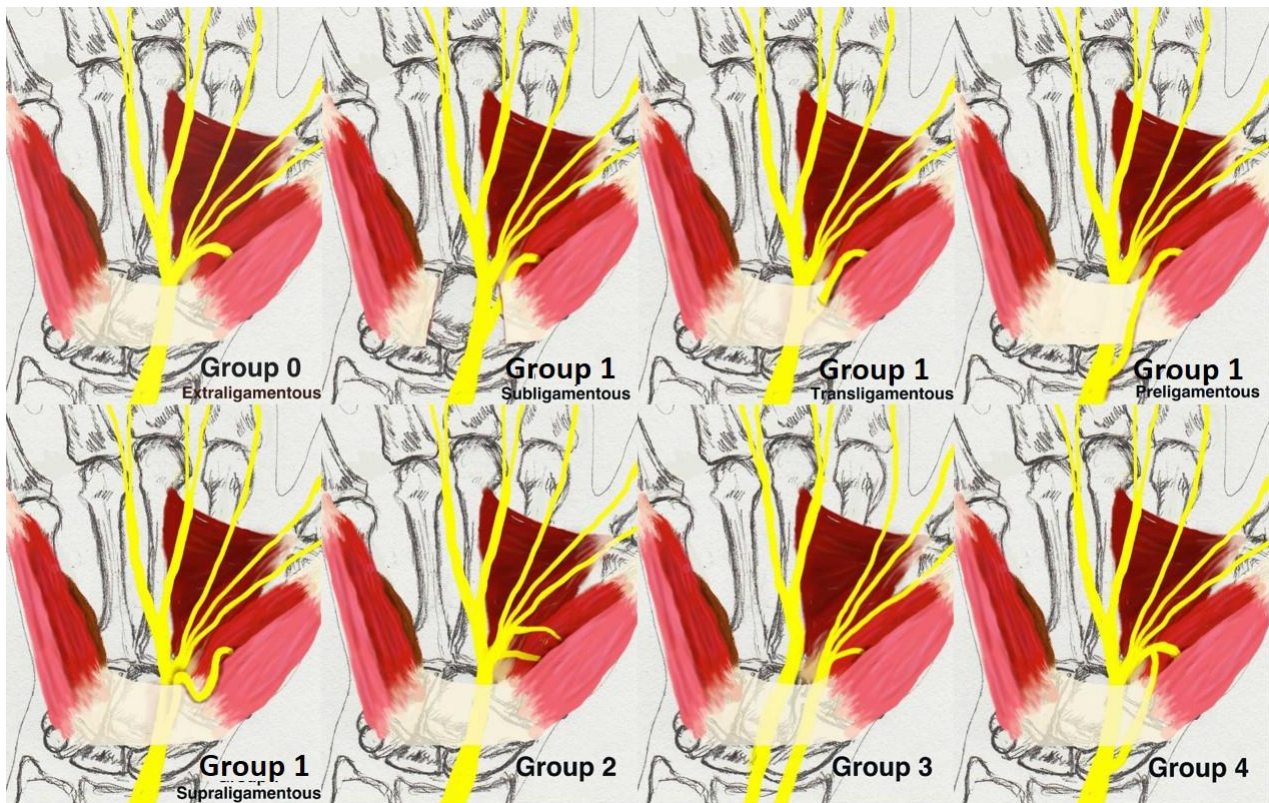
Figure Captions:

