Anterior subcutaneous transposition of the ulnar nerve improves neurological function in patients with cubital tunnel syndrome

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Abstract

Although several surgical procedures exist for treating cubital tunnel syndrome, the best surgical option remains controversial. To evaluate the efficacy of anterior subcutaneous transposition of the ulnar nerve in patients with moderate to severe cubital tunnel syndrome and to analyze prognostic factors, we retrospectively reviewed 62 patients (65 elbows) diagnosed with cubital tunnel syndrome who underwent anterior subcutaneous transposition. Preoperatively, the initial severity of the disease was evaluated using the McGowan scale as modified by Goldberg: 18 patients (28%) had grade IIA neuropathy, 20 (31%) had grade IIB, and 27 (42%) had grade III. Postoperatively, according to the Wilson & Krout criteria, treatment outcomes were excellent in 38 patients (58%), good in 16 (25%), fair in 7 (11%), and poor in 4 (6%), with an excellent and good rate of 83%. A negative correlation was found between the preoperative McGowan grade and the postoperative Wilson & Krout score. The patients having fair and poor treatment outcomes had more advanced age, lower nerve conduction velocity, and lower action potential amplitude compared with those having excellent and good treatment outcomes. These results suggest that anterior subcutaneous transposition of the ulnar nerve is effective and safe for the treatment of moderate to severe cubital tunnel syndrome, and initial severity, advancing age, and electrophysiological parameters can affect treatment outcome.

Key Words: nerve regeneration; peripheral nerve injury; ulnar nerve compression syndrome; age; motor nerve conduction velocity; electrophysiology; sensory nerve conduction velocity; modified McGowan scale; Wilson & Krout criteria; anterior transposition; ulnar nerve; NSFC grant; neural regeneration

Introduction

Cubital tunnel syndrome (CuTS) is the second most common peripheral compression neuropathy in the upper extremity (Zlowodzki et al., 2007; Macadam et al., 2008; Kawanishi et al., 2014; Mirza et al., 2014). This condition was first described in 1878, and the term cubital tunnel syndrome was initially adopted in 1958 (Feindel and Stratford, 1958).

The ulnar nerve, originating from the medial cord of the brachial plexus, consists of C_8 and T_1 nerve roots. The nerve is in the cubital tunnel, behind the medial epicondyle of the humerus. During elbow flexion and extension, nerve tension and traction increase, leaving the ulnar nerve predisposed to compressive neuropathy.

The syndrome is mainly characterized by numbness of the little and ring fingers, intrinsic hand muscle atrophy, and an inability to perform fine motor activity. In some patients, pain appears at the medial aspect of the elbow and radiates to the wrist and proximal forearm (Wojewnik and Bindra, 2009; Mitsionis et al., 2010).

Currently, surgeons treat patients initially using conservative measures because symptoms may resolve in up to 50% of the cases. Conservative treatment should be tried for at least 3 months before surgical intervention, particularly in mild cases (Wojewnik and Bindra, 2009).

There are three commonly used surgical treatments for patients whose symptoms do not relieve after nonsurgical intervention: (1) simple decompression, in which Osborne's band can be released using either open or endoscopic surgical methods; (2) medial epicondylectomy; and (3) anterior transposition of the ulnar nerve by intramuscular, submuscular or subcutaneous placement of the nerve. When comparing the different types of surgical interventions, previous studies reported no method with encouraging outcomes

(Zlowodzki et al., 2007; Macadam et al., 2008; Zarezadeh et al., 2012; Bolster et al., 2013; Bacle et al., 2014). In patients with an advanced stage of CuTS, anterior transposition of the ulnar nerve should be considered. Anterior transposition of the ulnar nerve can wholly release the nerve and resolve the dynamic factors involved in CuTS (Bacle et al., 2014).

Evidence indicates that 70–90% of the surgical results from anterior subcutaneous transposition of the ulnar nerve are good to excellent (Glowacki and Weiss, 1997; Asami et al., 1998; Lascar and Laulan, 2000). This operation was also proved effective in patients with recurrent CuTS (Caputo and Watson, 2000). However, results among previous publications are variable, and factors that affect the outcome of this surgery are controversial. In addition, many previous studies included mild cases and small sample sizes, which influenced the evaluation of the surgical effect (Hamidreza et al., 2011; Bacle et al., 2014).

