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GENEESKUNDE EN LEVENSWETENSCHAPPEN

master in de biomedische wetenschappen: klinische moleculaire wetenschappen

Masterproef

Minimally invasive decompression as treatment for the cubital tunnel syndrome: anatomical guidelines and surgical outcome evaluation

Promotor :
Prof. Dr. Frank WEYNS
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Masterproef voorgedragen tot het bekomen van de graad van master in de biomedische wetenschappen , afstudeerrichting klinische moleculaire wetenschappen

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ABBREVIATIONS

CubTS	cubital tunnel syndrome
MACN	medial antebrachial cutaneous nerve
AT	anterior transposition
SD	simple decompression
MID	minimally invasive decompression

ABSTRACT

Introduction: The cubital tunnel syndrome (CubTS) is the most common ulnar nerve compression neuropathy at the elbow and is a major disability in daily life. The simple decompression (SD) procedure has become more popular as surgical treatment because of its effectiveness and low invasive character. In order to increase the wellbeing of the patients, minimally invasive approaches of the SD procedure are being investigated, such as the use of a smaller SD incision. However, there is still some debate about this minimally invasive SD approach and insufficient attention is being directed to the anatomy. Yet it is important to avoid injury to the posterior branch(es) of the medial antebrachial cutaneous nerve (MACN) and the crossing branch of the basilic vein during surgery in order to avoid the postoperative complications.

Goal: This study aimed to increase the insights into a minimally invasive SD approach to treat the CubTS. Therefore anatomical guidelines were offered, which included the description of the position of the posterior branch(es) of the MACN and the crossing branch of the basilic vein, as well as the discussion of the required SD incision length and location in order to achieve a minimally invasive and effective SD procedure, based on the relevant anatomy. In addition, the surgical outcome of the minimally invasive decompression (MID) procedure was evaluated in CubTS patients. The MID procedure is based on the SD using a smaller incision of 3.5 cm. The evaluation of the surgical outcome included the investigation of the effectiveness, minimal invasiveness and remaining aspects of the MID procedure in order to examine the use of a smaller SD incision.

Materials & methods: Three upper limbs of three different formalin fixed cadavers were dissected. In two of these specimens the course of the posterior branch(es) of the MACN in relation to the medial epicondyle was preserved and documented. In all the three specimens the course of the crossing branch of the basilic vein in relation to the medial epicondyle was investigated and documented. The MID procedure is being performed in our hospital for several years as treatment for the CubTS. A retrospective patient study was performed in 31 CubTS patients by means of a postoperative questionnaire and subsequent consultation or telephone interview. The clinical outcome parameters to investigate the effectiveness and minimal invasiveness were the CubTS symptoms and the postoperative complications associated with injury to the MACN and basilic vein branches respectively.

Results: In the two specimens the following results were obtained regarding the course of the posterior branch(es) of the MACN in relation to the medial epicondyle: a distal crossing branch was present in the two specimens, a branch crossing at the medial epicondyle was present in one specimen and a proximal crossing branch was present in none of the specimens. The crossing branch of the basilic vein was identified in the three specimens and located a position of 2 to 3 cm proximal to the medial epicondyle. The MID surgery significantly reduced all the CubTS symptoms, i.e. an average reduction for pain of 44.51%, for paraesthesia of 66.04%, for hypaesthesia of 65.05% and for muscle weakness of 51.65% per patient. In the majority of patients the symptoms did improve. In most patients none of the postoperative complications were present near the wound, i.e. in 74.19% of the patients. Most patients were (very) satisfied regarding their MID surgery and returned to work between 1 to 4 weeks after surgery.

Conclusion: From the anatomical guidelines and the MID surgical outcome evaluation it was clear that when the MACN and basilic vein branches were taken into account during surgery and a smaller SD incision was applied based on the position of the MACN branches, the risk of injury to these branches was minimized and consequently the postoperative complications were avoided, implying that a minimally invasive SD procedure can be achieved in this manner. Altogether, these findings suggest that the use of a smaller SD incision of 3 to 3.5 cm in length, located exactly between the medial epicondyle and olecranon, could result in a minimally invasive SD procedure, without altering its effectiveness. These results of the study contribute to the wellbeing of CubTS patients.

ABSTRACT Dutch version

Inleiding: Het cubitaal tunnel syndroom (CubTS) is de meest voorkomende ulnaire zenuw compressie neuropathie ter hoogte van de elleboog en het is een grote hindernis in het dagelijkse leven. De simpele decompressie (SD) procedure is populair geworden als chirurgische behandeling omwille van zijn effectiviteit en laag invasieve eigenschap. Om het welzijn van de patiënten te verhogen, worden er minimaal invasieve benaderingswijzen van de SD procedure onderzocht, zoals het gebruik van een kleinere SD incisie. Er is echter nog discussie over deze minimaal invasieve SD aanpak en er wordt onvoldoende aandacht geschonken aan de anatomie. Toch is het belangrijk om beschadiging van posterior tak(ken) van de mediale antebrachiale cutane zenuw (MACN) en kruisende tak van de vena basilica te voorkomen tijdens de operatie om dan de postoperatieve complicaties te kunnen vermijden.

Doel: Deze studie had als doel om de inzichten in een minimaal invasieve SD aanpak te verhogen als behandeling van het CubTS. Daarom werden er anatomische richtlijnen gegeven die zowel de beschrijving van de positie van de posterior tak(ken) van de MACN en kruisende tak van de vena basilica inhield als de discussie van de vereiste SD incisie lengte en locatie om een minimaal invasieve en effectieve SD procedure te bereiken, op basis van de relevante anatomie. Hiernaast werd de chirurgische uitkomst van de minimaal invasieve decompressie (MID) procedure geëvalueerd in patiënten met het CubTS. De MID procedure is gebaseerd op de SD waarbij gebruik wordt gemaakt van een kleinere incisie van 3.5 cm. Het evalueren van de chirurgische uitkomst hield het onderzoeken van de effectiviteit, minimale invasiviteit en de overige aspecten van de MID procedure in, om dus het gebruik van een kleinere SD incisie te bestuderen.

Materialen & methoden: Drie bovenste ledematen van drie verschillende formaline-gefixeerde kadavers werden ontleed. In twee van de drie preparaten werd het verloop van de posterior tak(ken) van de MACN in relatie tot het epicondylus medialis bewaard en gedocumenteerd. In alle drie preparaten werd het verloop van de kruisende tak van de vena basilica in relatie tot het epicondylus medialis onderzocht en gedocumenteerd. De MID procedure wordt al enkele jaren uitgevoerd in ons ziekenhuis als behandeling voor het CubTS. Een retrospectieve patiënten studie werd uitgevoerd in 31 patiënten met het CubTS met behulp van een postoperatieve vragenlijst en daaropvolgende consultatie of telefonisch interview. De klinische uitkomst parameters om de effectiviteit en minimale invasiviteit te onderzoeken waren respectievelijk de CubTS symptomen en de postoperatieve complicaties geassocieerd met schade aan de MACN en vena basilica takken.

Resultaten: In de twee preparaten werden de volgende resultaten bekomen betreffende het verloop van de posterior tak(ken) van de MACN in relatie tot het epicondylus medialis: een distale kruisende tak was aanwezig in beide preparaten, een tak die kruiste over het epicondylus medialis was aanwezig in één preparaat en in geen enkel preparaat was een proximaal kruisende tak aanwezig. De kruisende tak van de vena basilica was geïdentificeerd in de drie preparaten ter hoogte van 2 tot 3 cm proximaal van het epicondylus medialis. De MID operatie reduceerde significant al de CubTS symptoms: een gemiddelde reductie per patiënt voor pijn met 44.51%, voor tintelingen met 66.04%, voor gevoelloosheid met 65.05% en voor spierzwakte met 51.65%. In de meerderheid van de patiënten verbeterden de symptomen. In de meeste patiënten waren geen enkele van de postoperatieve complicaties aanwezig: in 74.19% van de patiënten. De meeste patiënten waren (zeer) tevreden met de MID operatie en keerde terug naar het werk tussen de 1 en 4 weken na de operatie.

Conclusie: Uit de anatomische richtlijnen en de MID chirurgische uitkomst evaluatie, was het duidelijk dat wanneer er met de MACN en vena basilica takken rekening werd gehouden tijdens de operatie en wanneer een kleinere SD incisie werd toegepast gebaseerd op de positie van de MACN takken, het risico op schade aan deze takken werd geminimaliseerd en bijgevolg de postoperatieve complicaties vermeden werden, wat impliceert dat op deze manier een minimaal invasieve SD procedure kan bereikt worden. Alles samengenomen, suggereren deze bevindingen dat het gebruik van een kleinere SD incisie van 3 tot 3.5 cm in lengte, geplaatst tussen het epicondylus medialis en olecranon, kan resulteren in een minimaal invasieve SD procedure, zonder dat de effectiviteit gewijzigd wordt. Deze resultaten van de studie dragen bij tot het welzijn van de patiënten.

TABLE OF CONTENTS

1. INTRODUCTION

The cubital tunnel syndrome (CubTS) is a common ulnar nerve compression neuropathy at the elbow, which affects hand sensation and/or motor function. It is a major disability in daily life and usually requires surgical treatment in order to restore hand function or to prevent the progression of symptoms. This shows that the surgical treatment of the CubTS is a key aspect. In order to increase the wellbeing of the patients minimally invasive surgical procedures to treat the CubTS are under investigation. This study conducts research regarding a minimally invasive (and effective) surgical treatment approach for the CubTS.

First, relevant background information regarding the ulnar nerve and the CubTS is provided. The medial antebrachial cutaneous nerve (MACN) and the basilic vein are described as well, because of their importance during CubTS surgery. Then, an overview of the literature is given regarding the surgical treatment of the CubTS, after which the research project is described.

1.1 ULNAR NERVE

The ulnar nerve is a peripheral nerve which contains both sensory and motor axons, contributing to hand sensation and motor function.

1.1.1 Anatomy

In the axilla, the ulnar nerve arises as a large terminal branch from the medial cord of the brachial plexus receiving fibers from the C8 and T1 (and often C7) nerve roots and runs medial to the axillary artery. Next, the ulnar nerve descends along the medial upper arm in the anterior compartment, where it is closely related to the brachial artery, until the middle of the upper arm. At this point, the ulnar nerve pierces the medial intermuscular septum (figure 1.1) entering the posterior compartment of the arm, after which it descends anterior to the medial head of the triceps brachii muscle. (1-6)

Subsequently at the elbow, the ulnar nerve passes posterior to the medial epicondyle of the humerus into the ulnar groove (figure 1.1 and figure 1.2), where it runs subfascially and is palpable. As the ulnar nerve emerges from this groove, it immediately enters the cubital tunnel (figure 1.1 and figure 1.2). The roof of the cubital tunnel is formed by the tendinous arch between the humeral head and ulnar head of the flexor carpi ulnaris muscle, which is called the Osbourne's ligament. The medial collateral ligament and the elbow joint capsule form the floor of the cubital tunnel. (1-6)

In the medial forearm, the ulnar nerve passes between the flexor digitorum profundus and flexor carpi ulnaris muscles to the wrist. During this course, the ulnar nerve gives off muscular, dorsal cutaneous and palmar cutaneous branches (figure 1.3). At the level of the wrist, the ulnar nerve courses through the Guyon's canal and divides into the superficial and deep terminal branches (figure 1.4). (1-6)

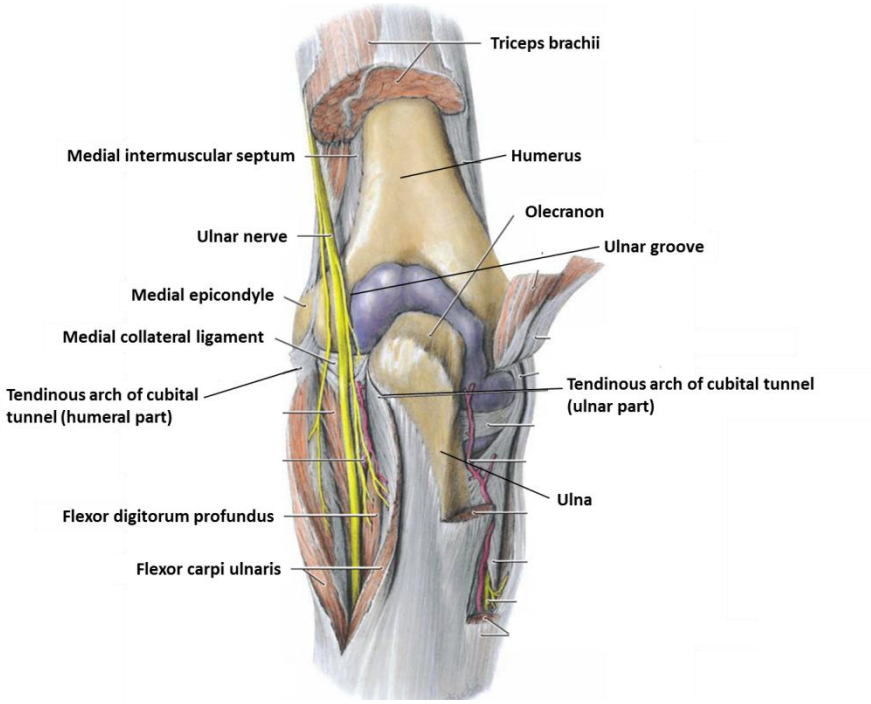


Figure 1.1. Posterior view of the elbow. (1)

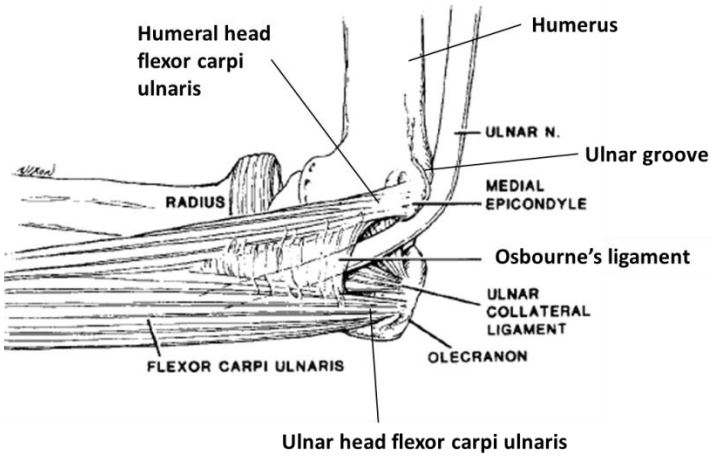


Figure 1.2. Medial view of the elbow. (7)

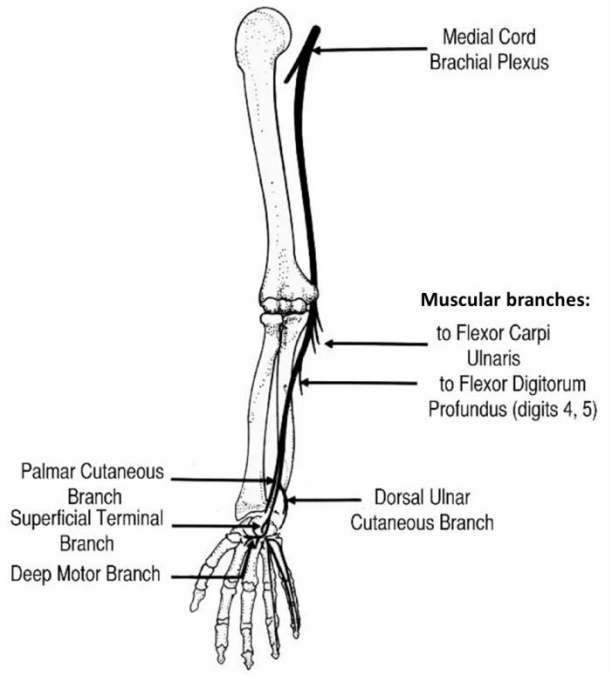


Figure 1.3. Branches of the ulnar nerve. (4)

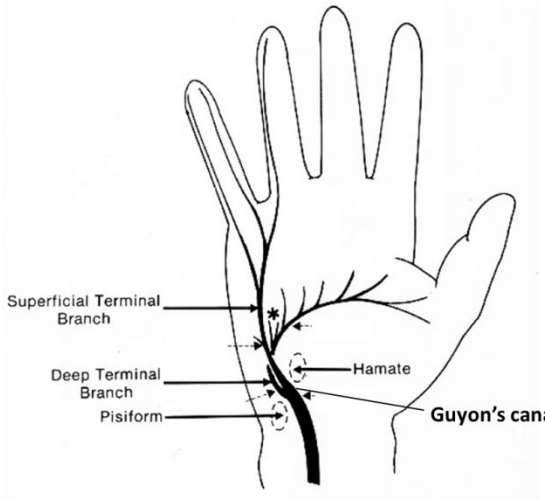


Figure 1.4. Branches of the ulnar nerve in the hand. (4)

1.1.2 Innervation

As described above, the ulnar nerve contributes to the motor and sensory innervation of the hand. The ulnar nerve provides the predominant innervation to the intrinsic hand muscles, which are muscles originating within the hand. The superficial terminal branch of the ulnar nerve supplies the palmaris brevis muscle, whereas the deep terminal branch of the ulnar nerve innervates the hypothenar muscles (i.e. abductor digiti minimi, flexor digiti minimi brevis and opponens digiti minimi muscles), the palmar and dorsal interossei muscles, the two medial lumbrical muscles (digits IV and V), the adductor pollicis muscle and the deep head of the flexor pollicis brevis muscle. The remaining intrinsic hand muscles are innervated by the median nerve and include three thenar muscles (i.e. abductor pollicis brevis, superficial head of flexor pollicis brevis and opponens pollicis muscles) and the two lateral lumbrical muscles (digits II and III). (1-4)

The ulnar nerve also innervates one and a half extrinsic hand muscles in the forearm (i.e. originating outside the hand). The muscular branches of the ulnar nerve innervate the flexor carpi ulnaris muscle and the medial half of the flexor digitorum profundus muscle (digits IV and V). The remaining extrinsic hand muscle are innervated by the median nerve and the radial nerve. (1-4)

Both the intrinsic and extrinsic hand muscles contribute to a normal hand function, i.e. movements of finger joints and wrist joint. The hand functions to grip objects, i.e. flexion of the fingers around an object. Both power grip and precision grip movements are possible depending on the amount of flexion at the finger joints and the position of the thumb (figure 1.5). Moreover, the thumb position also determines the power in the grip movements. The extrinsic hand muscles are more used in a firm grip, whereas the intrinsic hand muscles are more used in fine movements. (8-9)

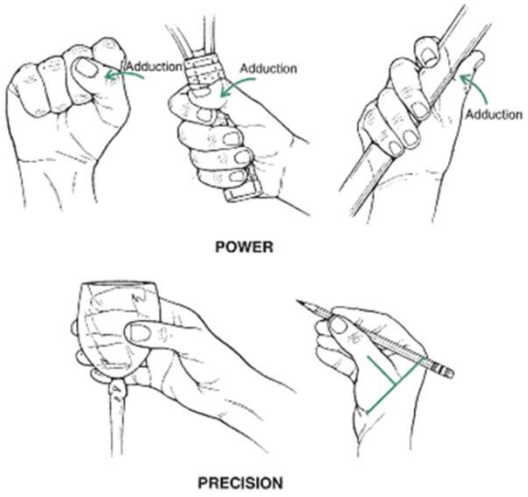


Figure 1.5. Hand functions: power grip and precision grip movements. (9)

During a power grip the fingers flex at all three joints to form a fist. Adduction of the thumb generates a more powerful grip. During a precision grip the fingers slightly flex at a small number of finger joints with the thumb perpendicular to the hand.