Fig 1 Normal Anatomy of the Median and Ulnar nerves



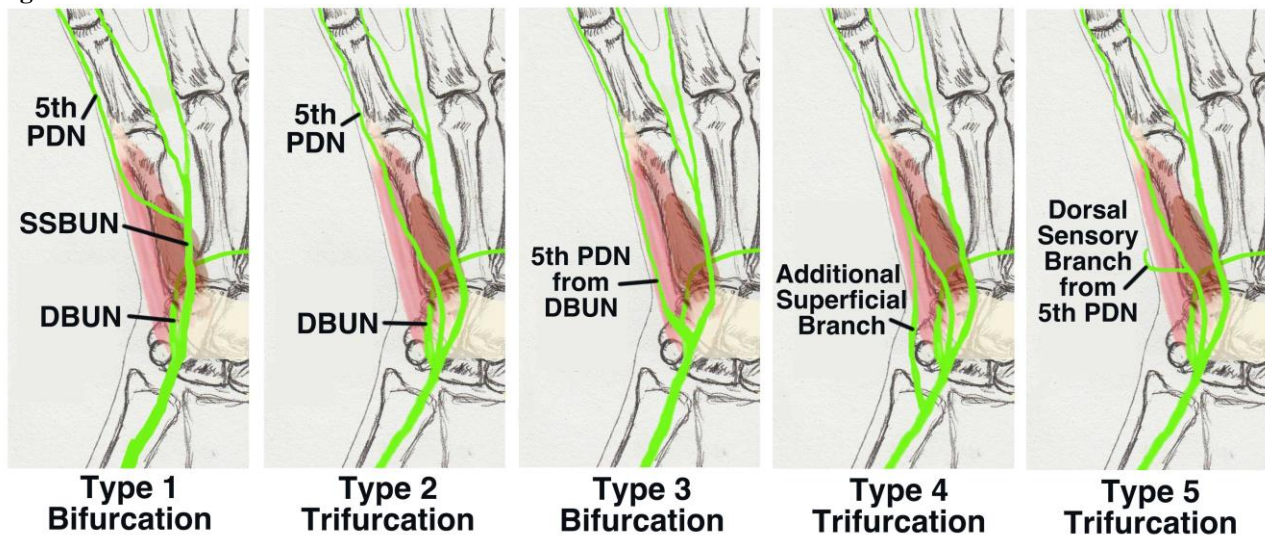
DorBUN – Dorsal branch of Ulnar nerve; DBUN – Deep Branch of Ulnar nerve; SSBUN – Superficial Sensory Branch of Ulnar Nerve; CDN – Common Digital Nerve; PDN – Proper Digital Nerve (Green – Ulnar & Yellow – Median); RMN – Recurrent median Nerve; PCBM – Palmar Cutaneous Branch of Median Nerve.

Fig 2 Median nerve Variations – Lanz Classification



The Lanz classification system concerns the branching of the main body of the Median nerve, and has 5 groups. It includes the previous Poisel classification system, which is concerned with the Recurrent Median nerve. Thus all Poisel classification groups either belong to Lanz Group 0 (Poisel extraligamentous) or Lanz Group 1 (Poisel Subligamentous, Transligamentous, Preligamentous and Supraligamentous). [29, 36, 54]

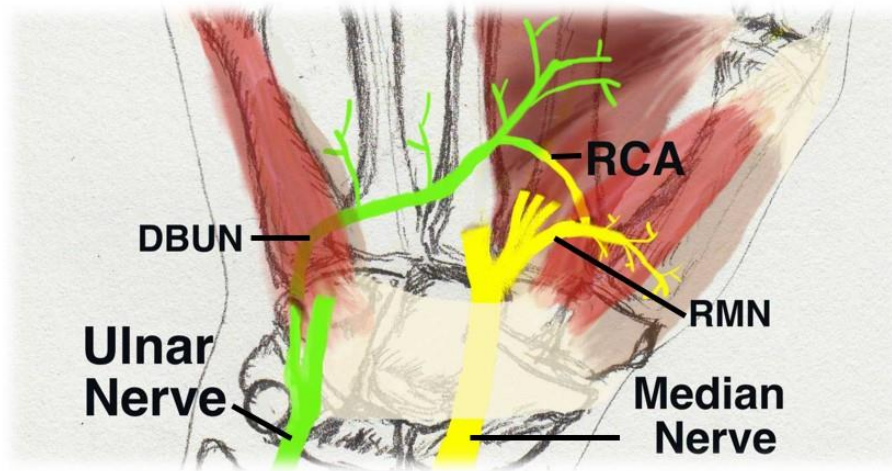
Fig 3 Murata Classification of the Ulnar nerve