Therefore, the present study retrospectively analyzed the surgical results of patients with advanced CuTS who underwent anterior subcutaneous transposition of the ulnar nerve and reviewed the factors that might affect surgical outcomes.

Subjects and Methods

Subjects
This retrospective analysis included all patients admitted to the department with a diagnosis of CuTS during 2008–2013. The Ethics Committee at the Peking University People's Hospital, China, approved the study. All subjects provided their written informed consent regarding participation in this study.

Diagnostic criteria: (1) Patients diagnosed using signs and clinical examination, such as numbness or hypoesthesia at one plus one-half ulnar-sided fingers; (2) intrinsic hand muscle atrophy or weakness; hypothenar muscle atrophy; (3) positive Tinel's sign or elbow flexion tests.

Inclusion criteria: Patients diagnosed with primary idiopathic CuTS, with no previous surgery at the elbow. Patients first treated using nonsurgical methods, and in cases of muscle atrophy, motor nerve conduction velocity (NCV) < 40 m/s or unresponsiveness, anterior subcutaneous transposition of the ulnar nerve surgically performed.

Exclusion criteria: (1) a double crush lesion, such as cervical spondylopathy or thoracic outlet syndrome; (2) Mc-Gowan grade I compression; (3) instability of the elbow or revision surgery; (4) patients who could not be followed.

In total, 113 patients underwent surgical treatment for CuTS in our department. Of these, 38 patients were unavailable for follow-up (the patients could not be contacted or the patients were reluctant to take part in the last follow-up during the outpatient service). In addition, 13 patients were excluded from this study for a double crush lesion, McGowan grade I compression, instability of the elbow, or revision surgery. Thus, 62 patients (65 elbows), 42 males (45 elbows from these 42 males) and 20 females, were included in this study.

Each patient was examined preoperatively, and the following

data were evaluated: initial chief concern, duration of symptoms, clawing, Tinel's sign around the elbow, flexion test at the elbow, weakness of intrinsic muscles, atrophy of the interosseous muscle, and the results of the electrophysiological studies.

Electrophysiological examination
A Viking IV electromyograph (Nicolet Biomedical, Madison, WI, USA) was used to conduct the electrophysiological examinations. All patients were subjected to examinations of motor conduction velocity (MCV) across the elbow (MCV1) and forearm segments (MCV2) of the ulnar nerve and of sensory conduction velocity (SCV) in the hand. During MCV recording, the recording surface electrodes were placed in the abductor digiti minimi. The stimulation sites were on the wrist, 5-cm distal and also 5-cm proximal to the medial epicondyle. During SCV recording, stimulating electrodes were placed on the fifth digit (the little finger), and needle electrodes were used at the wrist for recording. We also recorded nerve evoked amplitude, action potential latency, compound muscle action potential amplitude (CMAP, CMAP1 at the elbow and CMAP2 at the forearm), and the sensory nerve action potential (SNAP). The room temperature was approximately 25°C.

Surgical techniques
After inflating a tourniquet, a 10–12-cm incision was made from 5–6-cm proximal to 5–6-cm distal of the medial epicondyle. During the subcutaneous dissection, the medial antebrachial cutaneous nerve was located and care was taken to avoid damaging it. All structures that might compress the nerve were released and the internal intermuscular septum was incised.

During the manipulation, the artery to the ulnar nerve was preserved as much as possible. The nerve was then transferred forward of the medial epicondyle. A fascial flap was harvested from the superficial fascia of the medial epicondyle muscles to prevent nerve slippage. The flexion and extension of elbow were tested to confirm that the nerve was completely released and no new deformity at the flap had been formed.

Homeostasis was performed after the tourniquet was deflated. Subcutaneous and cutaneous tissues were sutured using 3-0 absorbable and 3-0 Ethilon sutures, respectively. Finger and elbow movements were initiated starting the day after the surgical procedure.

Assessment
Preoperatively, patients were categorized using the Mc-Gowan scale as modified by Goldberg (MGG) (Goldberg et al., 1989): grade I, with symptoms but without abnormal objective findings; grade IIA, good intrinsic strength, meaning, UK Medical Research Council (MRC) grade 4 motor strength, and no detectable muscle atrophy; grade IIB, detectable intrinsic muscle atrophy, intrinsic extremity strength MRC grade 3; grade III, serious sensory disturbances, severe intrinsic atrophy, and obviously decreased intrinsic hand muscle strength with an MRC grade 3 or less.