The three ulnar nerve branches responsible for the sensory innervation of the hand are the palmar cutaneous branch, the dorsal cutaneous branch and the superficial branch. Together they supply the skin of the ulnar side of the palm and dorsum of the hand, as well as the palmar and dorsal surfaces of digit V and the half of digit IV (figure 1.6). The median nerve and radial nerve innervate the remaining skin areas of the hand and fingers. (1-6)

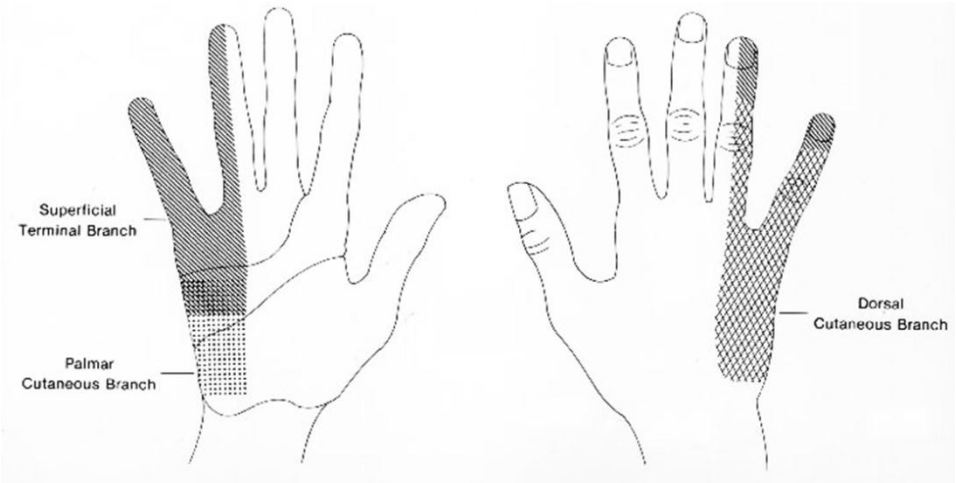


Figure 1.6. Sensory innervation area of the hand by the three ulnar nerve branches. (4)

1.2 CUBITAL TUNNEL SYNDROME

Chronic compression of the ulnar nerve at the elbow may result in the CubTS, which is the second most common entrapment neuropathy in the upper extremity. In the CubTS, the ulnar nerve may be compressed at multiple sites (figure 1.7): (1) the medial intermuscular septum, (2) the ulnar groove of the medial epicondyle of the humerus and (3) the cubital tunnel. However, the most common sites of compression are the ulnar groove and the cubital tunnel. (4-6)

During flexion of the elbow in an angel of 90 degrees, the distance between the medial epicondyle and olecranon increases by 10 mm (figure Supp 1.1 A). Consequently, the tendinous arch of the flexor carpi ulnaris muscle tightens over the ulnar nerve, the medial collateral ligament protrudes and the medial head of the of the triceps muscle presses the ulnar nerve anteromedially (figure Supp 1.1 B). Consequently, the ulnar groove of the humerus and the cubital tunnel narrows, causing the space to decrease and the pressure to increase. Moreover, the ulnar nerve is compressed against inflexible fibro-osseous structures and stretched proximal and distal to the ulnar groove (figure Supp 1.1 C). These pathological mechanisms cause compression of the ulnar nerve at the elbow. With extreme elbow flexion (> 90 degrees) these mechanisms aggravate. Furthermore, humans execute most activities with flexed elbows. The CubTS is a major disability in daily life and is characterised by specific symptoms. (4, 10-11)

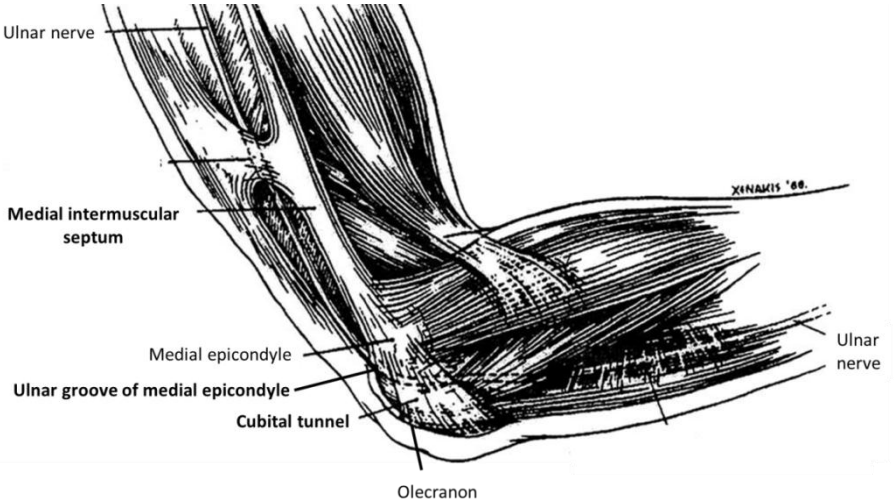


Figure 1.7. Ulnar nerve compression sites at the elbow. (6)

1.2.1 Symptoms and clinical signs

The symptoms of the CubTS are related to ulnar nerve distribution over the forearm and hand and include sensory and/or motor dysfunctions. However, these symptoms are variable for each individual and depend on the degree and the duration of ulnar nerve compression. (4-6)

In general, the sensory symptoms are the first to occur. These sensory symptoms range from intermittent paraesthesia and/or mild hypaesthesia to persistent paraesthesia and/or severe hypaesthesia in the ulnar half of the hand and digit V and the half of digit IV (figure 1.6). However, the affected area is variable. The paraesthesia is often uncomfortable and painful. Pain and/or unusual sensitivity are sometimes seen in the medial aspect of the elbow. The palmar cutaneous, dorsal cutaneous and superficial terminal ulnar nerve branches are affected. (4-6)

The motor symptoms usually occur when the CubTS progresses. Initially, pain in the medial forearm muscles and/or hand muscles may be observed. The motor symptoms may progress to weakness and eventually to atrophy of the ulnar innervated intrinsic and/or extrinsic hand muscles. However, the extrinsic muscle functions are usually maintained. The superficial and deep terminal branches are affected, whereas the muscular branches usually not. (4-6)

Intrinsic ulnar hand muscle weakness is associated with a decreased mobility of the thumb and fingers and ranges from clumsiness to progressively weakened pinch and grip movements (up to 70-80%). Clinical signs of intrinsic ulnar motor weakness and/or atrophy include Froment's sign (figure 1.8 A) due to paralysis of the adductor pollicis muscle, flattening of the hypothenar eminence due to atrophy of the hypothenar muscles, loss of finger abduction and adduction due to paralysis of the interossei muscles and a claw hand limited to digits IV and V (figure 1.8 B) due to paralysis of two medial lumbrical muscles and interossei muscles. Atrophy of the interossei muscles is most obvious in the dorsal thumb web space (figure 1.8 C). Due to weakness and/or atrophy of the ulnar innervated intrinsic hand muscles, precise hand movements and grip strength are affected, making daily activities difficult or even impossible to execute (e.g. opening bottles, closing buttons, playing music, typing, holding objects). (4-6, 12)

Moreover, in some CubTS patients only motor symptoms or only sensory symptoms may occur. The CubTS affects hand sensation and/or motor function and requires proper treatment in order to resume the activities in daily life.

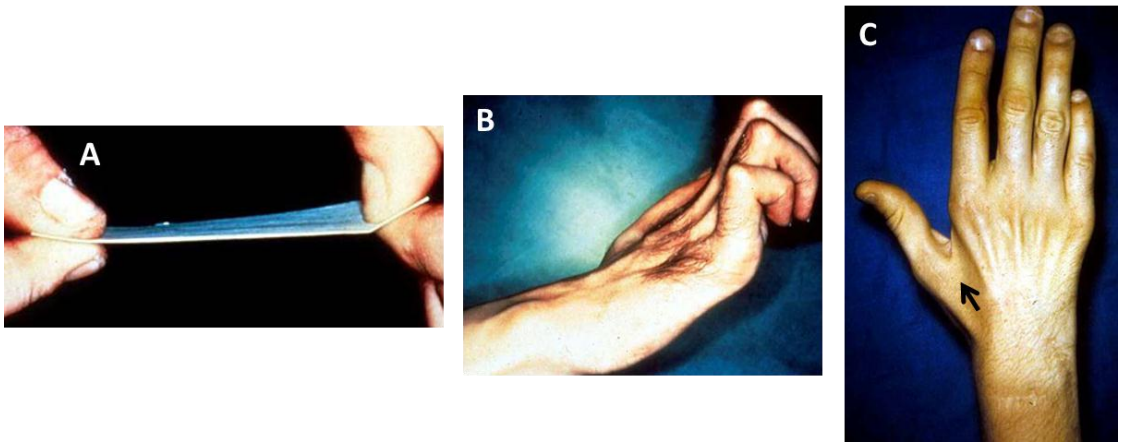


Figure 1.8. Clinical signs of intrinsic ulnar motor weakness and/or atrophy. (12)

A: Froment's sign. B: claw hand limited to digits IV and V. C: atrophy at dorsal thumb web space (arrow).

1.2.2 Treatment

According to the degree of ulnar nerve entrapment at the elbow, either conservative treatment or surgical treatment is advised. The conservative treatment is only performed in minimally symptomatic cases. This therapy involves minimizing elbow flexion (elbow joint immobilisation) and preventing direct pressure on the elbow using elbow pads. Painkillers and non-steroidal anti-inflammatory medication may be used as well. In cases of conservative treatment failure, persistent symptoms (> 3 months) and severe symptoms (i.e. muscle weakness and/or atrophy and sensory changes), surgical treatment is advised in order to prevent the progression of the symptoms and reduce the functional deficits. (4-6, 13-14)

Currently, variable surgical treatment options are available to decompress the ulnar nerve: the medial epicondylectomy, the anterior transposition (AT) and the simple decompression (SD). The medial epicondylectomy involves resection of the medial epicondyle in order to remove an important mechanical compression structure during elbow flexion (figure 1.9). The AT aims to transpose the ulnar nerve out of its original position in order to decrease the compression and tension on the ulnar nerve during elbow flexion. The ulnar nerve is transposed anteriorly, either subcutaneously, intramuscularly or submuscularly (figure 1.9). During these procedures several structures are manipulated depending on the procedure, e.g. ulnar nerve, muscles, bone, which may result in complications. Moreover, new ulnar nerve compression sites may be created. During the SD the ulnar nerve is left in its original position and the overlying compressive structures are released (figure 1.10). The conventional SD procedure is being performed by placing a longitudinal skin incision of 8 cm in length between the medial epicondyle and olecranon. An overview of the literature regarding the surgical treatment of the CubTS is provided in 1.4. (4-6, 13-14)

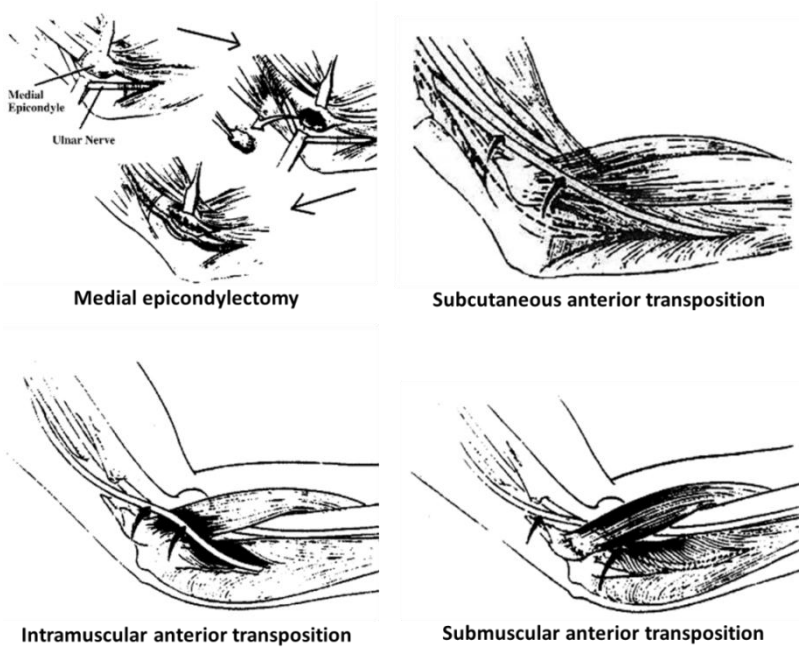


Figure 1.9. Medial epicondylectomy and subcutaneous, intramuscular and submuscular anterior transposition. (6)

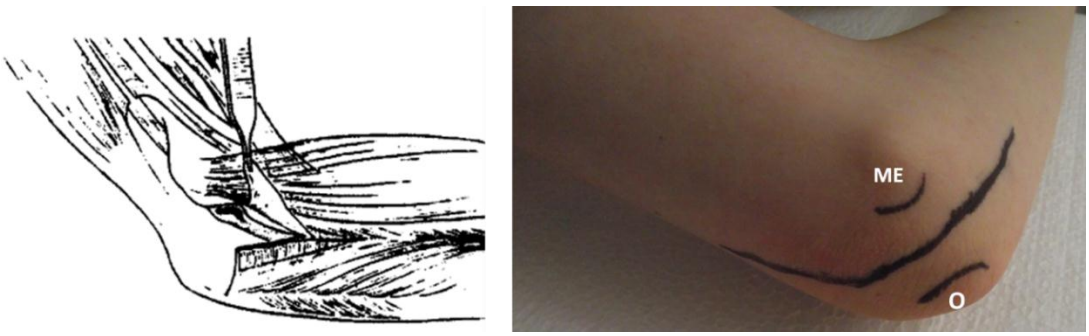


Figure 1.10. Simple decompression of the ulnar nerve.

Left: procedure (6). Right: conventional longitudinal skin incision of 8 cm in length between the medial epicondyle (ME) and olecranon (O).

1.3 MEDIAL ANTEBRACHIAL CUTANEOUS NERVE AND BASILIC VEIN

The MACN and the basilic vein are anatomical structures which cross the elbow during their course. Therefore, they are relevant to consider during CubTS surgery and their anatomy is described.

1.3.1 Medial antebrachial cutaneous nerve anatomy

In most cases, the MACN arises from the medial cord of the brachial plexus and runs down medial to the brachial artery. In the middle of the arm, the MACN pierces the deep fascia with the basilic vein. At a variable distance proximal to the medial epicondyle, the MACN divides into two main branches: the anterior and posterior branches. These branches stay closely related to the basilic vein for a variable distance, after which the posterior branch turns posteriorly. (1-2, 15-16)

The anterior branch courses anterior to the elbow and proceeds into the forearm to the level of the wrist. It sends branches to the distal anteromedial arm, the antecubital fossa and the anteromedial forearm. The posterior branch sends one to four branches posteriorly, which may cross at the medial epicondyle, proximally and/or distally to the medial epicondyle and innervate the posterior olecranon region and the proximal half of the posteromedial forearm (figure 1.11). A proximal crossing posterior branch of the MACN is a posterior branch which courses posteriorly by crossing proximal to the medial epicondyle. A distal crossing posterior branch of the MACN is a posterior branch which courses posteriorly by crossing distal to the medial epicondyle. A posterior branch of the MACN crossing at the medial epicondyle is a posterior branch which courses posteriorly by crossing at the medial epicondyle. (1-2, 15-16)

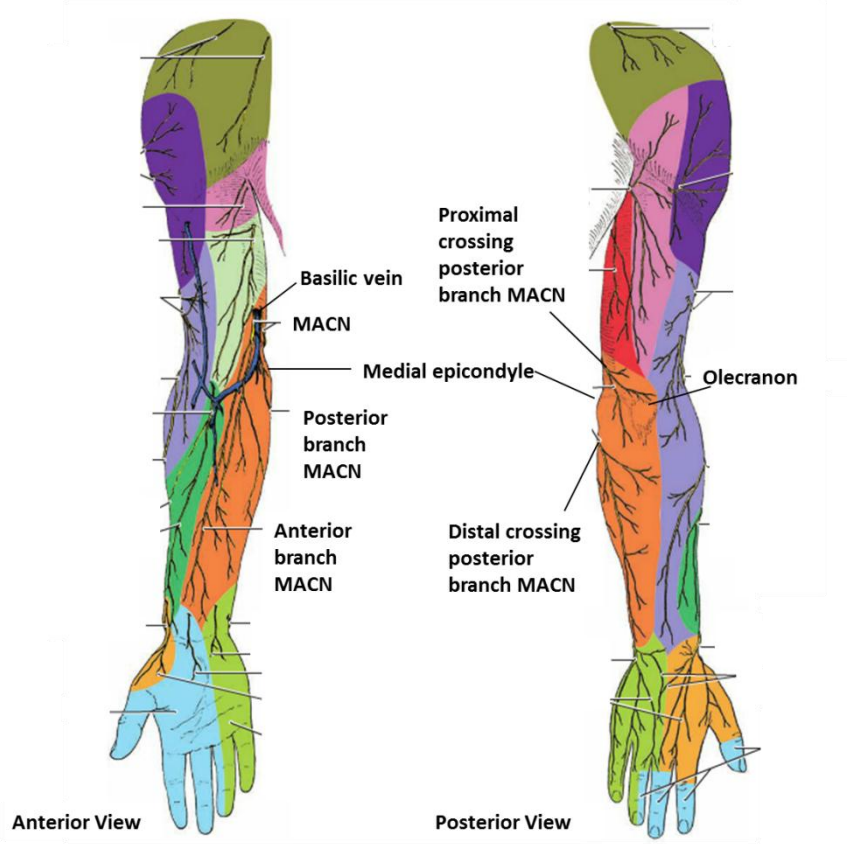


Figure 1.11. Medial antebrachial cutaneous nerve. (1)

The medial antebrachial cutaneous nerve (MACN) innervates the orange skin area.

