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# Neural entrapments associated with musculoskeletal anatomical variations of the upper limb: Literature review

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ABSTRACT

*Introduction:* In the upper there are different neural entrapment sites that can be associated with neighboring structures which in turn can mimic other neural entrapments syndromes. The objective of this study was to review the literature concerning neuromusculoskeletal anatomical variations in the upper limb and their possible clinical correlations with certain pathologies or syndromes.
*Methods:* A systematic literature search over different databases was used to examine the relationship between anatomical variations of neuromusculoskeletal structures and pathologies in the upper limb, using the search strategy proposed by the Cochrane Handbook for Systematic Reviews of Interventions.
*Results:* Analysis of the full text studies after the exclusion criteria had been applied showed that anatomical variations in the upper limb correlated in one third of the studies to nerve entrapment, such compressions frequently being attributable to some type of accessory muscle or variation in its insertion site. This demonstrates the importance of knowing the normal anatomy in order to investigate these structures and their possible variations, thus avoiding a non-specific differential diagnosis.
*Conclusions:* This literature review does not address a single type of anatomical variation but gives guidelines for considering different structures of the upper limb with anatomical variations that could predispose to some type of upper limb neural entrapment.

## 1. Introduction

The upper limb is characterized by its mobility and its ability to grasp, strike and perform fine motor actions. Its efficiency is largely due to the ability to place the hand in a controlled position in space. The muscles and joints of the shoulder girdle, shoulder, elbow, forearm and carpus contribute to this [1]. When there are functional alterations of the upper limb, deep knowledge of the neuromusculoskeletal anatomical structures is important for clinical reasoning towards a more detailed and accurate diagnosis [2] The most common of these anatomical variations are vascular, muscular and nervous ( [3–7]. Therefore, it is necessary to know the most common anatomical variants in the region. The purpose of this article is to review the most common anatomical variants in the upper limb and their clinical correlates.

### 1.1. Neuromusculoskeletal variants and their clinical correlates

As previously stated, there are many anatomical variants, and clinical consideration is not very frequent because access is complex and the costs of high definition imaging tests range between 500 and 4000 USD [8]. Also, there is no certainty about the significance of a variation for neuromusculoskeletal pathologies because there are so many variables in clinical reasoning models and their simplified approach [9].

Amongst the many muscles that are not commonly found in the upper limb, lies the chondroepitroclear muscle, which arises from the ventral edge of the pectoralis major muscle, the osteochondral junction of the fifth and sixth costal cartilage or the aponeurosis of the external oblique muscle, and is inserted into the medial intermuscular septum or

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the medial epicondyle after crossing the armpit and upper arm [10–12]. It appears as a very long and narrow slide applied closely to the inferolateral margin of the sternocostal head of the pectoralis major muscle. It curves away from the pectoralis major, takes an arcuate course while remaining tied to the axillary fascia, descends almost vertically distally along the medial aspect of the arm, and continues into an elongated thin tendon extending posteriorly to the ulnar nerve [13]. Therefore, its clinical relevance may be related to entrapment of the ulnar nerve as a possible result of compression by the abnormal muscle [14].

### 1.2. Anatomical variants of the elbow and the antebrachial region

Classically, more muscles have been described in this region than in the axillary and brachial regions: the anconeus epitrochlear (AE), Gantzer (GM), and variant palmar (APLM) muscles. They have potential implications in compression neuropathies.

The AE (anconeus epitrochlear or accessory anconeus) is a small aberrant muscle of the posteromedial aspect of the elbow that extends from the medial epicondyle to the olecranon with a transverse course. It takes exactly the same course as the ulnar tunnel retinaculum (Osborne ligament), suggesting it is superficial to the ulnar nerve [15,16]. The transverse planes through the ulnar tunnel seem particularly useful: (1) for evaluating the muscle and seeing that it is a separate entity from the adjacent medial head of the triceps and the ulnar head of the flexor carpi ulnaris; (2) for defining the relationships of the aberrant muscle to the underlying ulnar nerve; and (3) for assessing the state of the nerve. If there is a coexisting neuropathy, there is a definitive change in the cross-sectional area of the nerve between the EA and the proximal edge of the arcuate ligament [17].

The second anatomical variant in this region most often described in the literature is the Gantzer muscle (GM, or accessory head of the flexor pollicis longus). This is a very common muscle in the antebrachial region, generally presenting bilaterally; 75–85% of cases have their double or single proximal insertion in the medial epicondyle of the humerus, though it sometimes inserts proximally in the coronoid process of the ulna, or even more rarely in the flexor digitorum superficialis muscle (FDS); it inserts distally into the ulnar edge of the flexor pollicis longus muscle ( [18,19]. The GM is innervated by the anterior interosseous nerve, a branch of the median nerve, and its clinical relevance is precisely related to the median nerve and its anterior interosseous branch. There is possible involvement in compressive neuropathies, especially when the muscle is hypertrophied ( [20,21]. The belly of the GM can bridge the anterior interosseous nerve, either anterior or posterior to that nerve, possibly predisposing it to local entrapment [20,22].