Bonnell and Vila's classified the Ulnar nerve into Type 1 (Bifurcation into SSBUN and DBUN) or Type 2 (Trifurcation into DBUN, 3rd CDN and 5th PDN). Types 3 – 5 were latter added by Murata et al. Type 3 demonstrate a different pattern of bifurcation with 5th PDN branching from DBUN. Type 4 demonstrate trifurcation plus an additional communicating superficial branch. In Type 5 there is trifurcation with the DorBUN branching off distally, from the 5th PDN. [50]

SSBUN – Superficial Sensory Branch of Ulnar nerve; DBUN – Deep Branch of Ulnar nerve; CDN – Common Digital Nerve; PDN – Proper Digital nerve; DorBUN - Dorsal Sensory Branch of the Ulnar nerve;

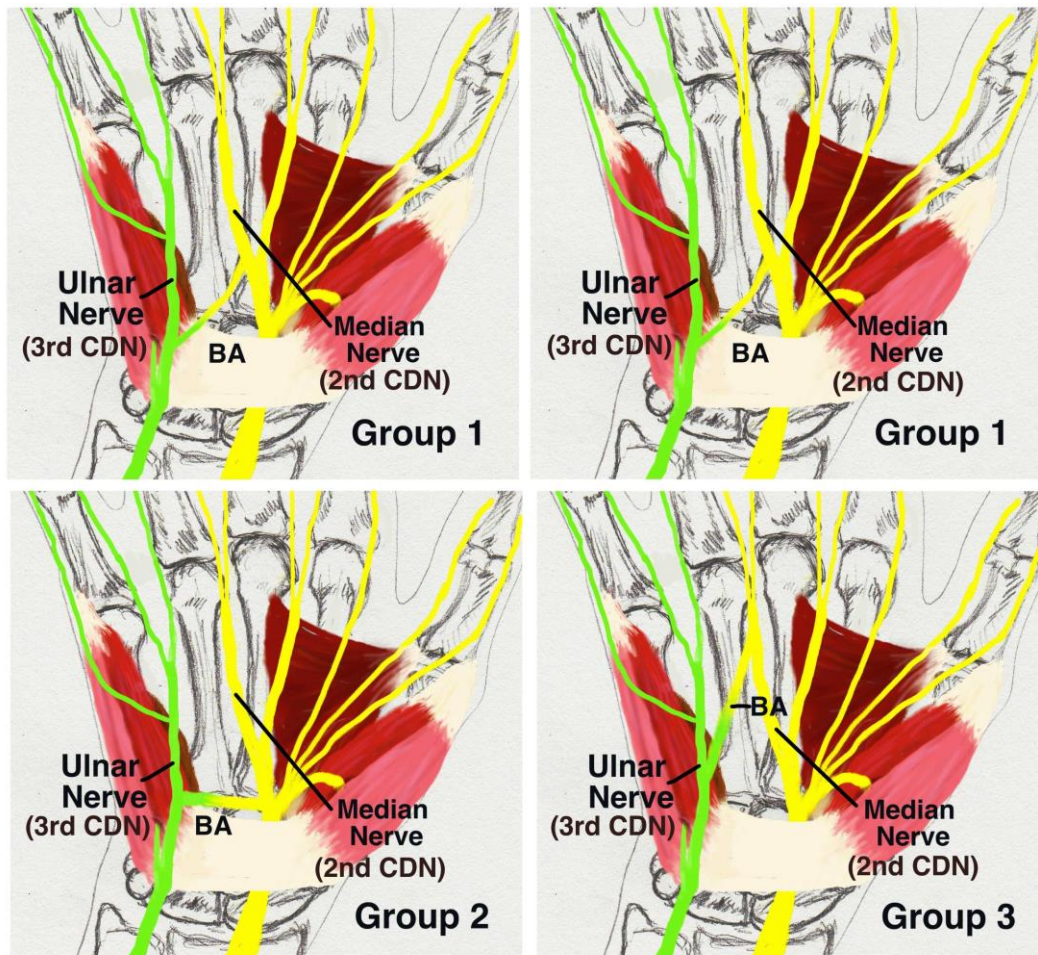
Fig 4 Riche-Cannieu Anastomosis



The Riche-Cannieu Anastomosis is a motor anastomosis between the RMN and the DBUN with a reported prevalence of 19 – 77%. [2, 28, 57, 70]