1.3.2 Basilic vein anatomy

The basilic vein arises from the ulnar part of the dorsal venous network and courses proximally at the posteromedial side of the forearm. Subsequently, it turns anterior to the elbow and joins the median cubital vein. The basilic vein continues into the medial arm, pierces the deep fascia in the middle of the arm and ascends medial to the brachial artery. It then joins the brachial veins and continues as the axillary vein. During its course, the basilic vein has many variable branches. A crossing branch of the basilic vein is present proximal to the medial epicondyle. (1-2)

1.3.3 Injury to posterior and crossing branches during surgery: postoperative complications

Especially the posterior branch(es) of the MACN and the crossing branch of the basilic vein are in close proximity to the operative field during CubTS surgery. Therefore, injury to these structures is relatively common, which may result in severe postoperative complications. (15, 17)

Injury to the posterior branch(es) of the MACN during CubTS surgery may result in severe postoperative complications, including hypaesthesia in the area posterior and distal to the wound (scar) and depending on the presence of a neuroma (i.e. entrapment of the cutaneous nerve in the scar), an additional area of pain in the scar is observed (figure 1.12). This pain may be so severe that it may even overshadow a postoperative improvement. These complications may resolve after many months or may be permanent. Injury to the crossing branch of the basilic vein during CubTS surgery may result in postoperative haematoma and increased risk of infection in the upper arm. (15, 17)

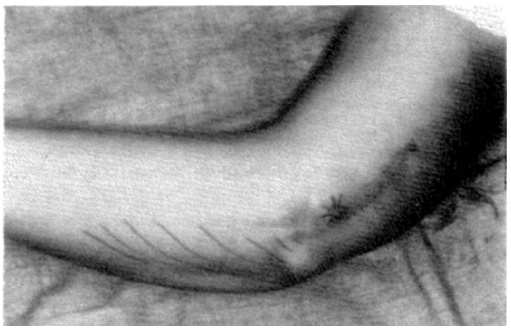


Figure 1.12. Area of hypaesthesia (lines) after injury to the posterior branch(es) of medial antebrachial cutaneous nerve. (15)

1.4 LITERATURE REGARDING SURGICAL TREATMENT OF THE CUBITAL TUNNEL SYNDROME

An overview of the research regarding the surgical treatment of the CubTS and important anatomical structures during surgery is provided.

1.4.1 Overview research regarding surgical treatment cubital tunnel syndrome

As described above, several surgical procedures are available to treat the CubTS. However, the AT and SD are most commonly performed and yield satisfying results (13). Several studies compared these methods and concluded that they are equally effective in reduction of symptoms (18, 19). However, the SD is less invasive because the ulnar nerve is left within its original bed, the blood

supply is not interrupted and no manipulation of muscles is involved. Therefore, the SD is associated with reduced tissue trauma and confers less postoperative complications. There is a fast postoperative recovery and early return to work and resumption of daily activities. In addition, the procedure is simpler to perform and is associated with lower costs. (18, 20-21)

In the contemporary society, minimally invasive procedures are becoming more popular in several medical fields (e.g. cardiology, gynaecology, peripheral nerve surgery). Minimally invasive procedures aim to minimize injuries, pain and complications and accelerate recovery and therefore could be beneficial for patients' wellbeing. Recently, minimally invasive approaches of the SD method to treat the CubTS are being investigated as well, because of the potential benefits to the wellbeing of the patients (e.g. minimal tissue trauma and less postoperative complications). (22)

The endoscopic assisted approaches of the SD procedure are being investigated as minimally invasive approach. The endoscopic release of the ulnar nerve involves decompression of the ulnar nerve through a skin incision of 2 cm using special endoscopic equipment. However, the endoscopic procedure requires a long learning curve regarding the correct handling of the equipment and the precise execution of the endoscopic decompression through such a small incision. Haematoma formation is a common complication after endoscopic ulnar nerve decompression. Hypaesthesia distal to the wound is found (occasionally) after the procedure as well, probably due to the equipment struggling through a small opening. (23-25)

Next to endoscopic assisted approaches of the SD procedure, a trend in applying smaller SD incisions (i.e. smaller than the conventional SD incision of 8 cm between the medial epicondyle and olecranon) is being observed. In the available literature a variety of SD incision lengths and locations are being described, including: an incision of 1.5 to 2.5 cm between the medial epicondyle and olecranon (figure Supp 1.2) (26), an incision of 4 cm anteriorly to the medial epicondyle (figure Supp 1.3) (21), an incision of 2 cm between the medial epicondyle and olecranon (figure Supp 1.4) (27), an incision of 3.8 cm distal to the medial epicondyle (figure Supp 1.5) (28) and two incisions of 2 cm each proximal and distal to the medial epicondyle (figure Supp 1.6) (29). Related to the minimal invasiveness, smaller SD incisions are presumed to have advantages, such as reduced tissue trauma, reduced postoperative complications, smaller scars and less recovery time (22). However, several anatomical structures need to be considered during CubTS surgery as well (15, 17).

1.4.2 Overview research regarding important anatomical structures during surgery

As described above in 1.3, the posterior branch(es) of the MACN and the crossing branch of the basilic vein are in close proximity to the operative field. Therefore, these branches are particularly at risk during CubTS surgery. An overview of the literature is provided regarding these structures. To the best of our knowledge, no literature regarding the crossing branch of the basilic vein is available. No research regarding the position or the importance during CubTS was found.

The position of the posterior branch(es) of the MACN was elaborately investigated and described by Masear et al. and Lowe et al.. They discussed the importance of avoiding injury to the posterior branch(es) of the MACN during CubTS surgery and their studies aimed to increase the knowledge regarding the position of these branches. Masear et al. dissected 50 upper limbs in order to

investigate the course of the MACN (cadaver study), whereas Lowe et al. identified and measured the position of the MACN posterior branches during primary AT surgery in 97 patients (intraoperative study). An overview of their findings regarding the number and the course (in relation to the medial epicondyle) of the posterior branch(es) of the MACN is provided in table 1.1. (16, 30)

Both the cadaver and intraoperative studies described the number of possible posterior branches ranging from 1 to 4. A mean of 1.9 posterior branches per patient was found in the intraoperative study (16, 30). The cadaver study described the course of the posterior branches in a rather vague fashion, i.e. the posterior branches crossed posteriorly between 6 cm proximal and 4 cm distal to medial epicondyle and in 90% the posterior branches crossed at or proximal to the medial epicondyle. In 40% more than one branch was observed crossing posteriorly at or near the medial epicondyle. However, the precise course and amount of the proximal and distal posterior branch(es) is unclear. (16)

The intraoperative study offered a more accurate description of the course of the posterior branches (figure Supp 1.7). In all cases a distal crossing branch was found at an average distance of 3.1 cm (range 1 to 5.5 cm) to the medial epicondyle (figure Supp 1.7 'b'). Two distal branches were present in 22% of the patients and three distal branches were present in 2% of the patients. In 61% of the cases a branch crossing proximal or at the medial epicondyle was identified at an average distance of 1.8 cm (range 0 to 6 cm) (figure Supp 1.7 'a'). Only 4% of the patients had two proximal branches. (30)

Table 1.1. The number and the course of the posterior branch(es) of the medial antebrachial cutaneous nerve. (16, 30)

Study	Number of posterior branches		Course of posterior branches	
Cadaver (50)	1 - 4	/	between 6 cm proximal - 4 cm distal to ME	in 90% branches crossed at OR proximal to ME in 40% > 1 branch distal?
Intraoperative (97)	1 - 4	mean 1.9 per patient · 1 branch in 27 patients · 2 branches in 58 patients · 3 branches in 8 patients · 4 branches in 4 patients	average 3.1 cm (range 1 - 5.5) distal to ME average 1.8 cm (range 0 - 6) proximal to ME	in 100% branches crossed distal to ME in 22% 2 branches, in 2% 3 branches in 61% branches crossed proximal OR at ME in 4% 2 branches

ME: medial epicondyle.

The importance of avoiding injury to the posterior branch(es) of the MACN during CubTS surgery was also described by Race et al. and LIuch. Their studies focused on this issue and they discussed an alternative skin incision for the AT procedure, taking into account the position of the posterior branch(es) of the MACN. These alternative AT skin incisions aimed to decrease the risk of injury to the posterior branch(es) of the MACN during CubTS surgery and to avoid the postoperative complications. Race et al. described a long AT skin incision starting posteriorly in the middle of the arm, running further distally over the middle of the olecranon and then 10 cm over the bony border of the ulna (figure Supp 1.8). LIuch investigated a transverse AT skin incision of 4 to 5 cm in length over the medial epicondyle at the level of the elbow flexion crease (figure Supp 1.9). (31-32)

1.5 RESEARCH PROJECT

Smaller SD incisions are being investigated as a minimally invasive approach of the SD procedure and various incision lengths and locations are found in the literature. However, from the literature it appears that there is still some debate about this minimally invasive approach and insufficient attention is being directed to the relevant anatomy.

Yet it is clear that the posterior branch(es) of the MACN and the crossing branch of the basilic vein need to be preserved during CubTS surgery in order to avoid postoperative complications. Therefore, knowledge and awareness of the position of the posterior branch(es) of the MACN and the crossing branch of the basilic vein is important during CubTS surgery.

This study aimed to increase the insights into a minimally invasive approach of the SD procedure as surgical treatment for the CubTS. The use of a smaller SD incision, as well as the position of the posterior branch(es) of the MACN and the crossing branch of the basilic vein were the main focus. This study investigated the following research questions:

1) Does a smaller SD incision result in a minimally invasive SD procedure? In other words: Does a smaller SD incision minimize the risk of injury to the posterior branch(es) of the MACN and the crossing branch of the basilic vein during surgery and therefore avoid the postoperative complications?

2) Moreover, which SD incision requirements, i.e. incision length and incision location, are necessary in order to achieve a minimally invasive SD procedure, without altering its effectiveness (i.e. capability to reduce the CubTS symptoms)?

Therefore, two main objectives were investigated.

The first objective was to offer anatomical guidelines in order to increase the insights into the minimal invasiveness based on the anatomy and SD incision. The anatomical guidelines include the description of the position of the posterior branch(es) of the MACN and the crossing branch of the basilic vein. In addition, the necessary requirements of the SD incision (in order to achieve a minimally invasive and effective SD procedure) are discussed based on the relevant anatomy.

The second objective was to evaluate the surgical outcome of the minimally invasive decompression (MID) procedure in CubTS patients. The MID method is based on the SD with a small incision (± 3.5 cm) and is being applied in our hospital for several years. The evaluation of the surgical outcome includes the investigation of the effectiveness, minimal invasiveness and remaining aspects of the MID procedure in order to examine the use of a smaller SD incision.

The anatomical guidelines were obtained by the dissection of the posterior branch(es) of the MACN and the crossing branch of the basilic vein, as well as an elaborate discussion with literature findings.

The surgical outcome of the MID procedure was retrospectively evaluated in CubTS patients by means of a postoperative questionnaire and a postoperative consultation or telephone interview.

The clinical outcome parameters to evaluate the MID effectiveness were the CubTS symptoms, i.e. pain, paraesthesia, hypaesthesia and muscle weakness. The clinical outcome parameters to evaluate the MID minimal invasiveness were the postoperative complications associated with injury to the posterior branch(es) of the MACN and crossing branch of the basilic vein, i.e. haematoma, signs of infection, pain and discomfort and hypaesthesia near the wound. The satisfaction of the patients and duration of inability to work were evaluated as remaining aspects of the MID procedure.

This study may contribute to the knowledge regarding minimally invasive CubTS surgery. Investigating the use of smaller SD incision and the position of the posterior branch(es) of the MACN and crossing branch of the basilic vein may contribute to the reduction of injury to these branches and therefore also the postoperative complications, increasing the wellbeing of the CubTS patients.

2 MATERIALS & METHODS

A dissection study and patient study were conducted in order to investigate the objectives.

2.1 DISSECTION STUDY

Three upper limbs of three different formalin fixed cadavers were superficially dissected to outline the course and the distribution of the posterior branch(es) of the MACN and the crossing branch of the basilic vein in relation to the medial epicondyle, olecranon and ulnar nerve. Standard dissection materials were used.

The first extremity was used to explore the course of the MACN from the brachial plexus to the lower arm and to explore the course of the basilic vein from the distal arm to the lower arm. The first extremity was a left arm.

In the two other specimens, the MACN branches were carefully dissected from the middle of the arm to just distal to the elbow and pinned down in order to preserve their course. The anterior and posterior MACN branches were identified and the course of the posterior branches in relation to the medial epicondyle was documented. The two specimens included one right arm and one left arm.

2.2 PATIENT STUDY

The MID surgical operations are being performed for several years in our hospital (Ziekenhuis Oost-Limburg, Lanaken, Belgium) as treatment for the CubTS. A patient study was conducted and the patient data regarding the MID surgery were postoperatively obtained by means of a questionnaire and subsequently by a consultation or telephone interview.

2.2.1 Minimally invasive decompression procedure

Next to the clinical presence of CubTS symptoms, the following electromyography requirement was met as indication for MID surgery: a motor nerve conduction velocity across the elbow of < 50 m/s, which confirms the presence of an ulnar nerve compression at the elbow. The MID surgical operations included in the study were performed by a single surgeon (FW) under standardized conditions in the same hospital.

After installing the patient in a supine position, the arm was abducted and the elbow was flexed in an angle of 90 degrees. The medial epicondyle and olecranon were palpated and a small, longitudinal skin incision with an average length of 3.5 cm was made exactly between them (figure 2.1). After opening the subcutaneous tissue up to the fascia covering the ulnar nerve, the subcutaneous tissue was detached from the underlying fascia. In this way, the cutaneous nerves branches can be preserved as much as possible. In order to decompress the ulnar nerve, the overlying fascia was divided both distally and proximally to the incision, releasing the ulnar nerve over a distance of 8 to 10 cm.

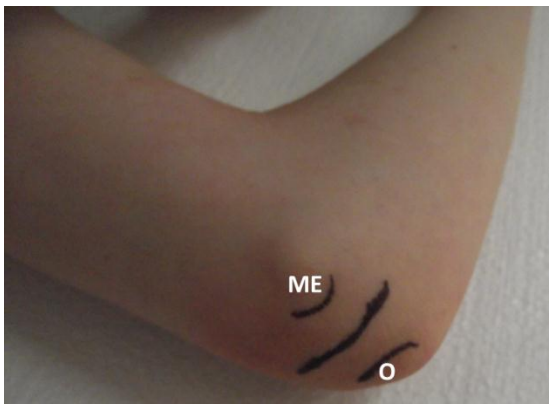


Figure 2.1. Incision applied during the minimally invasive decompression procedure.
An incision of 3.5 cm on average was applied exactly between the medial epicondyle (ME) and olecranon (O).

2.2.2 Patients

The postoperatively obtained patient data were reviewed and patients were included according to the following criteria: **1)** MID surgical operations by a single surgeon (FW), **2)** no traumatic cause of CubTS, **3)** maximum scar length of 4 cm and **4)** sufficient patient data in order to evaluate the MID procedure.

Thirty-one CubTS patients and 31 elbows were included in the study and underwent the MID surgical procedure between April 2009 and November 2011. There were 19 male and 12 female patients and the average age during surgery was 52.7 years (range 23 to 80 years). Eight right and 23 left elbows were surgically operated. In eight cases the dominant hand was affected. For most patients the duration of preoperative symptoms was 6 to 12 months or more than 1 year (table 2.1). The mean scar length was 3.5 cm (range 3 to 4 cm). For all we know, five patients suffered from diabetes and seven patients suffered from several neuropathies.

Table 2.1. Duration of preoperative symptoms.

> 1 year	6-12 months	4-6 months	2-4 months	5-8 weeks	1-4 weeks
6	11	4	4	5	1

The amount of patients (n=31) is given for each duration range.

In 24 patients, all the preoperative CubTS symptoms were present, i.e. pain, paraesthesia, hypaesthesia and muscle weakness (table 2.2). In four patients preoperative muscle weakness was absent, whereas in one patient hypaesthesia was absent. Pain was not present in two patients preoperatively. In other words: all the patients experienced preoperative paraesthesia, 30 patients suffered from hypaesthesia, 29 patients had pain and 27 patients experienced muscle weakness.

Table 2.2. Presence of preoperative cubital tunnel syndrome symptoms in included patients.

Amount of patients	Preoperative			
	Pain	Paraesthesia	Hypaesthesia	Muscle weakness
24	present	present	present	present
4	present	present	present	absent
1	present	present	absent	present
2	absent	present	present	present

The amount of patients (n=31) is given on the left. The corresponding present or absent preoperative symptoms are given on the right.

2.2.3 Postoperative questionnaire

Every included patient (31 out of 31 patients) completed the postoperative questionnaire (Figure Supp 2.1), which was formulated in patient's native language using clearly understandable words.

The questionnaire was related to several aspects of the MID surgical operation and required the description of: **1)** the intensity of four CubTS symptoms (i.e. pain, paraesthesia, hypaesthesia and muscle weakness) for both the preoperative and postoperative conditions by means of closed questions and Visual Analogue Scales (VAS), **2)** the scar length in cm, **3)** the wound related data (haematoma, infection, pain, discomfort, hypaesthesia) by means of yes/no questions and **4)** the remaining data (traumatic cause CubTS, duration preoperative complaints, conservative treatment, medical conditions, satisfaction surgery, duration of inability to work after surgery, hand dominance, occupation before surgery) by means of closed questions or yes/no questions. In addition, the patients had the opportunity to give their opinion about their surgical treatment by means of open questions.

Clear instructions were provided for completing the closed questions and the VAS for describing the intensity of each symptom before and after surgery. The **closed questions** included six possible answers ranging from 'no pain, paraesthesia, hypaesthesia, muscle weakness' to 'very pronounced pain, paraesthesia, hypaesthesia, muscle weakness'. A score was assigned to each answer ranging from zero to ten. Scores between zero and three correspond to mild symptoms, scores between three and seven correspond to moderate symptoms and scores between seven and ten correspond to severe symptoms (figure 2.2).

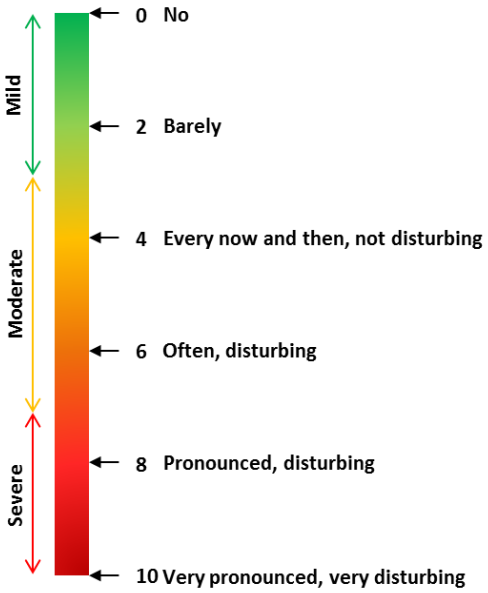


Figure 2.2. Closed questions answers and scoring.