Table 1 General information for the included 65 patients

Patient characteristics	Mean±SD	n(%)
Gender (male)		45(69)
Handedness (right)		38(58)
Age (year)	55.83±13.48	
Duration of symptom (month)	16.29±16.26	
Follow-up time (month)	28.50±13.88	
MCV1 (m/s)	38.96±12.82	
MCV2 (m/s)	47.90±13.92	
SCV (m/s)	38.32±17.30	
Tinel's sign		62(95)
Flexion test at elbow		60(92)
MGG grade		
IIA		18(28)
IIB		20(31)
III		27(42)

MCV1: Motor conduction velocity at elbow; MVC2: motor conduction velocity at forearm; SCV: sensory conduction velocity; MGG: McGowan scale as modified by Goldberg. m/s: Meter/second.

Table 2 DASH and VAS scores before and after operation

	Preoperative	Postoperative
DASH	39.14±17.16	18.72±14.64[*]
VAS	5.42±1.29	2.57±1.53[*]

[*]$P < 0.05$, *vs.* preoperative scores. Data are presented as the mean ± SD of 65 patients and were analyzed using Student's *t*-test. DASH: Disability of arm shoulder and hand; VSA: visual analogue scale.

Table 4 Distribution of related factors in patients with moderate to severe cubital tunnel syndrome based on postoperative outcomes

	Excellent/good	Fair/poor
Gender (n)		
Male	35	10
Female	19	1
Side (n)		
Left	23	4
Right	31	7
Age (year)	53.57±13.03	66.91±10.06[*]
Duration of symptom (month)	15.10±15.67	22.10±18.60
Follow-up time (month)	28.69±14.78	26.43±8.65
MCV1 (m/s)	40.90±11.50	29.45±15.22[*]
CMAP1 (mV)	6.88±5.08	2.30±2.16[*]
MCV2 (m/s)	49.63±11.20	39.45±15.74[*]
CMAP2 (mV)	8.31±5.65	3.34±4.44[*]
SCV (m/s)	40.58±16.52	27.24±17.50[*]
SNAP (μV)	16.55±15.88	3.68±1.88[*]

[*]$P < 0.05$, *vs.* excellent/good results. Relationships of variables such as gender and side with postoperative outcomes were analyzed using Fisher's exact tests. Other relationships were analyzed using Student's *t*-test or a nonparametric test. Measurement data are expressed as the mean ± SD. MCV1: Motor conduction velocity at elbow; CMAP1: compound muscle action potential at elbow; MCV1: motor conduction velocity at elbow; MCV2: motor conduction velocity at the forearm; CMAP2: compound muscle action potential at the forearm; SCV: sensory conduction velocity; SNAP: sensory nerve action potential.

Table 3 Relationship between preoperative MGG grade and postoperative Wilson & Krout classification

Wilson & Krout evaluation	MGG grade			
	IIA	IB	III	Total
Excellent	17[*]	14[*]	7	38
Good	1[*]	6[*]	9	16
Fair	0[*]	0[*]	7	7
Poor	0[*]	0[*]	4	4
Total	18	20	27	65

Data expressed as number were analyzed using the Kruskal-Wallis rank test, and intergroup differences were analyzed with the Mann-Whitney *U* test using an inspection level of 0.017. [*]$P < 0.001$, *vs.* MGG III; MGG: McGowan scale as modified by Goldberg.

Patients were also asked to complete the disability of arm shoulder and hand (DASH) questionnaire to evaluate the disability of the upper limb just prior to surgery and at the last follow-up (0 points reflect minimal disability and 100 points reflect maximal disability). Pre- and postoperative pain were evaluated using a visual analogue scale (VAS) (0–10 points).

Postoperatively, at the last follow-up during outpatient service, all patients were graded according to the Wilson & Krout criteria (Schnabl et al., 2011): patients with minimal sensory and motor deficits and no tenderness at the incision site were graded excellent; patients with a mild deficit but occasional ache or tenderness at the incision or osteotomy site were graded good; patients with an improved but persistent deficit were fair; and those with no improvement or a worsened condition were poor.