RCA - Riche-Cannieu Anastomosis; DorBUN – Dorsal Sensory Branch of Ulnar Nerve; RMN – Recurrent Median nerve

Fig 5 Variations of Berrettini Anastomosis



The Berrettini Anastomosis is a sensory anastomosis between the second and third palmar CDN i.e. between the Median and Ulnar nerve. It was classified by Ferrari and Gilbert into Groups 1 – 4, according to its branching pattern. [22, 62]

CDN – Common Digital Nerve

BA – Berrettini Anastomosis; CDN – Common Digital Nerve

Table 1 – Innervation of Thumb Muscles

Muscle	Function	Potential Innervation
Adductor Pollicis	Adduction of the thumb metacarpal, with extension of the interphalangeal joint [27]	Deep motor branch of the Ulnar Nerve (98%) [14, 27, 56] Median Nerve (2%) [27, 56] Dual innervation is possible though rare. [27, 56]
Abductor Pollicis Brevis	Abduction and flexion of the thumb metacarpal. Additional extension at the interphalangeal joint. It is a significant contributing muscle to the action of opposition. [27, 41]	Recurrent branch of the Median Nerve (95% - 100%) [2, 27, 39, 56] Ulnar Nerve (2.5%) [27, 39, 56] Dual median and ulnar innervation (2.5%) [27, 39, 56]
Flexor Pollicis Brevis	Its primary action is to flex the thumb at the MCPJ, along with extension of the distal phalanx and pronation of the metacarpal. [16, 27, 39]	Superficial Head: Recurrent branch of the Median Nerve (14% - 80%) [2, 7, 16] Ulnar Nerve (8% - 57%) [2, 7, 16] Dual median and ulnar innervation (23% - 68%) [2, 7, 16, 22] Deep Head: Median Nerve (9.5% - 13%) [7, 16] Ulnar Nerve (52% - 88%) [7, 16] Dual innervation (21% - 24%) [7, 16]
Opponens Pollicis	Initiates the movement of opposition by flexing and pronating the thumb metacarpal. It acts in conjunction with the APB to enhance opposition. [27, 31, 39]	Recurrent branch of the Median Nerve (80% - 83%) [2, 22, 56] Ulnar Nerve (9%) [2, 56] Dual median and ulnar innervation (7.5% - 20%) [2, 22, 56]

Table 2: Lumbrical Innervation

Lumbrical 1	Innervated by the Median Nerve, via the Radial Digital Nerve to the index finger [1, 37, 65]
Lumbrical 2	Innervated by the Median Nerve, via the CDN to the index and middle digits [37, 65] 5% innervated by DBUN [1]
Lumbrical 3	75% -100% innervated by the DBUN (via a single, separate branch) [37, 65] 2 - 25% innervated by the Median Nerve [1, 30, 33, 51, 65] 7% - 64% received dual innervation [1, 30]
Lumbrical 4	Innervated by the DBUN (via a single , separate branch) [1, 37, 65]

Table 3: Hypothenar muscle Innervation

Muscle	Function	Potential Innervation
Abductor Digiti Minimi	Primary function is small finger abduction, though it also contributes to metacarpophalangeal flexion and interphalangeal extension. [2]	Usually the Ulnar Nerve [2, 24, 56] Very rarely innervated solely by the Median Nerve.* [56]
Flexor Digiti Minimi	Primary function is metacarpophalangeal flexion with some contribution to abduction of the finger. [2]	Ulnar Nerve (85% - 100%) [2, 24, 53] Dual innervation by Ulnar and Median Nerves (15%) [2]
Opponens Digiti Minimi	Flexes and opposes the fifth metacarpal. No action on the metacarpophalangeal joint. [2]	Ulnar Nerve (88% - 100%) [2, 24, 53] Dual innervation by Ulnar and Median Nerves (12%) [2]

* Rowntree reported one case of a fully innervated hypothenar eminence, observed in a patient with an elbow ulnar nerve lesion. [56]