The six possible answers regarding the intensity of each symptom were given on the right. The scores assigned to each answer ranged from zero to ten i.e. from mild to severe.

The **VAS** is a measurement instrument used to assign a score to the symptom intensity (33). It consists of a horizontal line of 100 mm in length (figure 2.3). At the left side of the line a minimal score of zero (i.e. no pain, paraesthesia, hypaesthesia, muscle strength) is indicated, whereas a maximal score of ten (i.e. very pronounced pain, paraesthesia, hypaesthesia, muscle strength) is given on the right side. The patient draws a vertical line on the scale (blue line) corresponding to the (subjectively) experienced symptom intensity. The VAS score is then determined by measuring the distance between the minimal score and the indicated vertical line (arrow). This scale is valuable in evaluating symptom intensity changes (between preoperative and postoperative conditions) within each individual and the VAS scores can be used for statistical analysis. The scores of the closed questions and the VAS correspond.

Figure 2.3. Visual Analogue Scale and scoring.

The Visual Analogue Scale (VAS) ranges from a minimal score of zero to a maximal score of ten. The VAS score (arrow) was determined by measuring the distance between the minimal score and the vertical blue line.

The postoperative data regarding the intensity of the symptoms (obtained by means of closed questions and VAS) correspond to the postoperative situation immediately after the surgery, i.e. short-term postoperative data (< 3 months after surgery).

The description of the wound related data by means of yes/no questions included two parts for the presence of discomfort and hypaesthesia near the wound. The first part related to the presence of discomfort and hypaesthesia during the healing process, whereas the second part related to the presence at the moment of filling in the questionnaire.

2.2.4 Postoperative consultation or telephone interview

The patient data obtained from the questionnaire were then verified and, if necessary, clarified by either a postoperative consultation (16 out of 31 patients) or by telephone (ten out of 31 patients).

Furthermore, during the postoperative consultation the scar lengths were measured using a tape measure and in a standardized manner, i.e. elbow flexed in an angle of 90 degrees. Data regarding the postoperative situation at that moment were obtained by questioning and a clinical examination. During the questioning the patient described their pain, paraesthesia, hypaesthesia and muscle weakness (if any) at that moment. The clinical examination included the evaluation of muscle strength, i.e. grip strength (figure 2.4) and finger abduction strength (figure 2.5) were examined without the use of measuring devices. Differences between the surgically operated hand and non-operated hand were observed. Moreover, the patients were asked to consecutively adduct and

abduct their fingers and the surgically operated hand was examined for clinical signs of motor symptoms as described in the introduction (figure 1.8). The data obtained by questioning and clinical examination included only information regarding the presence or absence of the symptoms and no intensities of the symptoms.

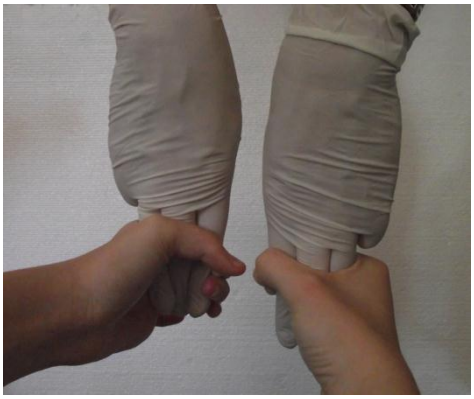


Figure 2.4. Evaluation of grip strength.

The patient was asked to pinch in three fingers as much as possible.

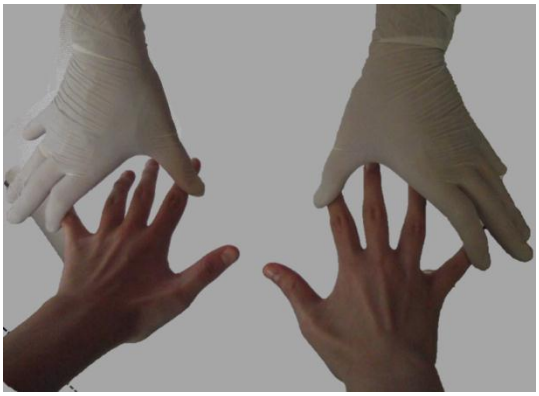


Figure 2.5. Evaluation of finger abduction strength.

The patient was asked to abduct digits II and IV against resistance as much as possible.

Patients who were unable to come to the postoperative consultation, were interviewed by telephone. During this telephone interview similar aspects were ascertained as during the consultation, i.e. patients were asked to measure their scar length with their elbows flexed in an angle of 90 degrees by using a tape measure and the postoperative situation at that moment was questioned. The data obtained by the questioning included only information regarding the presence or absence of the symptoms and no intensities of the symptoms.

The postoperative data regarding the presence or absence of the symptoms (obtained by questioning or clinical examination) correspond to the postoperative situation for a longer period of time after the surgery, i.e. long-term postoperative data (between 3 months and 3 years after surgery).

In the five remaining patients (five out of 31 patients) only data from the questionnaire could be obtained. These patients could not be reached and consequently no telephone interview or consultation were conducted. Therefore, only short-term postoperative data were obtained for these patients.

2.2.5 Statistical analysis

For statistical analysis the SPSS software (IBM SPSS Statistics 20.0, Armonk, New York) was used. The effectiveness of the MID procedure was statistically determined by means of a Paired-Samples T test, which compared the mean VAS scores of the preoperative and postoperative symptom and computed the difference between them for each patient. The average difference between the preoperative and postoperative VAS scores for each symptom is statistically significant from zero when $P < 0.05$.

3 RESULTS

This study aimed to increase the insights into a minimally invasive approach of the SD procedure as surgical treatment for the CubTS. The position of the posterior branch(es) of the MACN and the crossing branch of the basilic vein were investigated and the surgical outcome of the MID procedure, using a smaller SD incision of 3.5 cm, was evaluated in CubTS patients.

3.1 ANATOMY IN OPERATIVE FIELD

In three upper arms, the posterior branch(es) of the MACN and the crossing branch of the basilic vein were dissected and the positions were described in relation to the medial epicondyle. The SD incision was related to the relevant anatomy.

3.1.1 The position of the posterior branch(es) of the medial antebrachial cutaneous nerve

The number and the course of the posterior branch(es) of the MACN in relation to the medial epicondyle were investigated in two upper limbs.

In the dissected right arm (figure 3.1) one main posterior branch of the MACN was present and crossed posteriorly just distal to the medial epicondyle (white arrows). Hereafter, it divides into multiple smaller branches (yellow arrows). In the dissected left arm (figure 3.2) the main posterior branch of the MACN (white arrows) divides into two major branches at the medial epicondyle: one crossing posteriorly distal to the medial epicondyle (red arrows) and one crossing posteriorly at the medial epicondyle (green arrows). Subsequently, each of these branches divides into two branches (yellow arrows), coursing more posteriorly and distally. In both arms, no posterior branch was present crossing proximal to the medial epicondyle.

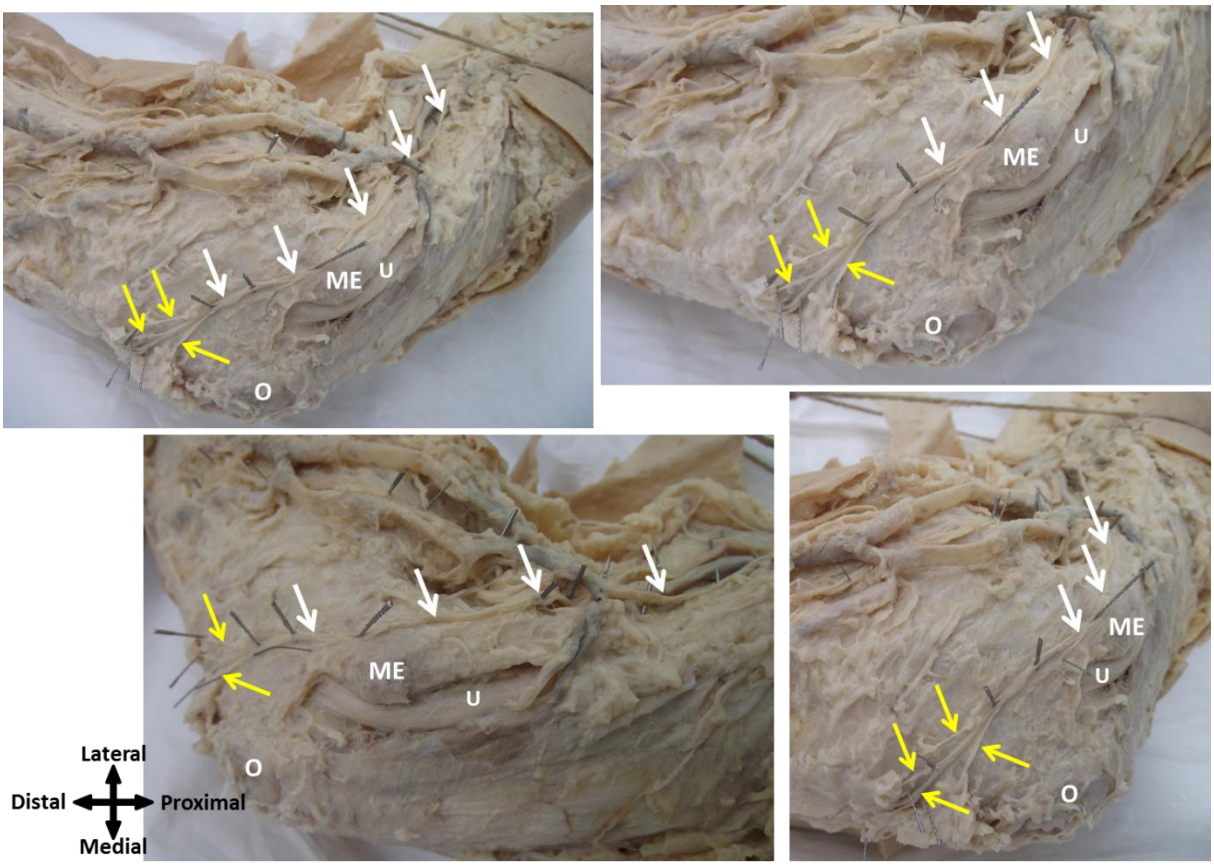


Figure 3.1. The posterior branch(es) of the medial antebrachial cutaneous nerve.

Right arm showing distal crossing posterior branch of the MACN (white arrows) and its smaller branches (yellow arrows). ME: medial epicondyle, O: olecranon, U: ulnar nerve.

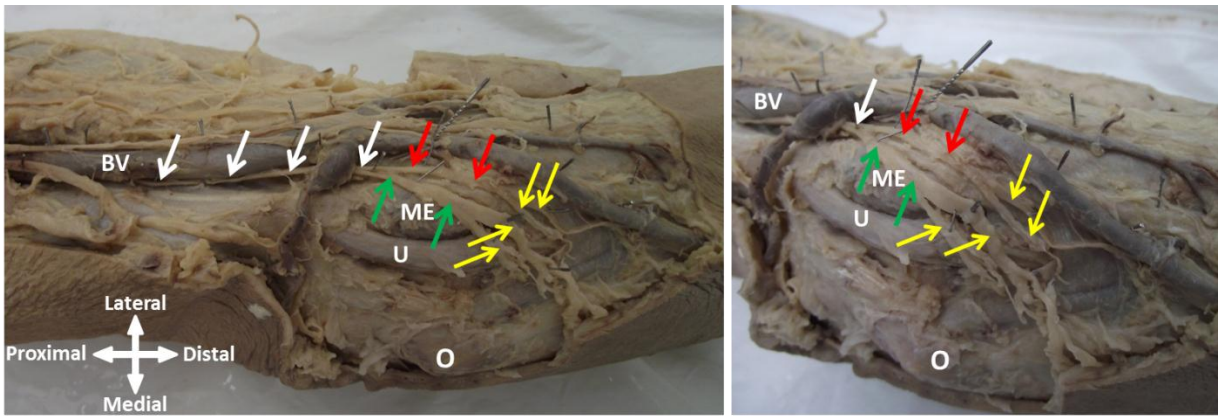


Figure 3.2. The posterior branch(es) of the medial antebrachial cutaneous nerve.

Left arm showing a main posterior branch of the MACN (white arrows) which divides into a distal crossing branch (red arrows) and a branch crossing at the medial epicondyle (ME) (green arrows). These branches divide into multiple branches (yellow arrows). O: olecranon, U: ulnar nerve, BV: basilic vein.

An overview of the dissection findings is provided in table 3.1. The number of the posterior branch(es) of the MACN in the two upper limbs ranged from one to four. As described above, one branch was present in the right arm, which coursed posteriorly by crossing distal to the medial epicondyle. In the left arm, four posterior branches were present, of which two coursed posteriorly by crossing distal to the medial epicondyle and two coursed posteriorly by crossing at the medial epicondyle. In all cases (100%), a distal crossing posterior branch of the MACN was found. A posterior branch crossing at the medial epicondyle was present in one case (50%) and in none of the arms a proximal crossing posterior branch was present (0%).

Table 3.1. Dissection findings: the number and the course of the posterior branch(es) of the medial antebrachial cutaneous nerve in relation to the medial epicondyle.

Number of posterior branches		Course of posterior branches	
1 - 4	1 branch in right arm	1 branch distal to ME in right arm	in 100% branches crossed distal to ME
	4 branches in left arm	2 branches distal to ME in left arm	in 50% branches crossed at ME
		2 branches at ME in left arm	in 0% branches crossed proximal to ME

The results were obtained from two upper limbs. ME: medial epicondyle.

3.1.2 The position of the crossing branch of the basilic vein

A crossing branch of the basilic vein was encountered in the three dissected upper limbs and identified at a position of 2 to 3 cm proximal to the medial epicondyle (figure 3.3).

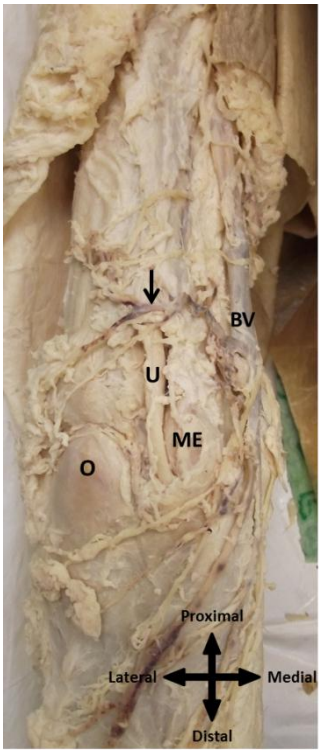


Figure 3.3. The crossing branch of the basilic vein.

Left posteromedial arm showing the crossing branch (arrow) of the basilic vein (BV). ME: medial epicondyle, O: olecranon, U: ulnar nerve.

3.1.3 The relation between the relevant anatomy and the simple decompression incision

During the dissection, the SD incision length and location were related to the relevant anatomy. The ruler shows the exact SD incision length and location, taking into account the position of the posterior branch(es) of the MACN (figure 3.4), as well as the proximal and distal ulnar nerve compression sites (figure 3.5).

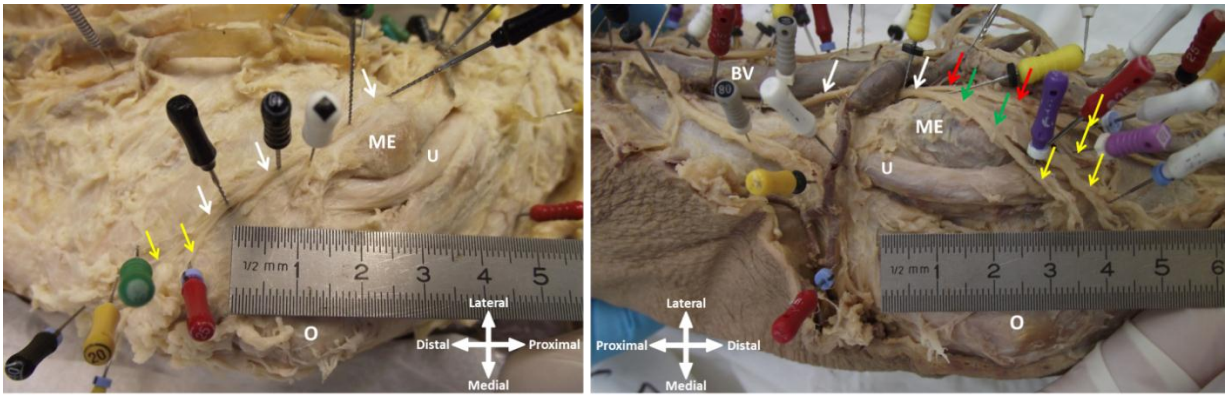


Figure 3.4. Minimally invasive incision length and location.

The incision is shown based on the position of the posterior branch(es) of the MACN. Left: right arm showing distal crossing posterior branch of the MACN (white arrows) and its smaller branches (yellow arrows). Right: left arm showing a main posterior branch of the MACN (white arrows) which divides into a distal crossing branch (red arrows) and a branch crossing at the medial epicondyle (ME) (green arrows). These branches divide into multiple branches (yellow arrows). O: olecranon, U: ulnar nerve, BV: basilic vein.

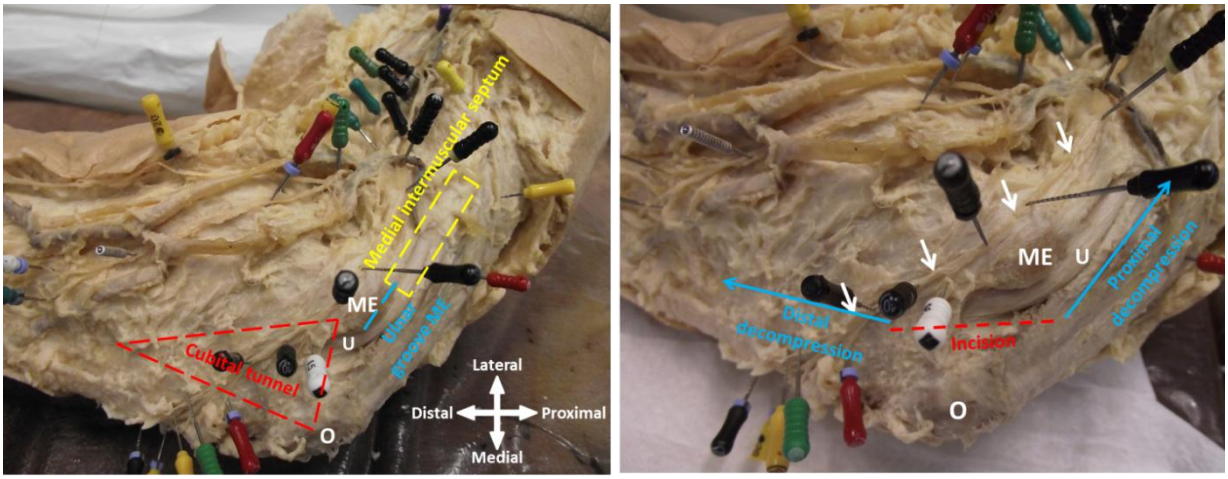


Figure 3.5. Effective incision length and location.