Statistical analysis

The SPSS 17.0 software (SPSS, Chicago, IL, USA) was used for data analysis. Data are expressed as the mean ± SD. The comparisons of preoperative *versus* postoperative DASH and VAS scores were analyzed using Student's *t*-test. The relationship between the preoperative McGowan grade and the postoperative Wilson-Krout score was analyzed using the Kruskal-Wallis rank-based test, and intergroup differences were analyzed using the Mann-Whitney *U* test, with an inspection level of 0.017. The relationships between variables such as gender, side, and postoperative results were analyzed with Fisher's exact test. The distribution differences in age, duration of symptoms, follow-up time, MCV, CMAP, SCV, and SNAP between the excellent/good group and fair/poor group were analyzed using Student's *t*-test or a nonparametric test based on the characteristics of the data. *P* values of less than 0.05 were considered statistically significant.

Results

General patient information

As shown in **Table 1**, the initial severity of the disease evaluated using the MGG preoperatively showed that 18 patients (28%) had grade IIA neuropathy, 20 (31%) had grade IIB, and 27 (42%) had grade III. Postoperatively, one patient had subcutaneous swelling that recovered after debridement.

Effects of anterior subcutaneous transposition of ulnar nerve on upper limb function improvement and pain relief in patients with moderate to severe CuTS

The postoperative DASH and VAS scores were significantly lower than the preoperative scores ($P < 0.05$). This result suggests that after anterior subcutaneous transposition of the ulnar nerve, upper limb function was markedly recovered and pain was markedly relieved, indicating that the surgery was effective (**Table 2**).

Surgical outcome according to Wilson & Krout classification

According to the Wilson & Krout classification, the surgical treatment outcomes were excellent in 38 patients (58%), good in 16 (25%), fair in 7 (11%), and poor in 4 (6%). Among these patients, 11 (16.92%) had unsatisfactory (fair and poor) outcomes, and all patients had severe intrinsic hand muscle atrophy and severe preoperative sensory obstacles classified as grade III using the modified McGowan score (**Table 3**).

Relationship between preoperative MGG grade and postoperative Wilson & Krout classification

The postoperative Wilson & Krout score was negatively correlated with the preoperative McGowan grade ($P < 0.001$). The surgical outcomes in groups MGG IIA and IIB were significantly superior to those in group MGG III ($P < 0.001$) (**Table 3**). All patients with moderate neuropathy (IIA or IIB) demonstrated excellent or good outcomes, but the 11 patients (40.74%) with grade III showed fair or poor outcomes (**Table 3**). These results indicate that the more severe the preoperative CuTS was, the worse the surgical outcome was.

We next analyzed the effect of patient age at the time of surgery on surgical outcome. The mean age in the excellent/good group was significantly lower than that in the fair/poor group (53.57 years *vs.* 66.91 years, respectively, $P < 0.01$), indicating that age at surgery was negatively related with surgical outcome (**Table 4**). As shown in **Table 4**, the mean preoperative motor nerve conduction velocity measured at the elbow was 40.90 m/s in patients whose final outcome was excellent/good and 29.45 m/s in patients whose final outcome was fair/poor. The MCV2 measured at the forearm was 49.63 m/s in patients whose final outcome was excellent/good and 39.45 m/s in patients whose final outcome was fair/poor. The SCV measured at the hand was 40.58 m/s in patients whose final outcome was excellent/good and 27.24 m/s in patients whose final outcome was fair/poor. These results indicate that a positive correlation exits between preoperative MCV or SCV and outcome ($P < 0.05$).

The CMAP1, CMAP2, and SNAP were significantly greater in patients with an excellent/good outcome than in those with a fair/poor outcome, indicating that the amplitude of action potential was positively correlated with surgical outcome (**Table 4**). However, there were no significant differences in the relationships of gender, side, follow-up time, and duration of symptoms with excellent/good and fair/poor postoperative outcomes (**Table 4**).

Discussion

Anterior transposition is an effective technique that relieves both tensile and compressive forces. Additionally, if the surgeon is careful of cutaneous nerves and vessels and is familiar with the operation, the risk of surgical complications can be controlled (Ogata et al., 1985). The present results demonstrated that moderate to severe CuTS treated by anterior subcutaneous transposition of the ulnar nerve can lead to good outcomes. The pain score (VAS) and the disability score (DASH) were reduced significantly, and most patients achieved excellent/good outcomes. These results are similar to those from previous studies (Asami et al., 1998; Lascar and Laulan, 2000; Hamidreza et al., 2011).