Finally, we find the abnormal palmaris longus muscle (APLM), a vestigial flexor muscle of the wrist (absent in 11.2% of the population), which can be considered one of the most variable muscles in the forearm with a 9% overall incidence of abnormalities [23]. The muscle belly is centrally located between the proximal and distal tendons (digastric variant) or even distally. When located distally, the muscle has a long proximal tendon, an appearance that resembles an “inverted palmar” (reverse palmaris). The APLM can also be bi-penniform. If the APLM is inverted, there is excess muscle tissue immediately superficial to the FDS and the flexor retinaculum, which contains among other structures the median nerve. This can cause dynamic compression of the median nerve related to effort during muscle contraction [24].

### 1.3. Anatomical variants of the wrist and hand

The wrist and hand muscles with variants most often mentioned in the literature are the accessory abductor digiti minimi (AADM), accessory flexor digitorum superficialis indicis (AFDS), palmaris profundus (PP), and extensor digitorum brevis manus (EDBM) muscles.

The AADM is the most common abnormal wrist muscle with a reported prevalence ranging from 24% to 47% [23,25,26]. It is inserted proximally in the antebrachial fascia or less commonly in the tendon of the palmaris longus muscle. Distally, it is commonly inserted in the abductor digiti minimi muscle, but there are cases where it has been inserted into the ulnar edge of the base of the proximal phalanx of the fifth finger [19]. Because this muscle is superficial to the ulnar nerve, described as a fleshy band that forms the roof of the Guyón tunnel anterior to the neurovascular ulnar bundle, it can compress it against the floor-hamate ligament during its contraction, generating an ulnar neuropathy or Syndrome of the Guyón tunnel [26–30].

The second wrist and hand muscle commonly described in the literature is the accessory flexor digitorum superficialis indicis muscle (AFDS). It generally has a normal origin and insertion, except in the index finger, where an accessory muscular belly accompanies or replaces the respective tendon. However, several variants of the AFDS have been reported, including: (1) a muscular belly located entirely within the palm and replacing the normal tendon; (2) a digastric muscle with a belly located proximally in the forearm and the other in the palm; and (3) a muscular belly located within the forearm and extending to but not beyond the carpal tunnel [23,31,32]. In the palm, the AFDS is normally inserted in the index finger in the region of pulley A1. A1 pulley is the first of 5 annular pulleys numbered from proximal to distal that are fibrous tissue condensations which wrap around the flexor tendons of the retinacular portion of the tendon sheath. Its insertion is described occurring at the palmaris ligament in the 1st metacarpophalangeal joint. This pulley is one of the more flexible ones, hence it allows for compression during flexion without impinging on the tendons. In this way both, the retinacular and membranous portions of the sheath act to prevent bowstringing of the tendons and allow the transfer of the necessary forces for pinch and grasp [33]. But given the common insertion point between A1 pulley and the AFDS, its repetitive contraction could generate discomfort during movements of the index finger. During wrist and finger movements the accessory muscle enters the carpal tunnel during extension and exits it during flexion of the index finger, which could contribute to or generate medial nerve neuropathy and/or flexor tenosynovitis [5,34].

The next muscle described is the palmaris profundus (PP), a rare but known anatomical variant of the anterior wrist region, innervated by the anterior interosseous nerve. It has been classified into three main subtypes on the basis of its proximal insertion: the proximal or middle third of the radius (type 1), the superficial flexor digitorum fascia (SDF) (type 2), or the distal ulna (type 3). In most cases the PP emits a distal tendon that passes under the flexor retinaculum, and after traversing the carpal tunnel it joins the deep surface of the distal retinaculum or the palmar fascia. In some cases, the PP nerve and tendon share the same tendon sheath, or the nerve even penetrates the sheath and divides it at the wrist level. Owing to the intimate relationship between the PP tendon and the median nerve it is possible to compress the latter, generating symptoms of a compressive neuropathy [23,35].

The final muscle most often mentioned in the scientific literature is the extensor digitorum brevis (EDBM), an accessory muscle of the back of the hand found among 1–3% of the population [36,37]. Its proximal insertion is the dorsal surface of the wrist capsule and its distal insertion is the extensor retinaculum of the second or third finger through a tendon or a sheet of connective tissue. It is innervated by the posterior interosseous nerve. It can be seen as a fusiform lump located next to the extensor tendons of the index finger. This can be misinterpreted as compartment IV dorsal ganglion tenosynovitis, a benign soft tissue tumor, or a carpal lump. It is usually asymptomatic but can be associated with exercise-induced pain or tenosynovitis, and actively resisted extension of the fingers results in increased firmness of the mass; this sign suggests the correct diagnosis [38,39].