Left: right arm showing the proximal and distal ulnar nerve compression sites: the medial intermuscular septum (yellow box), the ulnar groove of the medial epicondyle (ME) (blue line) and the cubital tunnel (red triangle). Right: right arm showing the incision based on the position of the proximal and distal ulnar nerve compression sites. O: olecranon, U: ulnar nerve, BV: basilic vein.

3.2 SURGICAL OUTCOME OF MINIMALLY INVASIVE DECOMPRESSION

The surgical outcome of the MID procedure was retrospectively evaluated in 31 CubTS patients by means of a postoperative questionnaire and subsequently by a consultation or telephone interview. The evaluation of the surgical outcome included the investigation of the effectiveness, minimal invasiveness and remaining aspects of the MID procedure in CubTS treatment.

3.2.1 The effectiveness of the minimally invasive decompression procedure

The effectiveness of the MID procedure was determined by evaluating the pre- and postoperative CubTS symptoms, i.e. pain, paraesthesia, hypaesthesia and muscle weakness. The preoperative symptoms' intensity information and the short-term postoperative symptoms' intensity information (i.e. < 3 months after surgery) was obtained from the questionnaire by means of closed questions and VAS. In order to analyse these data, scores were assigned to the answers of the closed questions and to the VAS (figure 2.2 and figure 2.3). Subsequently, a postoperative consultation or telephone interview provided long-term data regarding the postoperative symptoms (i.e. between 3 months and 3 years after surgery).

The VAS scores were used for the statistical determination of the MID effectiveness (short-term). A Paired-Samples T test was used to compare the mean VAS scores of the pre- and postoperative symptom (figure 3.6). The MID surgery significantly reduced all the symptoms with an average VAS score difference of 1.56 for pain (44.51%), 4.61 for paraesthesia (66.04%), 4.42 for hypaesthesia (65.05%) and 4.41 for muscle weakness (51.65%) per patient. The largest mean differences between preoperative and postoperative VAS scores were observed for paraesthesia, hypaesthesia and muscle weakness.

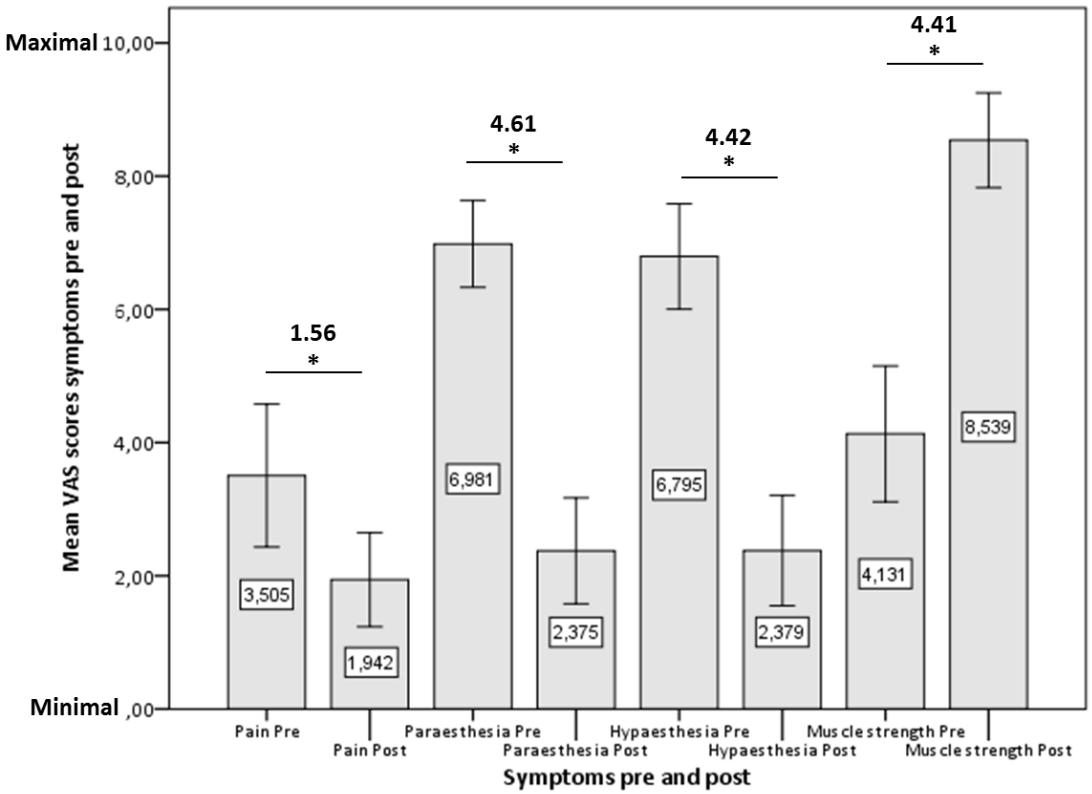


Figure 3.6. Comparison of mean pre- and postoperative VAS scores for pain, paraesthesia, hypaesthesia and muscle strength.

Means are shown in bars, mean differences are shown above and between corresponding bars, error bars indicate standard error mean (x2), statistically significant difference between pre- and short-term postoperative mean VAS score per symptom when $P < 0.05$ (*), n=31. Paired Samples T test.

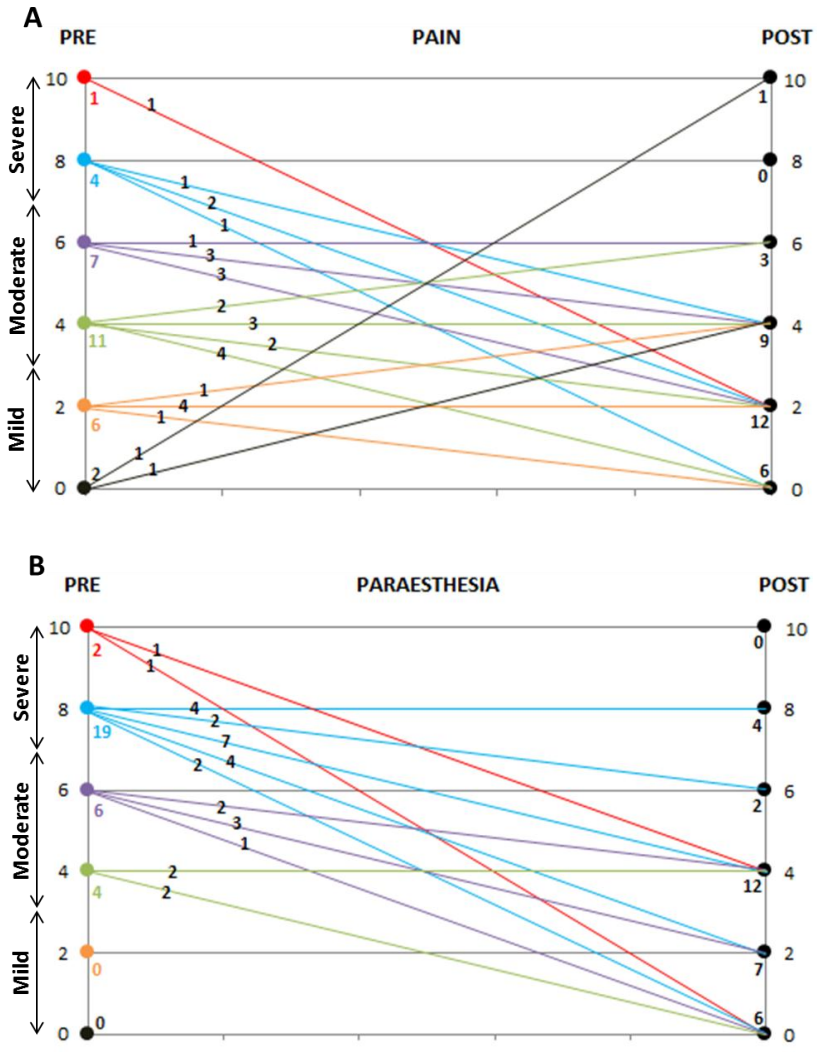
The evolution of the symptoms (from the preoperative condition to the short-term postoperative condition) is also shown in figure 3.7 by means of the pre- and postoperative scores of the closed questions' answers and the lines between these scores. The evolution of the symptoms is given for each symptom separately, i.e. for pain (figure 3.7 A), paraesthesia (figure 3.7 B), hypaesthesia (figure 3.7 C) and muscle weakness (figure 3.7 D) and each time for the 31 patients. The pre- and postoperative scores range from zero to ten and represent the intensity of the symptoms ranging from mild to severe. The numbers within the graph area represent the amount of patients.

Pain was moderately present in most patients before surgery, i.e. a score of 4 was observed in 11 patients and a score of 6 was observed in seven patients (figure 3.7 A). Postoperatively, most patients had mild pain, i.e. a score of 2 was observed in 12 patients and a score of 0 was observed in six patients.

The majority of the patients had moderate to severe preoperative paraesthesia, i.e. a score of 8 was observed in 19 patients and a score of 6 was observed in six patients (figure 3.7 B). Postoperatively, most patients experienced only mild to moderate paraesthesia, i.e. a score of 4 was observed in 12 patients, a score of 2 in seven patients and a score of 0 in six patients.

Moderate to severe preoperative hypaesthesia was observed in most patients, i.e. 20 patients had a score of 8 and six patients had a score of 6 (figure 3.7 C). Most patients had mild to moderate postoperative hypaesthesia, i.e. a score of 2 was observed in ten patients, a score of 4 in six patients and a score of 0 in five patients.

Preoperatively, moderate to severe muscle weakness was observed in most patients, i.e. 12 patients had a score of 8 and ten patients had a score of 6 (figure 3.7 D). Most patients experienced mild postoperative muscle weakness, i.e. a score of 2 was observed in 15 patients and a score of 0 was observed in 11 patients.



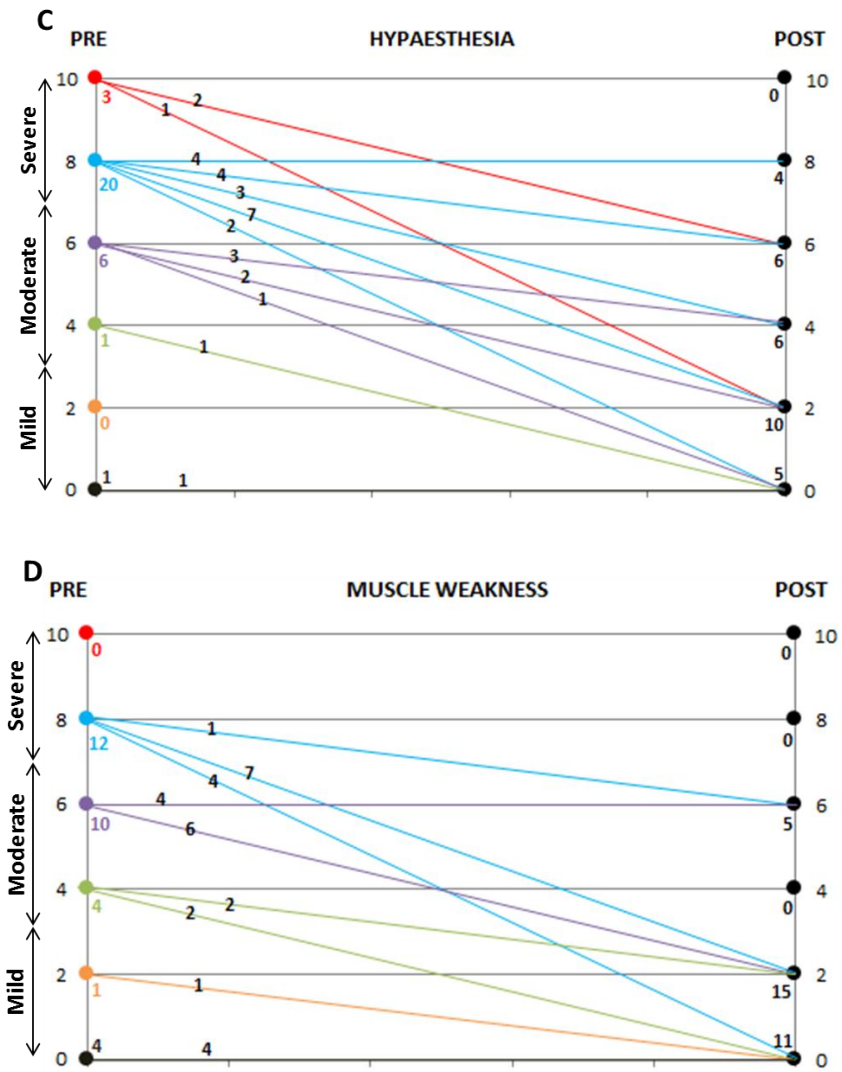


Figure 3.7. The evolution of the symptoms from the preoperative condition to the short-term postoperative condition.

The evolution (coloured lines) is given for pain (A), paraesthesia (B), hypaesthesia (C) and muscle weakness (D) and each time for the 31 patients. Pre- and postoperative scores ranging from zero to ten are shown on the left and the right respectively. The numbers within the graph next to these scores represent the amount of patients experiencing the pre- or postoperative scores respectively. The numbers next to the coloured lines represent the amount of patients evolving from the preoperative to postoperative condition.

For each symptom, the amount of patients is shown in table 3.2 in which the symptom was present preoperatively (each time out of the 31 patients) and either improved, remained the same or worsened postoperatively (short-term). Preoperatively, pain was present in 29 out of 31 patients, paraesthesia in all 31 patients, hypaesthesia in 30 out of 31 patients and muscle weakness in 27 out of 31 patients (table 2.2 and table 3.2).

In the majority of the patients the symptoms improved after the MID surgery. Pain improved in 18 out of 29 patients (62.07%), paraesthesia improved in 25 out of 31 patients (80.65%), hypaesthesia

improved in 26 out of 30 patients (86.67%) and muscle weakness improved in 23 out of 27 patients (85.19%) (table 3.2 and figure 3.7).

In a small number of patients the symptoms remained the same postoperatively. In eight patients the pain remained the same, in six patients the paraesthesia remained the same, in four patients the hypaesthesia remained the same and in four patients the muscle weakness remained the same (table 3.2). For pain, four patients had the same pre- and postoperative score of 2, three patients a score of 4 and one patient a score of 6 (figure 3.7 A). For paraesthesia, the same pre- and postoperative score of 8 was observed in four patients and a score of 4 in two patients (figure 3.7 B). For hypaesthesia, four patients had the same pre- and postoperative score of 8 (figure 3.7 C) and for muscle weakness, four patients had the same score of 6 (figure 3.7 D).

A postoperative worsening was observed only for pain in three patients (table 3.2), i.e. two patients had a preoperative score of 4 and a postoperative score of 6 and one patient had a preoperative score of 2 and a postoperative score of 4 (figure 3.7 A).

Two out of 31 patients did not experience pain before surgery (table 2.2). However, in these patients pain was present postoperatively, i.e. in one patient a postoperative score of 10 was observed and in the other patient a postoperative score of 4 was observed (figure 3.7 A). In one patient no preoperative hypaesthesia was present and remained absent postoperatively (figure 3.7 C). The same was true for the four patients in which muscle weakness was absent preoperatively (figure 3.7 D).

Table 3.2. Postoperative evolution of the symptoms.

Symptom	Preoperative	Postoperative		
		Worse	Same	Improved
Pain	29	3	8	18 (62.07%)
Paraesthesia	31	0	6	25 (80.65%)
Hypaesthesia	30	0	4	26 (86.67%)
Muscle weakness	27	0	4	23 (85.19%)

The amount of patients is shown in which pain, paraesthesia, hypaesthesia and muscle weakness was present preoperatively and either worsened, remained the same or improved postoperatively (short-term).

In table 3.3 the amount of patients is shown in which one or more present symptoms remained the same (or worsened) postoperatively (short-term). The blank boxes indicate postoperative improvement of the corresponding symptom. The patients listed in the table suffered from all the four preoperative symptoms, except for one patient in which preoperative muscle weakness was absent (indicated by '*' in table 3.3).

There were 13 different patients out of the 31 patients in which one or more present symptoms remained the same (or worsened) postoperatively. In the first five patients shown in the table, more than one of the present symptoms did not improve after the surgery. In two of these patients three symptoms remained the same postoperatively and either muscle weakness or hypaesthesia improved. In the other three patients none of the present symptoms improved and pain worsened slightly in two of these patients.

In the next eight patients in the table, only one of the present symptoms did not improve postoperatively. In six of these patients only pain did not improve, i.e. in five patients pain remained the same after the surgery and in one patient pain worsened slightly. In the other two patients either paraesthesia or muscle weakness remained the same postoperatively.

Overall, in three patients none of the present symptoms improved postoperatively, in six patients only pain did not improve and in four patients one of the present symptoms either improved or not improved.

Table 3.3. Postoperative evolution of the symptoms per patient.

Amount of patients	Postoperative				
	Pain	**Paraesthesia**	**Hypaesthesia**	**Muscle weakness**	**Improvement**
1*	same	same	same	/	none improved
1	same	same	same		one improved
1	same	same		same	one improved
2	worse	same	same	same	none improved
5	same				only pain not improved
1	worse				
1		same			one not improved
1				same	one not improved

The postoperative symptoms are shown of which one or more remained the same (or worsened) within a single patient (short-term). Blank boxes indicate postoperative improvement of the corresponding symptom. The listed patients suffered from all the preoperative symptoms, except for one patient in which preoperative muscle weakness was absent (*).

Moreover, in two out of the 31 patients, only pain was absent preoperatively and worsened shortly after the surgery. Paraesthesia, hypaesthesia and muscle weakness improved postoperatively. In the remaining 16 out of the 31 patients all present preoperative symptoms improved after the surgery.

Shortly after the surgery, the postoperative results were considered as good within a single patient when all the present symptoms improved (in 16 patients), when all the present symptoms improved except for pain (in six patients) and when absent preoperative pain worsened and all the other present symptoms improved (two patients). The postoperative results were considered as fair within a single patient when one of the present symptoms improved (in two patients) and when one of the present symptoms did not improve (pain not included) (in two patients). The postoperative results were considered as the poor within a single patient when none of the present symptoms improved (in three patients).

In figure 3.8 the evolution of symptoms is shown for shortly after the surgery (i.e. < 3 months) and for a longer period of time after the surgery (i.e. between 3 months and 3 years). Shortly after the surgery (figure 3.8 'post short-term') the symptoms improved in most patients, i.e. 24 out of 31 patients (good results). In four out of 31 patients the preoperative symptoms improved partially (fair results), whereas in three out of 31 patients the present preoperative symptoms remained the same (poor results).