Although numerous operative procedures have been developed for the treatment of CuTS, the best procedure remains controversial (Chan et al., 1980; Lascar and Laulan, 2000; Dellon and Coert, 2004; Qing et al., 2014). Thus, surgeons generally select surgical methods based on their own preferences and experiences. In the present study, we preferred anterior subcutaneous transposition of the ulnar nerve for treating moderate to severe CuTS. There are many advantages of this technique. During the operation, both the sites of compression and release of the ulnar nerve can be thoroughly examined. The disadvantages include the relative complexity of the procedure, potential injury to the medial antebrachial cutaneous nerve, higher likelihood of nerve injury, and damage to the nerve's blood supply (Ogata et al., 1985). Using soft tissue ultrasonography, the blood supply to the ulnar nerve has been shown to decrease during anterior transposition (Seyfettinoglu et al., 2012).

Both compression and traction forces on the ulnar nerve contribute to CuTS. When the elbow extends, the shape of cubital tunnel is ovoid, but when the elbow flexes, the shape becomes elliptic (Apfelberg and Larson, 1973). With the elbow flexed, the area of the cubital tunnel decreases (Vanderpool et al., 1968). The volume of cubital tunnel decreases by approximately half, while the pressure within the cubital tunnel increases significantly both inside and outside the ulnar nerve (Lundborg, 1975; Pechan and Julis, 1975).

With elbow flexion movement, the ulnar nerve slides and stretches in the elbow tube. On fresh frozen cadaver specimens, more than 5.0 mm of the ulnar nerve was extended when the elbow was flexed from 10 to 90 degrees. When combined with the motions of other joints, such as shoulder, wrist and fingers, more than 20 mm of ulnar nerve excursion was needed (Wright et al., 2001). Therefore, treatment requires the relief of both the tensile and compressive forces that develop in cubital tunnel syndrome.

In simple decompression therapy, the compressive tissues, mainly Osborne's ligament, are released. For medial epicondylectomy after simple decompression, a part of the medial epicondyle is removed to expand the bone tunnel. However, neither of these two methods relieves ulnar nerve

tension during elbow flexion. Many meta-analysis studies did not show a significant difference in outcome among the three operation methods (Bartels et al., 1998; Mowlavi et al., 2000; Macadam et al., 2008). This might be because there were no unified inclusion/exclusion criteria or standards for the postoperative curative effect evaluation (Bartels et al., 1998; Mowlavi et al., 2000; Macadam et al., 2008). Simple decompression was often conducted in mild cases, and the patients who received anterior transposition often have severe disease (Bartels et al., 1998; Mowlavi et al., 2000; Macadam et al., 2008).

The present study also explored potential predictors of surgical outcomes. Some studies showed that the preoperative severity of the condition did not influence the postoperative outcome (Taha et al., 2004; Gervasio et al., 2005). However, we found that the postoperative outcome was closely related to the preoperative stage of CuTS. Patients with poor or fair outcomes were all classified as grade III on the McGowan scale as modified by Goldberg, whereas outcomes were often better in patients with preoperative severity grades of IIA or IIB.

Many previous studies support this result (Lascar and Laulan, 2000; Dellon and Coert, 2004). With increasing age, the ability of the nerve to regenerate gradually decreases, and so it can be assumed that advancing age is an important predictor of poor outcome. Indeed, we found that patients with a fair/poor surgical outcome were older, consistent with the results of many other studies (Seradge and Owen, 1998).

Clinical presentation is the gold standard for the diagnosis of CuTS, and electrophysiological methods are often used to confirm the diagnosis. At the early stage of neuropathy, the results of electrophysiological evaluations show a conduction block: as nerve compression becomes more aggravated, nerve conduction velocity is reduced. Gervasiol et al. (2005) concluded that both preoperative and postoperative electrophysiological values help predict the functional outcome of surgery, a conclusion similar to ours. The results of the present study showed that MCV at the elbow and forearm and SCV at the hand in the excellent/good outcome group were significantly higher than those in the fair/poor group. In addition, there was no significant difference in the nerve evoked amplitude during the SCV and NCV tests between these two groups.