## 2. Materials and methods

This review of the literature considered specific scientific articles and human anatomy books written in Spanish or English, published between 2000 and 2019.

Electronic databases were searched systematically to compile the available literature on the subject, taking as reference the Cochrane Handbook for Systematic Reviews of Interventions [40]. The following databases were searched: Medline (Via pubmed), SCIELO, SPORT DISCUS, CINHAL, SCOPUS and GOOGLE SCHOLAR up to Jaunary 15, 2019, using as search terms "Upper extremity", "Pathologies upper extremity" and "anatomy sciences", for which the following boolean connectors "AND", "OR" and "NOT" were used. The search algorithm is shown in Fig. 1. Letters to the editor, bibliographic reviews and articles of gray literature were excluded [40].

## 3. Results

In the first instance, two researchers dedicated themselves to reading the titles and summaries of the articles filtered by the search in order to define the line of research and the relevance of the topics to be discussed. Subsequently, a third researcher reviewed the full texts of the articles filtered by those first two authors. That yielded a total of 57 articles, which were reviewed in full text, verifying that they met the inclusion criteria. After the reading and analysis, a total of 27 articles were included in this literature review identifying upper limb pathologies associated with anatomical variations. These scientific articles were published in English or Spanish between 2005 and 2020. Review of them revealed that 16 compared anatomical variations in different regions of the upper limb with nerve compression pathologies associated with some types of anatomical variation of skeletal muscles. Nineteen of the filtered studies described associations between anatomical variations of the upper limb and nerve compression, leading to a previously mentioned pathology. In a smaller number of studies, specific variations were identified that produced articular or muscular alterations in the same structure or neighboring structures. The anatomical variations in most cases were associated with pathological involvement in early adulthood, very few presenting an anatomical variation in which some pathology during childhood or adolescence had been studied.

### 3.1. Nerve compression of the upper limb associated with anatomical variations

The brachial plexus is an extensive network of nerves that emerge through the thoracic operculum towards the upper limb. Compression of either roots, trunks or terminal nerves is always associated with a neighboring structure not belonging to the nervous system. Brachialgia is associated with repetitive loading or uncomfortable positions of the upper limb that produce changes in structures of the skeletal muscle system and sometimes cause nerve injuries, which is common in incidences of upper limb pathologies [41].

The studies analyzed in this review reported that the vast majority of pathologies associated with anatomical variations of the upper limb were entrapments of the terminal nerves of the brachial plexus. Of which twenty seven of them reported neural entrapment, distributed as follows: 1 of the studies showed compression of the musculocutaneous nerve [42]; 1 showed compression of the axillary nerve [42] 4 showed compression of the radial nerve [42–45]; 6 showed compression of the ulnar nerve [26,42,46–49]; 12 studies showed compression of the median nerve [5, 23, 35, 45, 47, 50–57]; only one study showed compression of the axillary nerve [42]; and finally 2 studies showed other nerve root/trunks structures entrapments [45, 58] (Table 1).

### 3.2. Musculocutaneous nerve compression

The musculocutaneous nerve (MN) runs through the axillary fossa and the anterior and medial aspects of the forearm. Classically, compression of the MN is identified when it passes through the coracobrachialis muscle, or is associated with some injury to the short head of the biceps brachii muscle [59]. The only study regarding MN nerve compression associated with a musculoskeletal variation reported an accessory head of the biceps brachii muscle, which produced nerve compression causing pain and paresthesias in the medial area of the arm. The findings were in an adult male cadaver. Although anatomical variations of the biceps brachii muscle are frequent, it is rare to see four heads, or for them to be associated with some type of nerve compression [42].