For a longer period of time after the surgery (figure 3.8 'post long-term') the symptoms remained improved or further improved in most patients. Shortly after the surgery, the symptoms improved in 24 patients. In 18 out of the 24 patients the symptoms remained improved in the long-term. In two out of the 24 patients the symptoms recurred partially (only paraesthesia) or completely (all four symptoms). In four out of the 24 patients no long-term data could be obtained. In three out of four patients, in which the symptoms partially improved shortly after the surgery, all symptoms improved in the long-term. In one out of the four patients no long-term data could be obtained. In three patients the present symptoms remained the same in the short-term and in the long-term. In most patients all symptoms improved in the long-term, i.e. in 21 out of 26 patients.

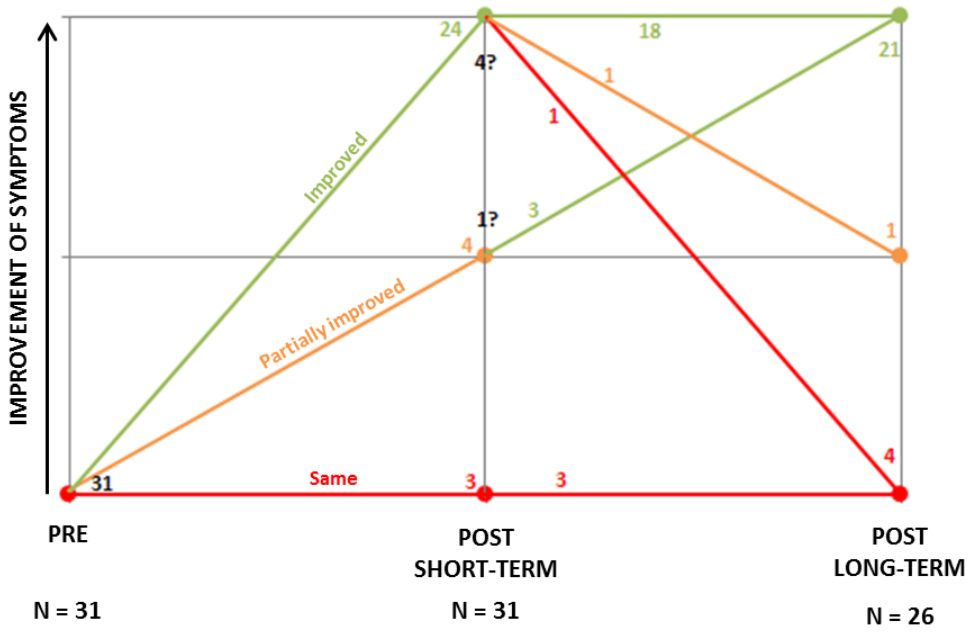


Figure 3.8. The short-term and long-term postoperative evolution of symptoms.

The short-term postoperative evolution of the symptoms in comparison with the preoperative condition, was shown as improvement of the symptoms (good results), partially improvement of the symptoms (fair results) or no improvement (the same) symptoms (poor results). For the long-term postoperative evolution of the symptoms the green lines indicate the maintaining of improvement (horizontal line) and further improvement (upward line), the orange line indicates partial recurrence of the symptoms and the red lines indicate complete recurrence of the symptoms (downward line) or maintaining of no improvement (the same) (horizontal line). The numbers represent the amount of patients. In five patients no long-term data could be obtained (numbers with question marks).

3.2.2 The minimal invasiveness of the minimally invasive decompression procedure

The minimal invasiveness of the MID procedure was determined by evaluating the presence of postoperative complications near the wound, i.e. haematoma, signs of infection, pain and discomfort and hypaesthesia. The wound related information was obtained from the questionnaire by means of yes/no questions.

The amount of patients who answered either yes or no to the presence of the postoperative complications are shown in table 3.4. Haematoma was present in five out of 31 patients, signs of infection in one out of 31 patients, pain in three out of 31 patients and discomfort and hypaesthesia in seven out of 31 patients. Twenty-three out of 31 patients (74.19%) had none of the postoperative complications, whereas eight patients experienced one or more complications (table 3.5). In three patients only discomfort and hypaesthesia were present, in one patient both haematoma and signs of infection were present, in one patient haematoma and discomfort and hypaesthesia were present and in three patients haematoma, pain and discomfort and hypaesthesia were present. For all we know, in five of the seven patients the discomfort and hypaesthesia disappeared over time.

Table 3.4. Presence of postoperative complications.

Haematoma	Signs of infection	Pain	Discomfort and hypaesthesia
Yes (5)	Yes (1)	Yes (3)	Yes (7)
No (26)	No (30)	No (28)	No (24)

For each postoperative complication, i.e. haematoma, signs of infection, pain and discomfort and hypaesthesia, the amount of patients is shown between brackets in which the complication was either present or absent (each time for the 31 patients).

Table 3.5. Presence of postoperative complications per patient.

Amount of patients	Haematoma	Signs of infection	Pain	Discomfort and hypaesthesia
23	no	no	no	no
1	yes	yes	no	no
3	yes	no	yes	yes
1	yes	no	no	yes
3	no	no	no	yes

The postoperative complications are shown of which one or more were present or absent within a single patient.

3.2.3 The remaining aspects of the minimally invasive decompression procedure

The satisfaction of the patients regarding the MID surgery and the duration of the inability to work after surgery were obtained from the questionnaire by means of closed questions.

The satisfaction of the patients regarding the surgery is shown in table 3.6 and ranges from very satisfied to very dissatisfied. Most patients were (very) satisfied, i.e. 16 out of 31 patients were very satisfied, eight out of 31 patients were satisfied and three out of 31 patients were rather satisfied. Two out of 31 patients were dissatisfied: for both patients no short-term or long-term improvement of the symptoms occurred (figure 3.8). Two patients were rather dissatisfied: for one patient there was no short-term or long-term improvement of symptoms (figure 3.8), the other patient improved in the short-term (long-term data unknown). None of the patients were very dissatisfied.

Table 3.6. Patient satisfaction.

very satisfied	satisfied	rather satisfied	rather dissatisfied	dissatisfied	very dissatisfied
16	8	3	2	2	0

The amount of patients (n=31) for each satisfaction degree.

The duration of the inability to work after the surgery is shown in table 3.7. Most patients returned to work between 1 to 4 weeks after the MID surgery, i.e. 20 out of 31 patients. The duration of the inability to work was 5 to 8 weeks for three out of 31 patients and 6 to 12 months for two out of 31 patients. In six out of 31 patients no data could be obtained.

Table 3.7. Duration of inability to work after surgery.

1-4 weeks	5-8 weeks	6-12 months	no data
20	3	2	6

The amount of patients (n=25) is given for each duration range.
In six patients no data could be obtained.

4. DISCUSSION

Several surgical procedures exist to treat the CubTS. However, the SD procedure has become more popular because of its effectiveness and low invasive character. Recently, more research is being conducted regarding minimally invasive SD procedures in order to increase the wellbeing of CubTS patients. Both endoscopic assisted SD approaches and SD approaches using a small incision are being investigated. However, there is still some debate regarding the minimally invasive SD approaches. Even though it is in the interest of the patient not to injure the posterior branch(es) of the MACN and the crossing branch of the basilic vein, insufficient attention is being directed to the anatomy during CubTS surgery.

Therefore, this study aimed to increase the insights into a minimally invasive SD approach to treat the CubTS. Especially the use of a smaller SD incision and the position of the posterior branch(es) of the MACN and the crossing branch of the basilic vein were addressed. Knowledge regarding the anatomy is the central aspect in order to discuss the SD minimal invasiveness and the related SD incision requirements, without altering the SD effectiveness. Therefore, anatomical guidelines were first provided.

4.1 ANATOMICAL GUIDELINES

In the first place, the knowledge and awareness of the position of the posterior branch(es) of the MACN and the crossing branch of the basilic vein is crucial in order to achieve the minimal invasiveness. Moreover, discussing the SD incision requirements based on the relevant anatomy, contributes to the insights into a minimally invasive and effective SD procedure (figure Supp 4.1).

4.1.1 Description of the position of the posterior branch(es) of the medial antebrachial cutaneous nerve and the crossing branch of the basilic vein

The number and the course of the posterior branch(es) of the MACN in relation to the medial epicondyle were investigated in two upper limbs by a dissection study (table 3.1). As described in the introduction, Masear et al. explored 50 cadaveric arms (cadaver study) and Lowe et al. investigated 97 arms during surgery (intraoperative study) regarding these posterior branch(es) as well (table 1.1) (16, 30). In all the studies the number of posterior branch(es) of the MACN ranged from one to four.

A distal crossing posterior branch of the MACN was found in all cases (100%) in the dissection study and the intraoperative study (30). Although the distal crossing branch was present in the cadaver study, no information was given regarding their frequency (16). A proximal crossing posterior branch of the MACN or a branch crossing at the medial epicondyle was found in 61% of the cases by Lowe et al. and in 90% by Masear et al.. However, the precise course and exact frequency was not provided for the proximal crossing branch and branch crossing at the medial epicondyle separately (16, 30). In the dissection study a posterior branch of the MACN crossing at the medial epicondyle was present in 50% of the cases and a proximal crossing branch in none of the cases (0%). The results of the three studies regarding the proximal crossing branch and the branch crossing at the medial epicondyle are rather different.

The short period of time allowed for the dissection of two arms and consequently, no significant results could be obtained. However, even the elaborate cadaver and intraoperative studies show different results. In any case, the dissection results contribute to the insights into the course of the posterior branch(es). The course of the posterior branch(es) were investigated in two random arms, which means that the dissection results, i.e. the presence of a distal crossing branch in 100%, a branch crossing at medial epicondyle in 50% and a proximal crossing branch in 0%, either could be attributed by chance or could represent the majority of the patients. In other words: it was either coincidence that these branches' positions were present in the two arms or given the fact that it were only two random arms in which these branches' positions were present, these branches' positions are the most common in the majority of the patients. Moreover, in the intraoperative study the distal crossing branch was always present as well and the cadaver study offered no information regarding the frequency. Since the frequencies of the proximal crossing branch and the branch crossing at the medial epicondyle were combined in both the intraoperative study (frequency of 61%) and cadaver study (frequency of 90%), it is possible that the branch crossing at the medial epicondyle was represented more in these frequencies than the proximal crossing branch (16, 30).

From these results it seems that the distal crossing posterior branch of the MACN is most likely present in all patients. Moreover, the posterior branch of the MACN crossing at the medial epicondyle is likely present as well. However, the proximal crossing posterior branch of the MACN could also be present, but probably less often. These results also indicate that the course of the posterior branch(es) of the MACN may be variable. Therefore, care should be taken during CubTS surgery. More studies should be performed in order to confirm these findings.

During the dissection study, the position of the crossing branch of the basilic vein was investigated as well. This branch was present in all three specimens and encountered at a position of 2 to 3 cm proximal to the medial epicondyle. To the best of our knowledge, no scientific literature was found regarding the crossing branch of the basilic vein. However, this branch was frequently encountered during CubTS surgery as well. These findings suggest that the crossing branch of the basilic vein is likely present in all patients.

4.1.2 Discussion of the simple decompression incision requirements based on the relevant anatomy

In order to achieve a minimally invasive SD procedure the risk of injury to the posterior branch(es) of the MACN and the crossing branch of the basilic vein should be minimized. Moreover, in order to maintain the effectiveness of the SD procedure as well, sufficient proximal and distal decompression of the ulnar nerve must be performed. Therefore, these anatomical aspects must be taken into account in order to determine the SD incision requirements, i.e. SD incision length and location (figure Supp 4.1). During the dissection, a SD incision was shown based on the position of the posterior branch(es) of the MACN and the proximal and distal compression sites of the ulnar nerve.

The risk of injury to the posterior branch(es) of the MACN during SD of the ulnar nerve could be minimized by using a small incision of approximately 3 cm exactly between the medial epicondyle

and olecranon (figure 3.4). Hereby, the position of the distal crossing posterior branch of the MACN was particularly taken into account because of its high prevalence (table 1.1 and table 3.1). The position of the posterior branch of the MACN crossing at the medial epicondyle was also taken into account since this branch is likely to be present as well. The findings of Masear et al. and Lowe et al. show that one should be aware of a possible proximal crossing posterior branch of the MACN as well (16, 30). Moreover, this incision length and location allows easy access and sufficient proximal (3 cm) and distal (3 cm) decompression of the ulnar nerve (figure 3.5). During the proximal decompression, one needs to pay attention to the crossing branch of the basilic vein located at a position of 2 to 3 cm proximal to the medial epicondyle. Being aware of this crossing branch and its position, minimizes the risk of injury during surgery.

Overall, based on the relevant anatomy, a small SD incision of approximately 3 cm exactly between the medial epicondyle and olecranon, could contribute to a minimally invasive and effective SD procedure.

Taking into account these anatomical guidelines, a SD procedure using a small incision of 3.5 cm exactly between the medial epicondyle and olecranon (i.e. MID procedure) was performed in our hospital in order to treat the CubTS. Subsequently, the surgical outcome of the MID procedure was evaluated.

4.2 EVALUATION SURGICAL OUTCOME MINIMALLY INVASIVE DECOMPRESSION PROCEDURE

Thirty-one CubTS patients, who underwent the MID surgery between April 2009 and November 2011, were retrospectively evaluated by means of a postoperative questionnaire and subsequent consultation or telephone interview. The evaluation of the surgical outcome of the MID procedure aimed to investigate the use of a smaller SD incision. Therefore, the effectiveness and minimal invasiveness of the MID procedure were evaluated by means of clinical outcome parameters, i.e. the CubTS symptoms and postoperative complications associated with injury to the posterior branch(es) of the MACN and the crossing branch of the basilic vein respectively (figure Supp 4.1).

4.2.1 Evaluation effectiveness of the minimally invasive decompression procedure

The results of the comparison of the mean pre- and postoperative VAS scores of the symptoms show that the surgery significantly reduced all the symptoms, i.e. pain, paraesthesia, hypaesthesia and muscle weakness. The average postoperative reduction for paraesthesia was 66.04%, for hypaesthesia 65.05% and for muscle weakness 51.65%, which reduced by more than the half. Their average postoperative reduction was higher than for pain, which reduced by 44.51%. From these average symptom reduction results it is clear that paraesthesia and hypaesthesia reduced the most on average postoperatively. However, the average symptom reduction results represent an average reduction of the symptom per patient, taking into account the results of all the 31 patients. It is clear that the symptom improvement is not the same in each patient and that the result of each patient influenced the average amount of symptom reduction. The higher average reduction for

paraesthesia and hypaesthesia and the lower average reduction for muscle weakness can be explained by the following observations, which influenced the average amount of symptom reduction.

A larger amount of patients had no preoperative muscle weakness in comparison to paraesthesia and hypaesthesia. Muscle weakness was not present in four patients and remained the same after the surgery. In only one patient hypaesthesia was absent and remained absent after the surgery. Paraesthesia was present in all 31 patients. Moreover, the amount of patients who improved the symptom and the amount of patients in which the symptom not improved or worsened, influenced the average amount of symptom reduction. The amount of patients who improved hypaesthesia (86.67%) and muscle weakness (85.19%) was larger than the amount of patients who improved paraesthesia (80.65%). However, only a small difference was observed. Only four patients did not improve or worsen their muscle weakness postoperatively. The same was true for hypaesthesia. For paraesthesia, six patients did not improve or worsen postoperatively. For none of these three symptoms a postoperative worsening was observed.

Furthermore, the amount of symptom reduction per patient influenced the average amount of symptom reduction. Hereby, the amount of patients who experienced higher preoperative scores was relevant to consider. For paraesthesia and hypaesthesia, more patients experienced higher preoperative scores in comparison with muscle weakness. Consequently, larger amounts of reduction were possible for paraesthesia and hypaesthesia. For paraesthesia, two patients had a preoperative score of 10, which reduced to a score of 4 in one patient and to a score of 0 in the other patient. For hypaesthesia, a preoperative score of 10 was observed in three patients, of which two patients improved to a score of 6 and one patient improved to a score of 2. Moreover, for both paraesthesia and hypaesthesia, most patients had a preoperative score of 8, of which most patients improved postoperatively. For muscle weakness, most patients had preoperative scores of 8, 6 and 4 and none of the patients had a score of 10. Consequently, lower amounts of reduction were possible in comparison with paraesthesia and hypaesthesia. However, 12 patients did have a preoperative score of 8 and most patients improved to a score of 2 and 0. Moreover, in ten patients a preoperative score of 6 was observed of which most patients reduced to a score of 2.

Altogether, the average reduction results do not indicate that the MID surgery is more capable to reduce paraesthesia and hypaesthesia and less capable to reduce muscle weakness. This can also be observed by the fact that most patients had mild muscle weakness after the surgery, i.e. in 15 patients a score of 2 was observed and in 11 patients a score of 0 was observed. Only five patients had a postoperative score of 6. One of these patients improved from a preoperative score of 8 to a postoperative score of 6. The remaining four patients in which a postoperative score of 6 was observed, had a preoperative score of 6 as well. For paraesthesia and hypaesthesia, most patients had postoperative scores of 4, 2 and 0, i.e. most patients had mild to moderate symptoms. A postoperative score of 8 was observed in only four patients, who had the same score before the surgery. Some patients had a postoperative score of 6, but all these patients experienced an improvement of the symptoms. For muscle weakness, more patients had a postoperative score of 0 and 2 in comparison to paraesthesia and hypaesthesia (even when the four patients who not suffered from preoperative muscle weakness were not included).

From all the symptoms, pain had the lowest average amount of reduction. The average postoperative reduction of 44.51% for pain can be explained by the amount of patients who improved postoperatively, i.e. 62.07%. Furthermore, in eight patients the pain remained the same and in three patients pain worsened with a score amount of 2. In most patients lower preoperative scores were observed and therefore lower amounts of reduction were possible. Moreover, in two patients who did not experience preoperative pain, pain was present postoperatively. The amount of this postoperative worsening, i.e. score amount of 10 and 4, affect the average symptom reduction as well. However, most patients experienced mild to moderate postoperative pain. Therefore, the average reduction of 44.51% does not indicate that the MID surgery is less capable to reduce pain.

Overall, the MID surgery significantly reduced all the symptoms (short-term). Postoperatively, mild to moderate symptoms were observed in most patients. Furthermore, for each symptom, most patients improved after the surgery. However, for each symptom, some patients did not improve after the surgery, i.e. paraesthesia remained the same in six patients, hypaesthesia in four patients and muscle weakness in four patients. Pain remained the same in eight patients and worsened in three patients. Considering the results within a single patient, it is clear that one or more present symptoms remained the same (or worsened) after the surgery. There were 13 different patients out of the 31 in which (some of) their present preoperative symptoms did not improve. In three of these patients none of the present symptoms improved and in four of these patients the present symptoms improved partially after the surgery (short-term) (discusses below).