Evidence exists that the duration of symptoms can predict surgical outcomes (Yamamoto et al., 2006; Mackinnon, 2009). In the present study, the duration of symptoms in the fair/poor outcome group was slightly, but not significantly, longer than that in the excellent/good group. This result may have been confounded by recall bias, or the sample size in the fair/poor group (11 patients) may have been too small to produce statistically significant differences between the two groups.

According to the present results, anterior subcutaneous transposition of the ulnar nerve is effective and safe for the treatment of moderate to severe CuTS; initial severity, advancing age and electrophysiological parameters can affect treatment results, but the complication rate is low. However,

there are some limitations. Because this is a retrospective study, recall bias is inevitable. The study had no control group. The evaluations of disease severity and surgical outcome were subjective, and the surgeons were not blinded to outcome assessments. The anterior subcutaneous transposition of the ulnar nerve operations were conducted by different doctors, who likely had differing abilities and techniques. In future studies, multicenter, prospective, controlled, clinical trials should be conducted. In addition, objective criteria should be used to evaluate both disease severity and surgical outcome.

Author contributions: *BGJ, TBW, PXZ designed the study. TBW, PXZ, FX performed the operations and determined disease severity prior to surgery and surgical outcomes. WH and ZP participated in the follow-up evaluations of patients and wrote the paper. All authors approved the final version of this paper.*
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References

Apfelberg DB, Larson SJ (1973) Dynamic anatomy of the ulnar nerve at the elbow. Plast Reconstr Surg 51:79-81.

Asami A, Morisawa K, Tsuruta T (1998) Functional outcome of anterior transposition of the vascularized ulnar nerve for cubital tunnel syndrome. J Hand Surg Br 23:613-616.

Bacle G, Marteau E, Freslon M, Desmoineaux P, Saint-Cast Y, Lancigu R, Kerjean Y, Vernet E, Fournier J, Corcia P, Le Nen D, Rabarin F, Laulan J (2014) Cubital tunnel syndrome: comparative results of a multicenter study of 4 surgical techniques with a mean follow-up of 92 months. Orthop Traumatol Surg Res 100:S205-208.

Bartels RH, Menovsky T, Van Overbeeke JJ, Verhagen WI (1998) Surgical management of ulnar nerve compression at the elbow: an analysis of the literature. J Neurosurg 89:722-727.

Bolster MA, Zophel OT, van den Heuvel ER, Ruettermann M (2013) Cubital tunnel syndrome: a comparison of an endoscopic technique with a minimal invasive open technique. J Hand Surg Eur Vol 39:621-625.

Caputo AE, Watson HK (2000) Subcutaneous anterior transposition of the ulnar nerve for failed decompression of cubital tunnel syndrome. J Hand Surg Am 25:544-551.

Chan RC, Paine KW, Varughese G (1980) Ulnar neuropathy at the elbow: comparison of simple decompression and anterior transposition. Neurosurgery 7:545-550.

Dellon AL, Coert JH (2004) Results of the musculofascial lengthening technique for submuscular transposition of the ulnar nerve at the elbow. J Bone Joint Surg Am 86-A Suppl 1:169-179.

Feindel W, Stratford J (1958) The role of the cubital tunnel in tardy ulnar palsy. Can J Surg 1:287-300.

Gervasio O, Gambardella G, Zaccone C, Branca D (2005) Simple decompression versus anterior submuscular transposition of the ulnar nerve in severe cubital tunnel syndrome: a prospective randomized study. Neurosurgery 56:108-117.

Glowacki KA, Weiss AP (1997) Anterior intramuscular transposition of the ulnar nerve for cubital tunnel syndrome. J Shoulder Elbow Surg 6:89-96.

Goldberg BJ, Light TR, Blair SJ (1989) Ulnar neuropathy at the elbow: results of medial epicondylectomy. J Hand Surg Am 14:182-188.

Hamidreza A, Saeid A, Mohammadreza D, Zohreh Z, Mehdi S (2011) Anterior subcutaneous transposition of ulnar nerve with fascial flap and complete excision of medial intermuscular septum in cubital tunnel syndrome: a prospective patient cohort. Clin Neurol Neurosurg 113:631-634.

Kawanishi Y, Miyake J, Omori S, Murase T, Shimada K (2014) The association between cubital tunnel morphology and ulnar neuropathy in patients with elbow osteoarthritis. J Shoulder Elbow Surg 23:938-945.