### 3.3. Radial nerve compression

The radial nerve (RN) runs through the posterior region of the arm and forearm innervating the muscles of the same region. The classical pathomechanics of RN injury is fracture of the humerus, causing neuropraxia as the RN passes through its groove on the posterior aspect of the humerus. However, in this location, the nerve is actually separated from the bone by the lateral intermuscular septum (LIS) of the arm. An intermuscular septum is described as a "deep intermuscular fascia" located deep to the deep peripheral fascia and separating muscles and muscle groups from each other. Deep to the muscles the deep intermuscular fascia is in continuity with the periosteum [60]. The LIS inserts proximally in the intertubercular sulcus of the humerus and unites with the posterior edge of the deltoid tendon. Distally it inserts along the whole length of the lateral edge of the humerus as far as the lateral epicondyle. The LIS separates the radial nerve by 1–5 cm specifically from the deltoid tuberosity of the humerus [61, 62]. Therefore, lesions of the RN in the distal third of the arm could have more to do with the fracture pattern than the proximity of the nerve to the bone [63]. Another way in which the RN can be associated with an anatomical variation of a surrounding musculoskeletal structure is the presence of an extensor carpi radialis longus muscle with its proximal origin in the supracondylar crest lateral to the humerus, presenting three heads: lateral, intermediate and medial. The lateral and intermediate heads are fused and their distal insertion is at the base of the second metacarpal bone. However, the medial head of the extensor carpi radialis longus (ECRL) is fused with the extensor carpi radialis brevis muscle (ECRB). The possible region of entrapment of the RN under the proximal insertion of the medial head of the ECRL muscle and its fusion with the ECRB is an important consideration in diagnosing and treating compression in the lateral epicondyle of the humerus [64, 65, 66]. Another anatomical variation associated with compression of the RN is the variation of four bellies of the biceps brachii muscle (Fig. 2). This variation occurs because the RN is compressed under the belly, which has a medial and posterior disposition, narrowing the space under the greater tubercle of the humerus and the aforementioned muscle. The possible symptoms were not described [42]. Moreover, another anatomical variation entails a correlation between the accessory pronator teres muscle and compression of the RN. This occurs in the lateral and distal part of the pronator teres muscle in its accessory belly, which projects towards the radial and posterior region of the forearm, producing sustained compression of the RN. No specific symptoms were reported [44]. Finally, the Axillary Arch (AA) which is most commonly a muscle (55,1% of the cases) that runs in most of the cases from the latissimus dorsi (LD) muscle to the pectoralis major (muscle or fascia) (35%) followed by the coracoid process (19.8%). Hence, the AA may run close by and compress neural and vascular structures present in the axilla while being stretched, and potentially compressing the radial nerve [45].

### 3.4. Compression of the median nerve

The median nerve innervates the muscles of the superficial plane of the anterior compartment of the forearm. Along its path in the arm and forearm it produces a series of motor branches for the different muscles. Along its route it also presents several compression sites, described

**Table 1**
Nerve entrapment and its correlations with anatomical variations in the upper extremity.

| Nerve | Anatomical Variation | Clinical presentation | Author |
|---|---|---|---|
| Median Nerve | Insertions of the Gantzer muscle in the flexor digitorum superficialis | Carpal tunnel syndrome. | Zdilla et al., 2019 |
| | and the braquialis fascia. | Flexor paralysis of the arm or sensory | Raza et al., 2018 |
| | Anomalous Innervation of the median nerve in the arm in the absence | loss in the lateral forearm. | Riveros et al., 2018 |
| | of the musculocutaneous nerve. | Nerve entrapment syndromes of the | Martinoli et al., 2010 |
| | Origin of the anterior interosseous nerve in the space between the arc | anterior interosseous nerve. | Sookur et al., 2008 |
| | of the flexor digitorum superficialis and the teres pronator and | Median or anterior interosseous nerve | Pirola et al., 2009 |
| | proximal to this point. | entrapment. | Silawal et al., 2018 |
| | Gantzer muscle. | Median nerve entrapment | Olewnik et al., 2017 |
| | Accessory brachialis muscle. | Neuropathy of the median nerve | Mizia et al., 2020 |
| | Palmaris profundus muscle. | Carpal tunnel syndrome | Roy et al., 2015 |
| | A biventered first lumbrical extending into the carpal tunnel combined | Median nerve entrapment | Taterra et al., 2019 |
| | with bilateral fifth superficial flexor digitorum tendon regression. | Median nerve entrapment | Symeonides., 1972 |
| | Pronator teres distal insertions. | Median or anterior interosseus nerve | |
| | Struthers' ligament | entrapment | |
| | Gantzer muscle | Median nerve entrapment | |
| | Axillary Arch | Median nerve entrapment | |
| | Supracondylar Process | | |
| Radial Nerve | Accessory head of the extensor carpi radialis longus muscle merging | Radial syndrome and epicondylalgia. | Yang et al., 2018 |
| | with the extensor carpi radialis brevis muscle. | Waterberg syndrome. | Kumar et al., 2017 |
| | Aberrant course of superficial radial nerve in the forearm that | Radial Nerve entrapment | Moore et al., 2018 |
| | perforates the brachioradialis tendon to become subcutaneous. | Radial nerve entrapment | Taterra et al., 2019 |
| | Muscular elevator of the latissimus dorsi tendon. | | |
| | Axillary Arch | | |
| Musculocutaneous Nerve | Four-headed biceps brachii. | Musculocutaneous nerve entrapment | Moore et al., 2018 |
| Ulnar Nerve | Epitrochlear anconeus. | Ulnar nerve entrapment. | Bladt et al., 2009 |
| | Accessory Abductor Digiti Minimi. | Compressive neuropathy of the ulnar | Harvie et al., 2004 |
| | Epitrochlear anconeus. | nerve. | Erdem Bagatur et al., |
| | Accessory extensor digitorum brevis. | Ulnar nerve entrapment. | 2016 |
| | Accessory abductor minimidigitimanus muscle. | Guyon tunnel syndrome | Moore et al., 2018 |
| | Accessory belly of the flexor digitiminimi. | Guyon tunnel syndrome | Ahmadreza et al., 2015 |
| | | Ulnar nerve entrapment | Ardouin et al., 2015 |
| Axillary Nerve | Muscular elevator of the latissimus dorsi tendon | Axillary nerve entrapment | Moore et al., 2018 |
| Other nerve root/trunks structures | Cervical Rib | Thoracic Outlet Syndrome | Henry et al., 2018 |
| entrapments | Axillary Arch | Thoracic Outlet Syndrome | Taterra et al., 2019 |