In the remaining six out of the 13 patients only pain remained the same in five patients or worsened slightly in one patient after the surgery. In these patients preoperative paraesthesia, hypaesthesia and muscle weakness were present as well, but did improve postoperatively. However, in these patients this pain was probably related to the surgery itself and not to symptom pain. Especially when all the other present symptoms did improve. Moreover, higher preoperative scores were observed for paraesthesia, hypaesthesia and muscle weakness in comparison with pain.

Next to these 13 patients, there were two patients in which preoperative pain was absent, but worsened after the surgery. In these patients moderate to severe paraesthesia, hypaesthesia and muscle weakness were present before the surgery and improved postoperatively. Therefore, the same explanation as described above for the six patients, was probably true in these patients as well. Therefore, the symptoms of these eight patients were considered as improved shortly after the surgery, next to the 16 patients in which all the present symptoms improved.

Overall, most patients improved shortly after the surgery (i.e. < 3 months after the surgery). For a longer period of time after the surgery (i.e. between 3 months and 3 years after the surgery), most patients remained improved as well. For five out of the 31 patients no long-term data could be obtained. Only in two patients who improved all the present preoperative symptoms shortly after the surgery, (some of) the symptoms recurred after a longer period of time after the surgery. In one patient only paraesthesia recurred. In the other patient the symptoms remained improved for 2 years after surgery and then recurred completely. This patient suffered from diabetes and several other conditions, which may have contributed to the recurrence.

In four patients the improvement occurred slower, i.e. shortly after the surgery the symptoms improved partially, but in the long-term all the symptoms did improve in three patients (in one patient the long-term data were unknown). In two of these three patients only one symptom

improved shortly after the surgery, after which the other symptoms improved in the long-term as well. These patients suffered from diabetes, which may contribute to the slower improvement. In one of the three patients, only one symptom (paraesthesia) did not improve shortly after the surgery, but did improve in the long-term. It is possible that the paraesthesia required a longer recovery period.

Only in three patients none of the present symptoms did improve in the short-term or the long-term. Severe paraesthesia and hypaesthesia and moderate pain were observed in all the three patients. In two patients severe muscle weakness was present as well. In two patients the symptoms were present for > 1 year and in the other patient 6 to 12 months. The severity and duration of preoperative symptoms may have contributed to the non-improvement of the symptoms. However, in this study, most patients experienced moderate to severe symptoms and for most patients the duration of preoperative symptoms was 6 to 12 months or more than 1 year (table 2.1). In these (other) patients the symptoms did improve after the MID surgery. Since the symptoms in the three patients did not worsen either (except for pain which worsened slightly in two patients), the MID surgery prevented the progression of the symptoms. The slightly worsened pain could be explained by pain related to the surgery.

The investigation of the CubTS symptoms aimed to evaluate the effectiveness of the MID procedure. As described above, the MID procedure significantly reduced pain, paraesthesia, hypaesthesia and muscle weakness. Hereby, the end result of the surgery within each patient is important: in most patients mild to moderate postoperative symptoms were observed. The MID surgery was capable to reduce severe, moderate and mild preoperative symptoms. Therefore the MID procedure is effective in severe, moderate and mild ulnar nerve compression neuropathies at the elbow, i.e. CubTS. In most patients an improvement of the symptoms was observed both shortly after the MID surgery and for a longer period of time after the MID surgery. However, in some patients no improvement was observed, but no worsening either. Therefore, the MID procedure was capable to prevent progression of the symptoms. Only in two short-term improved patients (some of) the symptoms recurred in the long-term, but this was probably related to other factors described above. The MID procedure is effective in the short-term and it seems effective in the long-term as well. Overall, the MID procedure is effective.

Since a retrospective patient study was conducted, the evolution of the symptoms (between the preoperative condition and postoperative condition) was investigated postoperatively by means of a questionnaire and consultation or telephone interview. Although the data regarding the symptoms were subjective, i.e. the intensities of the symptoms were described by the patients and no objective measurements were used, these data were valuable for the evaluation of the MID effectiveness. The VAS are accepted as valuable measuring tools in order to obtain the results and to determine the significance. Moreover, the closed questions were helpful as well in order to provide a clear overview of the symptoms' evolution. Even the long-term postoperative data regarding the presence or absence of the symptoms gave a clear overview.

4.2.2 Evaluation minimal invasiveness of the minimally invasive decompression procedure

The results of the presence of the postoperative complications near the wound show that the majority of the patients had none of the postoperative complications, i.e. 23 out of 31 patients (74.19%). Eight out of 31 patients suffered from one or more complications. Haematoma and discomfort and hypaesthesia were the most common complications, i.e. haematoma was present in five out of 31 patients and discomfort and hypaesthesia in seven out of 31 patients. Four out of 31 patients suffered from both complications, of which three had pain as well. One patient suffered from haematoma and signs of infection and three patients had only discomfort and hypaesthesia. To the best of our knowledge, five out of seven patients improved the discomfort and hypaesthesia over time, i.e. the postoperative complication was not permanent. None of the patients had reoperation for MACN injury or for haematoma.

The investigation of the postoperative complications aimed to evaluate the minimal invasiveness of the MID procedure. The presence of postoperative complications represent possible injury to the posterior branch(es) of the MACN and the crossing branch of the basilic vein during CubTS surgery.

Since a retrospective patient study was conducted, data regarding injury to the posterior branch(es) of the MACN and the crossing branch of the basilic vein could not be ascertained during surgery and the presence of the postoperative complications were obtained by a questionnaire. Consequently, it was not certain if injury to these structures during surgery really occurred and if the postoperative complications were really present. Moreover, it is possible that the presence of postoperative pain and discomfort and hypaesthesia were interpreted by the patients as the normal consequences after a surgery and were not related to MACN injury.

However, if the postoperative complications really were present and if they represent possible injury to the MACN and basilic vein branches, this indicates that injury to these branches still may occur, even when care was taken not to injure these branches during CubTS surgery. Therefore, the knowledge and awareness of the position of these branches is very important during CubTS surgery. This also means that in most patients none of the postoperative complications were present and therefore probably no injury to the posterior branch(es) of the MACN and the crossing branch of the basilic vein occurred in these patients during the MID surgery. Therefore, the MID procedure was associated with a minimal risk of injury to the posterior branch(es) of the MACN and the crossing branch of the basilic vein and consequently with a minimal postoperative complication rate. Overall, the MID procedure is minimally invasive.

4.2.3 Evaluation remaining aspects of the minimally invasive decompression procedure

Most patients were (very) satisfied regarding the MID surgery and returned to work between 1 to 4 weeks after the surgery. The satisfaction of the patients was related to the improvement of the symptoms, i.e. the three patients in which no short-term or long-term improvement of the symptoms occurred, were dissatisfied. Moreover, the MID procedure is simple to perform and is associated with a short surgery duration.

4.3 LINKING OF THE ANATOMICAL GUIDELINES AND SURGICAL OUTCOME EVALUATION OF THE MINIMALLY INVASIVE DECOMPRESSION

The surgical outcome of the MID procedure was evaluated in order to investigate the use of a smaller SD incision, i.e. 3.5 cm in length. The MID procedure is associated with minimal tissue trauma and a minimal postoperative complication rate and is capable to significantly reduce the CubTS symptoms. Therefore, these results indicate that the MID procedure is minimally invasive and effective. However, could this minimal invasiveness be attributed to the use of a smaller SD incision of approximately 3.5 cm? Given the fact that the position of the posterior branch(es) of the MACN and the crossing branch of the basilic vein was taken into account and care was taken not to injure these branches during the MID surgery, this resulted in reduced injury to these branches and consequently in reduced postoperative complications. This confirms that the knowledge and awareness of the position of these branches is crucial in order to achieve a minimally invasive SD procedure in the first place, as described in the anatomical guidelines. However, from the anatomical guidelines it is also clear that the SD incision, of which the requirements were based on the relevant anatomy, could contribute to the minimal invasiveness as well. Based on the position of the distal crossing posterior branch of the MACN and the posterior branch crossing at the medial epicondyle (because of high prevalence), a small SD incision of 3 cm exactly between the medial epicondyle and olecranon could minimize the risk of injury to these branches. Since the SD incision length and location of the MID procedure, i.e. incision of 3.5 cm between the medial epicondyle and olecranon, considered the position of the MACN posterior branch(es) as described in the anatomical guidelines, the use of this smaller SD incision probably contributed to the minimal invasiveness as well. Taking into account the possible presence of a proximal crossing posterior branch of the MACN and the presence of the crossing branch of the basilic vein located at a position of 2 to 3 cm proximal to the medial epicondyle, minimizes the risk of injury to these branches.

It is clear that a larger SD incision could increase the risk of injury to the posterior branch(es) of the MACN. However, smaller SD incisions do not necessarily make the SD procedure minimally invasive and they may even alter the SD effectiveness. The anatomical guidelines and the MID surgical outcome results showed that when the SD incision was located between the medial epicondyle and olecranon, the risk of injury to the posterior branch(es) of the MACN could be minimized and sufficient proximal and distal decompression of the ulnar nerve could be performed. Hereby, both the position of the MACN posterior branch(es) and the proximal and distal ulnar nerve compression sites were considered. Therefore, placing a smaller SD incision at a wrong location increases the risk of injury to the MACN posterior branch(es) and does not allow sufficient ulnar nerve decompression. Moreover, using a too small SD incision increases the risk of injury to the MACN posterior branch(es) as well, due to the struggling through a small opening, as reported for the endoscopic assisted SD approaches (23-25). A too small SD incision could compromise access to the ulnar nerve and may result in insufficient decompression.

In the literature various SD incision lengths and locations were described. Only Abuelem aimed to minimize injury to the MACN branches by decreasing the SD incision length. Therefore, they considered the position of the MACN branches in order to determine their incision requirements, i.e. an incision of 3.8 cm in length distal to the medial epicondyle. However, they did not investigate the course of the MACN posterior branch(es) themselves and based on our dissection results, this incision location probably will injure the branches. Moreover, this distal incision location does

probably not allow sufficient proximal decompression of the ulnar nerve. No patient results were described in this study and therefore no information was available regarding the minimal invasiveness and effectiveness of their procedure. Calisaneller et al. applied two incisions of 2 cm each proximal and distal to the medial epicondyle and investigated in only four patients. From their description good results were obtained and no postoperative complications were present. However, the location of the incision probably will injure the posterior branch(es) of the MACN. (28-29)

Taniguchi et al. investigated the use of smaller SD incision of 1.5 to 2.5 cm between the medial epicondyle and olecranon in 17 patients (and 18 elbows). They mentioned that they considered the branches of the MACN during surgery. According to their results, a postoperative haematoma was present in one elbow and no other complications were present in the other patients. A modified Messina classification was used to evaluate the symptoms: in four elbows complete resolution of the symptoms was observed, in ten elbows a general resolution of the symptoms occurred but with mild residual decreased sensibility and residual motor weakness and in four elbows an improvement of the symptoms was observed but with persistent residual sensory changes, motor loss and muscle wasting. These results may indicate the their procedure was minimally invasive and effective. However, it was not described which preoperative symptoms were present in each patient and which severity was associated with each symptom. The use of a smaller SD incision of 2 cm between the medial epicondyle and olecranon was investigated by Cho et al. in five patients. However, no attention was directed to the posterior branch(es) of the MACN. The outcome of the surgery was evaluated by a modified Bishop's scoring system, in which additional factors were included next to the symptoms. No information was provided regarding the presence or absence of the pre- and postoperative CubTS symptoms and no information was provided regarding the postoperative complications. Therefore, it is not clear whether this procedure was effective and/or minimally invasive. (26-27)

These findings indicate that the anatomy is important to consider and further research is necessary regarding the use of a smaller SD incision.

5. CONCLUSION

This study contributes to the insights into a minimally invasive SD approach to treat the CubTS. The linking of the anatomical guidelines and the MID surgical outcome evaluation, indicates that the anatomy is the central aspect in order to achieve a minimally invasive SD procedure.

The anatomical guidelines provide a description of the position of the posterior branch(es) of the MACN and the crossing branch of the basilic vein (increasing the knowledge and awareness of the position of these branches by peripheral nerve surgeons) and a discussion of the SD incision requirements based on the relevant anatomy, in order to achieve a minimally invasive SD procedure.

The evaluation of the surgical outcome of the MID procedure confirms that when these MACN and basilic vein branches are taken into account during surgery and a smaller SD incision is applied based on the position of the MACN branches, the risk of injury to these branches is minimized and consequently the postoperative complications are avoided, implying that a minimally invasive SD procedure can be achieved in this manner.

Altogether, these findings suggest that the use of a smaller SD incision of 3 to 3.5 cm in length, located exactly between the medial epicondyle and olecranon, could result in a minimally invasive SD procedure, without altering its effectiveness. These results of the study contribute to the wellbeing of CubTS patients.

It is clear that further research is required regarding the minimal invasiveness and effectiveness of the MID procedure. Hereby, a larger amount of CubTS patients should be investigated by means of a follow-up study. In this way, findings of before, during and after the MID surgery could be investigated and documented, for example, injury to the MACN posterior branch(es) and the crossing branch of the basilic vein could be ascertained during the surgery itself and the presence of postoperative complications could be observed immediately after the surgery (consultation). In addition to the VAS and closed questions, objective measurements of the symptoms should be applied as well, e.g. the execution of pre- and postoperative electromyography findings and measuring grip strength using a dynamometer.

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SUPPLEMENTARY INFORMATION

Supplementary Introduction

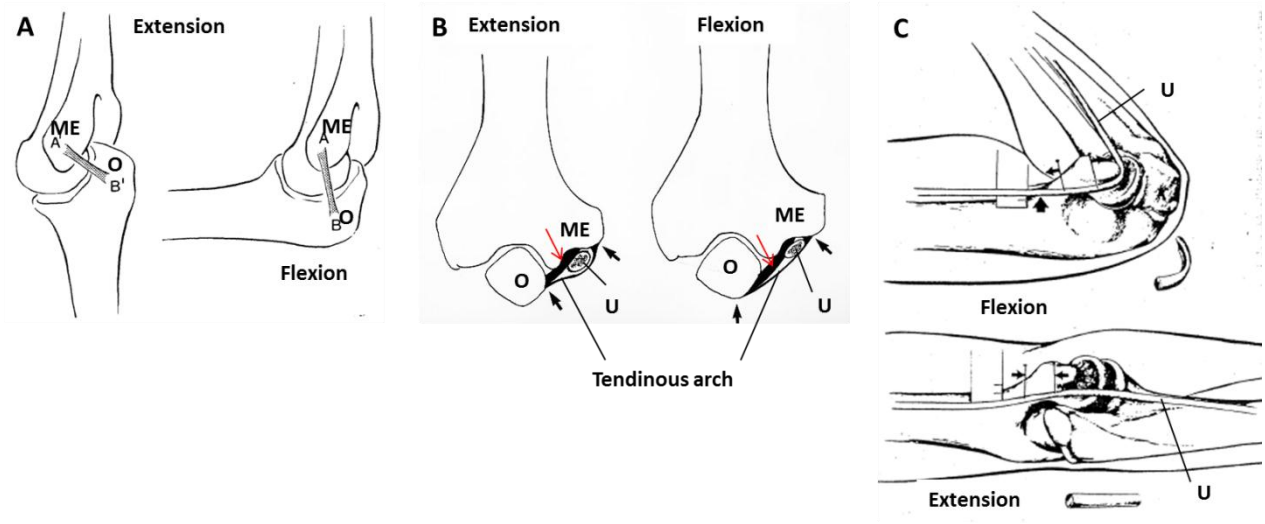


Figure Supp 1.1. Dynamic anatomy of the elbow. (4,10-11)

A: A-B = A'-B' + 10 mm. B: medial collateral ligament (red arrows). ME: medial epicondyle, O: olecranon, U: ulnar nerve.

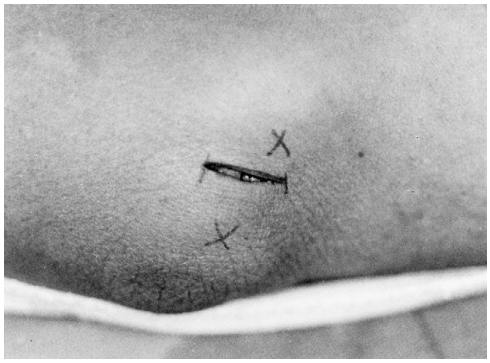


Figure Supp 1.2. Incision of 1.5 to 2.5 cm between the medial epicondyle and olecranon by Taniguchi et al. (26)

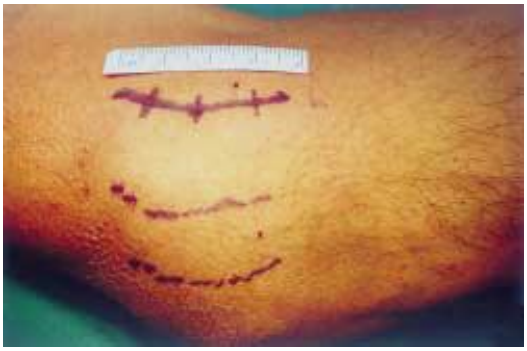


Figure Supp 1.3. Incision of 4 cm anteriorly to the medial epicondyle by Filippi et al. (21)

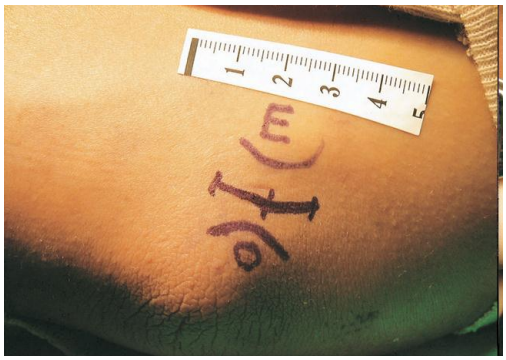


Figure Supp 1.4. Incision of 2 cm between the medial epicondyle and olecranon by Cho et al. (27)

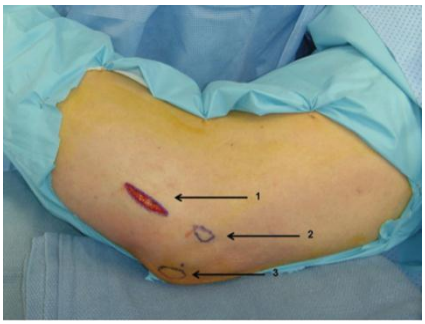


Figure Supp 1.5. Incision of 3.8 cm distal to the medial epicondyle by Abuelem. (28)

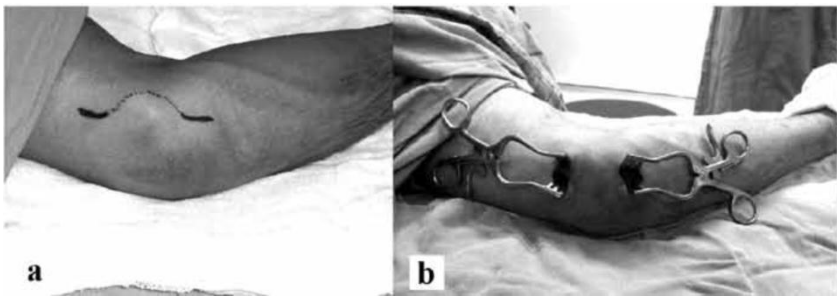


Figure Supp 1.6. Two incisions of 2 cm each proximal and distal to the medial epicondyle by Calisaneller. (29)

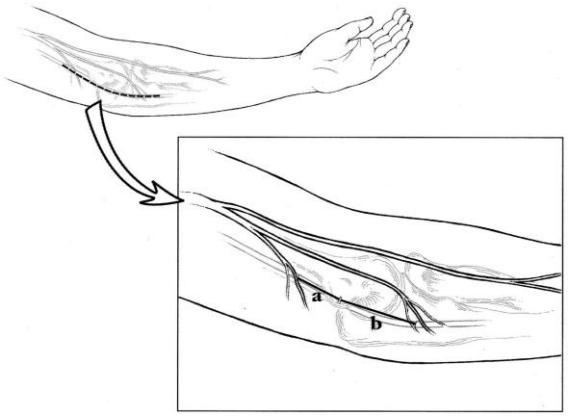


Figure Supp 1.7. Course of the posterior branch(es) of the medial antebrachial cutaneous nerve during intraoperative study by Lowe et al. (30)

The a marks the average distance of the proximal crossing branch of (1.8 cm) from the medial epicondyle and b marks the average distance of the distal branch (3.1 cm) from the medial epicondyle.