Lascar T, Laulan J (2000) Cubital tunnel syndrome: a retrospective review of 53 anterior subcutaneous transpositions. J Hand Surg Br 25:453-456.

Lundborg G (1975) Structure and function of the intraneural microvessels as related to trauma, edema formation, and nerve function. J Bone Joint Surg Am 57:938-948.

Macadam SA, Gandhi R, Bezuhly M, Lefaivre KA (2008) Simple decompression versus anterior subcutaneous and submuscular transposition of the ulnar nerve for cubital tunnel syndrome: a meta-analysis. J Hand Surg Am 33:1311-1314.

Mackinnon SE (2009) Comparative clinical outcomes of submuscular and subcutaneous transposition of the ulnar nerve for cubital tunnel syndrome. J Hand Surg Am 34:1574-1575.

Mirza A, Mirza JB, Lee BK, Adhya S, Litwa J, Lorenzana DJ (2014) An anatomical basis for endoscopic cubital tunnel release and associated clinical outcomes. J Hand Surg Am 39:1363-1369.

Mitsionis GI, Manoudis GN, Paschos NK, Korompilias AV, Beris AE (2010) Comparative study of surgical treatment of ulnar nerve compression at the elbow. J Shoulder Elbow Surg 19:513-519.

Mowlavi A, Andrews K, Lille S, Verhulst S, Zook EG, Milner S (2000) The management of cubital tunnel syndrome: a meta-analysis of clinical studies. Plast Reconstr Surg 106:327-334.

Ogata K, Manske PR, Lesker PA (1985) The effect of surgical dissection on regional blood flow to the ulnar nerve in the cubital tunnel. Clin Orthop Relat Res 195-198.

Pechan J, Julis I (1975) The pressure measurement in the ulnar nerve. A contribution to the pathophysiology of the cubital tunnel syndrome. J Biomech 8:75-79.

Qing C, Zhang J, Wu S, Ling Z, Wang S, Li H (2014) Clinical classification and treatment of cubital tunnel syndrome. Exp Ther Med 8:1365-1370.

Schnabl SM, Kisslinger F, Schramm A, Dragu A, Kneser U, Unglaub F, Horch RE (2011) Subjective outcome, neurophysiological investigations, postoperative complications and recurrence rate of partial medial epicondylectomy in cubital tunnel syndrome. Arch Orthop Trauma Surg 131:1027-1033.

Seradge H, Owen W (1998) Cubital tunnel release with medial epicondylectomy factors influencing the outcome. J Hand Surg Am 23:483-491.

Seyfettinoglu F, Karaer A, Sertoz Z, Dulgeroglu A, Koruyucu MB, Bora OA (2012) Assessment of the effects of surgical treatment options for cubital tunnel syndrome on the ulnar nerve by USG and EMG. Eklem Hastalik Cerrahisi 23:88-93.

Taha A, Galarza M, Zuccarello M, Taha J (2004) Outcomes of cubital tunnel surgery among patients with absent sensory nerve conduction. Neurosurgery 54:891-896.

Vanderpool DW, Chalmers J, Lamb DW, Whiston TB (1968) Peripheral compression lesions of the ulnar nerve. J Bone Joint Surg Br 50:792-803.

Wojewnik B, Bindra R (2009) Cubital tunnel syndrome-Review of current literature on causes, diagnosis and treatment. J Hand Microsurg 1:76-81.

Wright TW, Glowczewskie F Jr., Cowin D, Wheeler DL (2001) Ulnar nerve excursion and strain at the elbow and wrist associated with upper extremity motion. J Hand Surg Am 26:655-662.

Yamamoto K, Shishido T, Masaoka T, Katori Y, Tanaka S (2006) Postoperative clinical results in cubital tunnel syndrome. Orthopedics 29:347-353.

Zarezadeh A, Shemshaki H, Nourbakhsh M, Etemadifar MR, Moeini M, Mazoochian F (2012) Comparison of anterior subcutaneous and submuscular transposition of ulnar nerve in treatment of cubital tunnel syndrome: a prospective randomized trial. J Res Med Sci 17:745-749.

Zlowodzki M, Chan S, Bhandari M, Kalliainen L, Schubert W (2007) Anterior transposition compared with simple decompression for treatment of cubital tunnel syndrome. A meta-analysis of randomized, controlled trials. J Bone Joint Surg Am 89:2591-2598.