clinically and with a high incidence of pathologies [67]. Median nerve compressions are associated with different compression points in the upper limb, the most common being compression by the pronator teres muscle in the proximal distribution of the nerve, while in its distal distribution the most common pathology is carpal tunnel syndrome [52]. The different anatomical variations revealed by our search to be associated with some type of compression of the median nerve are detailed below.

The first of these anatomical variations was the accessory belly of the flexor pollicis longus, also described in the literature as the Gantzer muscle. The GM can cause a compressive neuropathy that affects the anterior interosseous nerve, a branch of the median nerve, also called Kiloh-Nevin syndrome; the main clinical presentation is carpal tunnel syndrome [5,18, 50, 68].

The second anatomical variation concerned the distribution of innervation by the median nerve, in which as well as innervating muscles of the forearm it innervates the coracobrachial muscle in the absence of the MN. This variation was described only in a cadaver and the belly of the coracobrachial muscle was implicated, which could not show symptoms since it was a cadaveric study [51].

The third variation was in the origin of the anterior interosseous branch of the median nerve in the arch formed in the proximal insertion of the superficial flexor digitorum and pronator muscles. This generates a type of entrapment of the nerve in its passage through this area. There are very few reports of this variation and even fewer are associated with the clinic, but there is always a clinical and anatomical relationship to consider [67].

The fourth anatomical variation associated with compression of the median nerve is the accessory brachial muscle. The brachial muscle arises from the anterior surface of the lower half of the axis of the humerus and inserts into the tuberosity of the ulna and the adjacent surface of the coronoid process. An accessory brachial muscle originates from the medial axis of the humerus and the medial intermuscular septum, with distal attachment to the common tendon of the muscles of the antebrachial flexor compartment. The accessory brachial muscle runs medial to the elbow and crosses the median nerve and brachial artery. The distal tendon can divide and enclose the median nerve, which can cause symptoms of compression of that nerve in its proximal territory [23].

The fifth variation in the selected studies was the presence of an accessory muscle called the palmaris profundus (PP). The PP runs under the pronator teres muscle, parallel and lateral to the flexor digitorum superficialis. Distally, the PP muscle tendon runs under the flexor retinaculum accompanied by the median nerve, where its possible compression is associated. Anatomical variations of the muscles in the flexor compartment of the forearm can have functional, diagnostic, and surgical implications in the management of median nerve compressions [35].

The sixth variation was an accessory belly of the first lumbrical with disposition towards the carpal tunnel. The lumbrical muscle variations that extend into the carpal tunnel, especially those associated with auxiliary tendons such as the flexor pollicis longus, have significant clinical relevance owing to their association with carpal tunnel syndrome and consequently compression of the median nerve. All of the above can influence the diagnosis, treatment and recovery of the aforementioned pathology [53].

The seventh variation affecting the median nerve was the compression in the distal insertion of the pronator teres muscle presenting two heads, which are pierced by the median nerve, producing compression in the distal insertion of the aforementioned muscle. This could generate symptoms in the area of the ulnar fossa or in the carpal tunnel region [54].

Finally, three other structures were found to be implicated with the median nerve entrapment. The Struthers' ligament, a fibrous band that could compress the median nerve at the medial aspect of the elbow, found in 0,3 to 2,7% [55, 57]. The AA was also found to be potentially related to the median nerve compression in the axillar region or fossa by its over stretching [45]. And finally, the last anatomical variation found to compress the median nerve was the supracondylar process of the humerus which is a rare congenital abnormality that frequently manifest symptoms of compression of the median nerve [57].