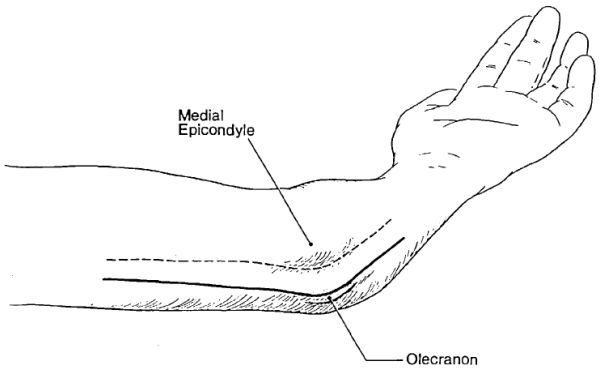


Figure Supp 1.8. Anterior transposition skin incision by Race et al. (31)

Old incision (dotted line) and current incision (black line).

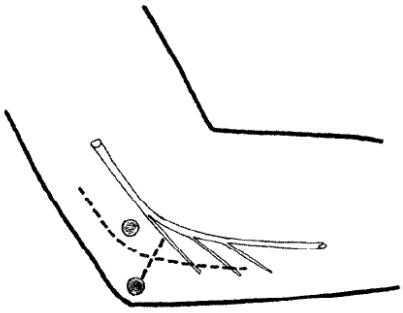


Figure Supp 1.9. Transverse anterior transposition skin incision by LIuch. (32)

Supplementary Materials & Methods

Postoperative questionnaire (figure Supp 2.1.)

VRAGENLIJST IN VERBAND MET DE OPERATIE

NAAM : … VOORNAAM : …

GEBOORTEDATUM : … / … / ……

Datum operatie: … / … / … … Elleboog: links / rechts

VÓÓR DE OPERATIE

Deze vragen handelen over de toestand **vóór** U werd geopereerd !

Duur van de klachten alvorens operatie :
Hoelang duurden Uw klachten in hand en arm alvorens U de operatie onderging ? Duid het juiste hokje aan :

- ☐ 1 à 4 weken
- ☐ 5 à 8 weken
- ☐ 2 à 4 maanden
- ☐ 4 à 6 maanden
- ☐ 6 à 12 maanden
- ☐ méér dan 1 jaar

Optreden van klachten :
Traden uw klachten op na een werkongeval, trauma, of dergelijke ? ☐ ja ☐ neen

Indien ja, vermeld het ongeval, trauma, … : ……

Pijn :
Hoe ernstig was de pijn die U voor de operatie ondervond? Duid het hokje aan dat het best de toestand beschrijft **vóór** de operatie :

- ☐ Geen pijn.
- ☐ Nauwelijks pijn.
- ☐ Een beetje pijn, af en toe. Geen pijnstillers nodig.
- ☐ Regelmatig pijn, af en toe pijnstillers nodig.
- ☐ Veel pijn, gebruik van pijnstillers noodzakelijk.
- ☐ Zeer veel pijn, nauwelijks uit te houden, kan niet zonder pijnstillers.

Hoe ernstig was de pijn die U **vóór** de operatie ondervond? Trek een vertikaal streepje op de onderstaande lijn *tussen* 0 en 10, waarbij 0 betekent dat U géén pijn had voor de operatie, 10 betekent dat U extreem hevige pijn had vóór de operatie :

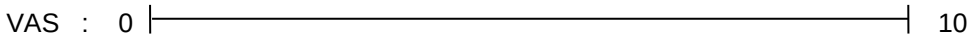
VAS : 0 ├──┤ 10

Geen pijn Extreem hevige pijn

Tintelingen :
Ondervond U vóór de operatie een **abnormaal** gevoel, zoals *tintelingen, prikkelingen*, … (gevoel of men " met tientallen fijne naaldjes in de huid prikt ") in de hand of de vingers? Duid het hokje aan dat het best de toestand **vóór** de operatie beschrijft :

- ☐ Geen tintelingen
- ☐ Nauwelijks tintelingen
- ☐ Af en toe tintelingen, niet storend
- ☐ Regelmatig tintelingen, wel storend
- ☐ Veel tintelingen, quasi continu aanwezig
- ☐ Zeer veel tintelingen, erg storend en onhoudbaar

Hoe storend waren deze tintelingen voor U? Trek een vertikaal streepje op de onderstaande lijn *tussen* 0 en 10, waarbij 0 betekent dat U helemaal géén tintelingen ondervond, en 10 dat U zeer veel en extreem storende tintelingen ondervond :

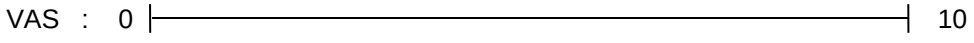


Geen tintelingen — Zeer veel tintelingen

Voosheid :
Ondervond U vóór de operatie een **verminderd** gevoel, alsof er een een *voos en dof gevoel* was in de hand en vingers en de hand en vingers leken te *slapen*? Duid het hokje aan dat het best de toestand **vóór** de operatie beschrijft :

- ☐ Geen voosheid
- ☐ Nauwelijks voosheid
- ☐ Een beetje voosheid, niet storend
- ☐ Lichte voosheid, wel storend
- ☐ Duidelijk verminderd gevoel, storend
- ☐ Erg uitgesproken voosheid, erg storend

Hoe storend was dit verminderd gevoel voor U? Trek een vertikaal streepje op de onderstaande lijn *tussen* 0 en 10, waarbij 0 betekent dat U helemaal geen voosheid ondervond, en 10 dat U een zeer sterk verminderd en voos gevoel ondervond :



Geen voosheid — Ernstig verminderd gevoel

Krachtsvermindering :
Had U **vóór** de operatie het gevoel dat de vingers en/of de hand **minder kracht** hadden? Was er volgens U een verlamming aanwezig? Duid het hokje aan dat het best de toestand **vóór** de operatie beschrijft :

- ☐ Volledig normale kracht
- ☐ Nauwelijks verminderde kracht, niet storend in het dagelijks leven
- ☐ Verminderde kracht, valt op in dagelijks leven
- ☐ Verminderde kracht, storend bij de activiteiten van het dagelijks leven
- ☐ Sterk verminderde kracht, duiselijke weerslag op gebruik van hand
- ☐ Kracht zeer slecht, nauwelijks bruikbare spieren

Hoe ernstig was de krachtsvermindering volgens U **vóór** de operatie? Trek een vertikaal streepje op onderstaande lijn *tussen* 0 en 10, waarbij 0 betekent dat U een zeer uitgesproken krachtsverlies ondervond, 10 betekent dat U een volledig normale kracht had :

VAS : 0 ├──┤ 10

Sterk verminderde kracht Normale kracht

Reeds ondergane behandelingen ?
Welke behandeling (van huisarts, andere specialist, …) onderging U reeds vóór U werd geopereerd?

Medicatie ? □ ja □ neen

Indien ja, welke medicatie: ……

Corticoied-infiltraties ? □ ja □ neen

Andere (accupunctuur, …) ? □ ja □ neen

Beroep ?
Welk beroep oefende U uit op het moment van de operatie? ……

Bent U rechts- of linkshandig ?

□ Rechtshandig
□ Linkshandig

Lijdt U aan een bepaalde aandoening(en) (diabetes, …) ?

□ ja □ neen

Indien ja, welke aandoening(en): ……...

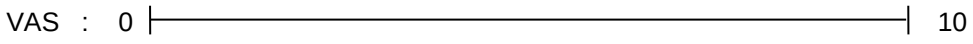
NA DE OPERATIE

Deze vragen handelen over de toestand **nadat** U werd geopereerd !

Pijn :
Hoe ernstig was de pijn die U **ná** de operatie ondervond? Duid het hokje aan dat het best de toestand beschrijft **ná** de operatie :

□ Geen pijn meer
□ Nauwelijks pijn
□ Een beetje pijn, af en toe
□ Regelmatig pijn
□ Even veel pijn als vóór de operatie
□ Meer pijn dan vóór de operatie

Hoe ernstig was de pijn die U **ná** de operatie ondervond? Trek een vertikaal streepje op de onderstaande lijn *tussen* 0 en 10, waarbij 0 betekent dat U geen pijn meer had na de operatie, 10 betekent dat U nog steeds zeer hevige pijn had na de operatie :

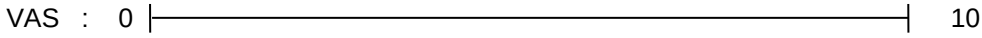


Geen pijn Extreem hevige pijn

Tintelingen :
Ondervond U **ná** de operatie een abnormaal gevoel, zoals *tintelingen, prikkelingen*, … (gevoel of men " met tientallen fijne naaldjes in de huid prikt ") in de hand of de vingers? Duid het hokje aan dat het best de toestand **ná** de operatie beschrijft **:**

- ☐ Geen tintelingen meer
- ☐ Nauwelijks nog tintelingen
- ☐ Af en toe nog tintelingen
- ☐ Nog regelmatig tintelingen
- ☐ Even veel tintelingen als vóór de operatie
- ☐ Méér tintelingen als vóór de operatie

Hoe storend waren deze tintelingen voor U? Trek een vertikaal streepje op de onderstaande lijn *tussen* 0 en 10, waarbij 0 betekent dat U helemaal géén tintelingen ondervond, en 10 dat U zeer veel en extreem storende tintelingen ondervond **ná** de operatie :

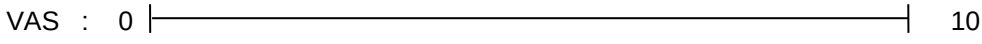


Geen tintelingen Zeer veel tintelingen

Voosheid :
Ondervond U **ná** de operatie een **verminderd** gevoel, alsof er een een *voos en dof gevoel* was in de hand en vingers en de hand en vingers leken te *slapen*? Duid het hokje aan dat het best de toestand **ná** de operatie beschrijft :

- ☐ Geen voosheid meer
- ☐ Nauwelijks voosheid, niet storend
- ☐ Een beetje voosheid
- ☐ Nog lichte voosheid, doch beter dan vóór de operatie
- ☐ Voosheid even erg als vóór de operatie
- ☐ Voosheid erger dan vóór de operatie

Hoe storend is dit verminderd gevoel voor U? Trek een vertikaal streepje op de onderstaande lijn *tussen* 0 en 10, waarbij 0 betekent dat U helemaal geen voosheid meer ondervindt, en 10 dat U nog steeds een zeer sterk verminderd en voos gevoel ondervindt :



Geen voosheid Ernstig verminderd gevoel

Kracht :
Had U **ná** de operatie het gevoel dat de vingers en/of de hand minder kracht hadden? Was er volgens U een verlamming aanwezig? Duid het hokje aan dat het best de toestand **ná** de operatie beschrijft :

- □ Volledig normale kracht
- □ Nauwelijks verminderde kracht, niet storend in het dagelijks leven
- □ Verminderde kracht, valt op in dagelijks leven
- □ Verminderde kracht, storend bij de activiteiten van het dagelijks leven
- □ Sterk verminderde kracht
- □ Kracht slechter dan vóór de operatie

Hoe ernstig was de krachtsvermindering volgens U **ná** de operatie? Trek een vertikaal streepje op onderstaande lijn *tussen* 0 en 10, waarbij 0 betekent dat U een zeer uitgesproken krachtsverlies ondervond, 10 betekent dat U een volledig normale kracht had **ná** de operatie:

VAS : 0 ├──┤ 10

Sterk verminderde kracht Normale kracht

Tevredenheid over ingreep ?
Duid het juiste hokje aan, dat het best beschrijft hoe tevreden U bent met het resultaat van de ingreep:

- □ Zeer tevreden
- □ Tevreden
- □ Eerder tevreden
- □ Eerder ontevreden
- □ Niet tevreden
- □ Zeer ontevreden

Lengte van het litteken ?
Mogen wij U vragen de lengte van het litteken te meten met een latje ? …….cm

Wondgenezing ?

Had U tijdens het genezingsproces veel pijn ter hoogte van de wonde ?
□ ja □ neen

Was er een bloeduitstorting ter hoogte van de wonde ?
□ ja □ neen

Waren er tekens van infectie ter hoogte van de wonde ?
□ ja □ neen

Werden antibiotica voorgeschreven om de wondgenezing te verbeteren ?
□ ja □ neen

Had U tijdens het genezingsproces veel hinder (gevoelloosheid, ongemak, …) ter hoogte van de wonde ?
□ ja □ neen

Indien ja, heeft U nu nog steeds hinder ter hoogte van de wonde ? □ ja □ neen

Hoelang was U na de ingreep werkongeschikt ?

Duid het juiste hokje aan :

- ☐ 1 à 4 weken
- ☐ 5 à 8 weken
- ☐ 2 à 4 maanden
- ☐ 4 à 6 maanden
- ☐ 6 à 12 maanden
- ☐ méér dan 1 jaar

Huidige situatie ?

Kan U in Uw eigen woorden omschrijven hoe de situatie sinds de ingreep is geëvolueerd? Is de toestand verder verbeterd, hetzelfde gebleven of opnieuw verslechterd?

…
…
…
…
…

Bent U na de operatie nog ergens anders behandeld voor hetzelfde probleem? Zo ja, welke behandelingen onderging U dan? Werd U nogmaals geopereerd?

…
…
…
…
…

Wenst U zelf nog iets toe te voegen (eigen commentaar op operatie, verzorging, evolutie van de klachten, …)?

…
…
…
…

Supplementary Discussion

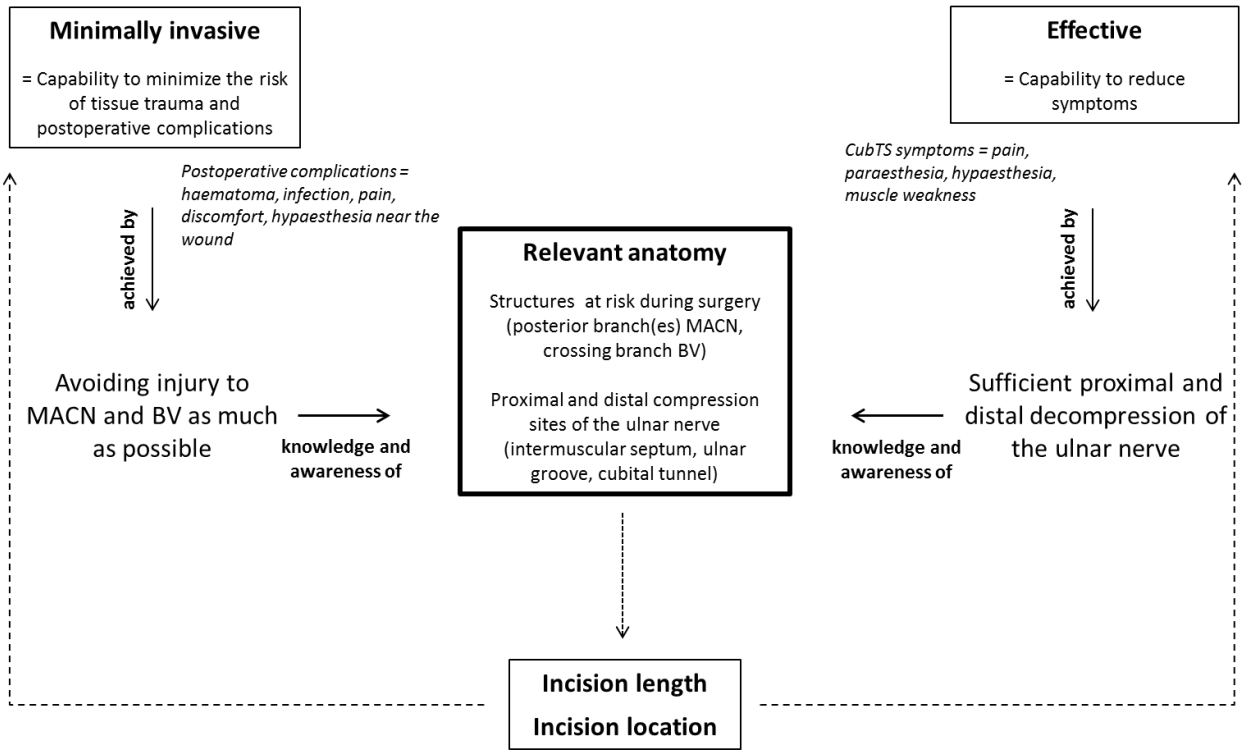


Figure Supp 4.1. Minimal invasiveness and effectiveness based on relevant anatomy and incision length and location.

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Ik/wij verlenen het wereldwijde auteursrecht voor de ingediende eindverhandeling:
Minimally invasive decompression as treatment for the cubital tunnel syndrome: anatomical guidelines and surgical outcome evaluation

Richting: **master in de biomedische wetenschappen-klinische moleculaire wetenschappen**
Jaar: **2012**

in alle mogelijke mediaformaten, - bestaande en in de toekomst te ontwikkelen - , aan de Universiteit Hasselt.

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Voor akkoord,

Claeskens, Jorien

Datum: **21/08/2012**