### 3.5. Compression of the ulnar nerve

The ulnar nerve leaves few innervations in its route through the forearm, its most abundant innervation being the hypothenar region of the hand. The most frequent locations of compression of the ulnar nerve are: at the elbow, in the cubital tunnel, and at the level of the wrist in the Guyón canal [69]. The anatomical variations associated with compression of the ulnar nerve revealed in our search were as follows. The first variation was the accessory muscle called the extensor digitorum brevis muscle, which was reported to generate compression in the medial part of the fifth metacarpal producing referred symptoms in the region of innervation of the ulnar nerve in the hand, or also symptoms associated with the Guyón channel [42]. The second anatomical variation was the appearance of an accessory abductor digiti minimi muscle, which caused alterations in the ulnar nerve region or characteristic symptoms similar to Guyón canal syndrome [18,28]. The third variation was an abdominal variant fascicle of the flexor digiti minimi brevis, which produced compression in the medial region of the fifth metacarpophalangeal joint causing compressive pathology of the ulnar nerve and generating symptoms in its innervation region [48,50]. Finally, the fourth anatomical variation associated with compression of the ulnar nerve is the anconeus epitrochlearis muscle, which is a common anatomical variation with a prevalence of up to 34%; however, clinical diagnosis of ulnar neuropathy of the elbow as a result of this variation is rare. Where the ulnar nerve is compressed as it passes through the epitrochlear region, this anatomical variation has unknown prevalence; but it has to be considered in clinical reasoning [46,47].

### 3.6. Axillary nerve compression

The axillary nerve is one of the shorter terminal nerves of the brachial plexus in the upper limb. Therefore, it is less likely to present any type of compression, since its path is shorter and has fewer sites of possible compression. Compared to the previous conditions, our search revealed only one study indicating a relationship between compression of the axillary nerve and a neighboring anatomical variation. The variation was an accessory tendon in the proximal insertion of the latissimus dorsi muscle, which produced compression in the axillary fossa. No specific symptoms for this clinical condition were reported [42].

### 3.7. Nerve root/trunks entrapments

Another anatomical variation regarding nervous structures entrapments was the Cervical Rib (CR) which is a supernumerary rib that arises from the seventh cervical vertebra and is believed to be resultant from mutations in Hox genes [70, 71]. CR can terminate freely in soft tissue or can have a fused terminal end with the first rib [70,71]. Thoracic outlet syndrome (TOS) develops from neural and/or vascular compression of the structures passing through the interscalene triangle, which is bordered by the anterior scalene muscle anteriorly, middle scalene muscle posteriorly, and superior surface of the first rib inferiorly [72,73]. Therefore, a CR, can further constrict the boundaries of the interscalene triangle and result in neurovascular compression and TOS. On one study, 51.3% of the symptomatic patients with CR had vascular TOS, and 48.7% had neurogenic TOS [59]. Another cause of TOS can be the over stretching of the AA that can compress the brachial plexus fascicles due to its proximity with the brachial plexus structures in the axilla region [45].

## 4. Discussion

Although most clinical and anatomical studies that analyze nerve compression pathologies present a characteristic epidemiology or population distribution strongly associated with acute or chronic traumatic pathology, this can be decisive in clinical evaluation to reach to a correct diagnosis and consequently a correct treatment. Although many patients are assertively treated on the basis of this principle of evaluation and treatment, there will always be a few patients who do not respond well to that approach, so new treatments or new possibilities of evaluation and diagnosis for treatment should be considered. Therefore, knowing all the possible options will leave a range of evaluation possibilities and conditioning factors that could cause the injury, from which the anatomical variations of structures surrounding the different nerve branches of the upper limb appear. On that basis, the development of our literature review revealed no other reviews addressing the incidences of different anatomical variations that can produce compression of any nerve in the upper limb.

It should also be considered that there are anatomical variations that alter the path of the upper limb nerves which could be related to compressions with neighboring structures. In a recent study variations were found regarding the path of the thenar motor branch of the median nerve at the level of the carpal tunnel, which is responsible of innervating the muscles of the thenar region once the median nerve passes the transverse carpal ligament. They found that the most common course is the extraligamentous type, so it should be taken into consideration in surgical procedures at the level of the carpal tunnel [72,73].

Nerve anastomoses are also present in the upper limb, most commonly between the ulnar and median nerve, which can be found in:

(I) the cubital fossa from the main trunk of the median nerve or from 1 of its branches to the forearm flexors, especially the anterior interosseous nerve crosses superficial to the FDP before joining to the ulnar nerve.
(II) in the distal forearm as an infrequently reported neural interconnection between the ulnar and the median nerve.
(III) as a palmar anastomosis between the recurrent branch of the median nerve and the deep branch of the ulnar nerve, leading to complete innervation of the thenar muscles by the ulnar nerve.
(IV) or a communication in the palmar surface of the hand at the level of the third commissure known as the ramus communicans cum nervi ulnari, which is a neural connection between the common digital nerves arising from median and ulnar nerve.

All of the above can be involved in the exacerbation or diminishing of neural entrapment symptoms [68].

While we were carrying out this review, we found a large number of studies reporting anatomical variations that cause compression of different nerves in the upper limb, indicating that anatomical variations in the upper limb can be of diagnostic value, or provide alternatives to considering the different pathologies of nerve compression of the upper limb [42].

## 5. Conclusion

The scientific and clinical data supported the view that anatomical musculoskeletal variations of structures surrounding the nerves of the upper limb can produce nerve compression and consequent clinical presentations. This indicates that knowing the normal anatomy and the possible anatomical variations that could be present provides a good guideline for the differential and clinical diagnosis of patients with nerve compression pathology.

## Ethical approval

Ethics approval was not needed because the data used for this literature review had been obtained from individual trials contributing primary data for descriptive analysis. There were no concerns about the privacy of patients because all data was fully anonymized prior to being imported into our database.

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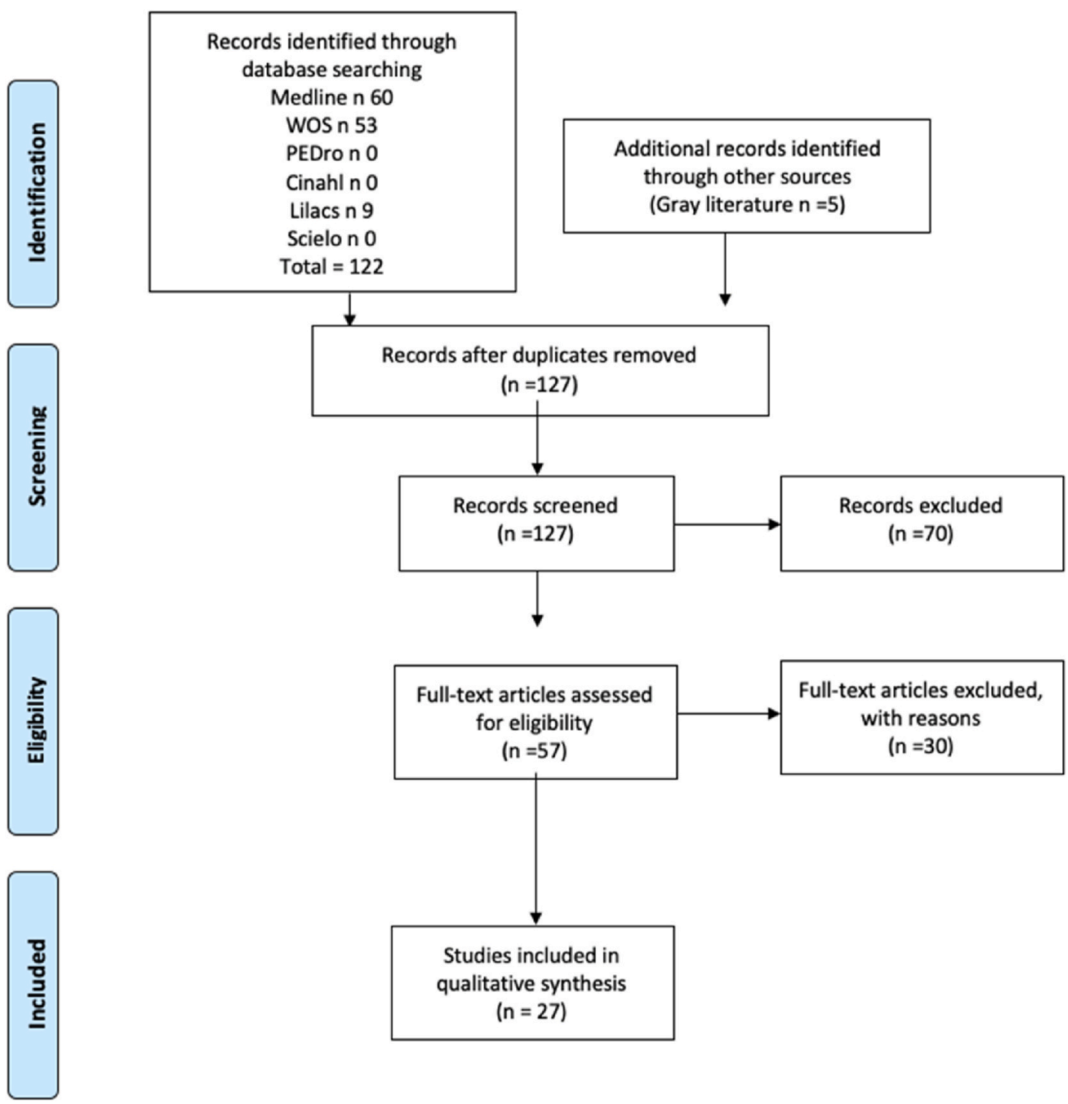
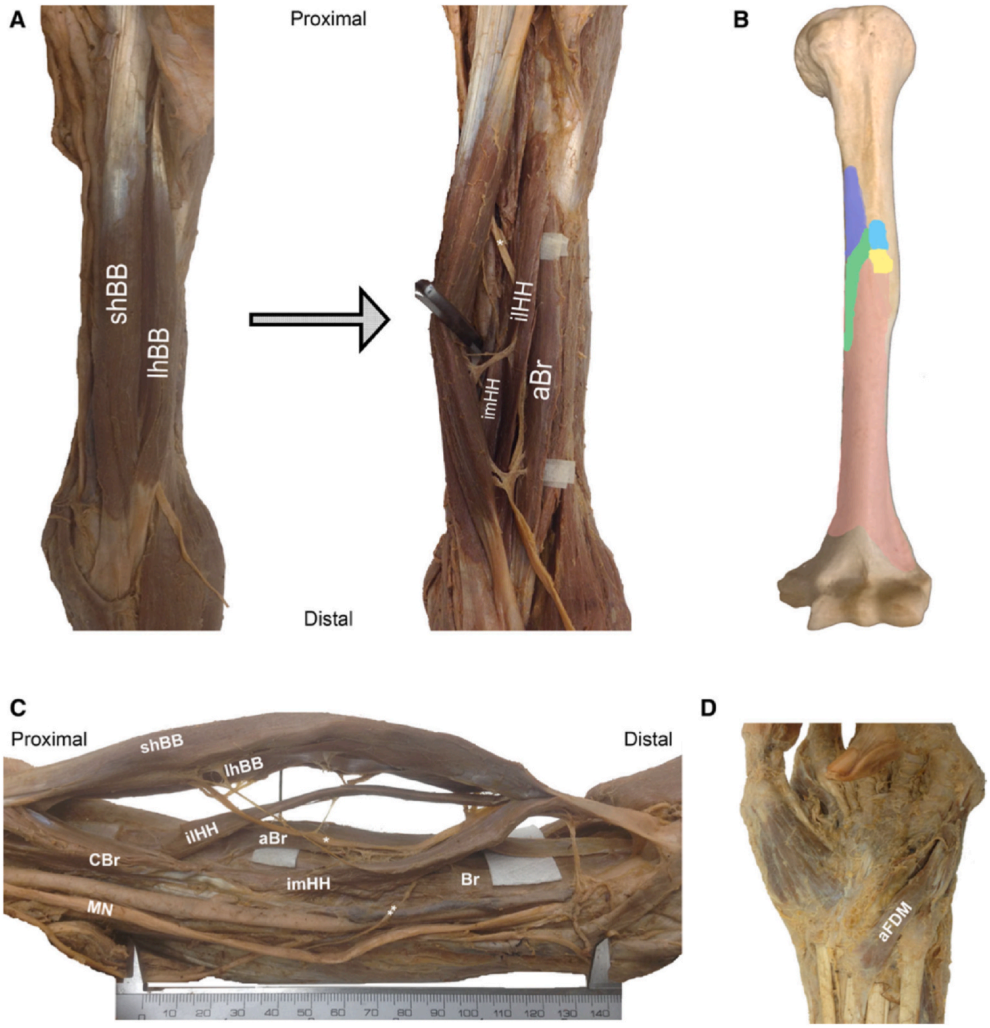
## Appendices




**dfig1.** Search algorithm.




**dfig2.** Cadaveric upper limb depicting the four-headed biceps brachii and other variant musculature identified in the arm and hand. a Reflection of the short (shBB) and long (lhBB) heads of the biceps brachii exposing the infero-medial (imHH) and infero-lateral (ilHH) humeral heads of the biceps brachii and the accessory brachialis (aBr). b Spatial relationships of the variant musculature (aBr yellow, imHH green, ilHH light blue) with respect to the brachialis origin (Br pink) and coracobrachialis insertion (cBr dark blue). c Variant innervation pattern consisting of a communication branch (**) between the median (MN) and musculocutaneous (*) nerves. d Accessory flexor digiti minimi brevis (aFDM) located in the palm (color figure online). Reprinted by permission from Springer [John Wiley & Sons, Inc.]: [Anatomical Science International] [Moore C., Rice C. Rare muscular variations identified in a single cadaveric upper limb: a four-headed biceps brachii and muscular elevator of the latissimus dorsi tendon. Anat Sci Int. 2018, Vol 3 16; 4 (21). (Rare Muscular Variations Identified in a Single Cadaveric Upper Limb: A Four-Headed Biceps Brachii and Muscular Elevator of the Latissimus Dorsi Tendon, Moore et al., [Springer] (2018), advance online publication, July 6, 2017 (https://doi.org/10.1007/s12565-017-0408-8 [Anat Sci Int.].).

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