Results of reoperation for failed ulnar nerve surgery at the elbow: a systematic review and meta-analysis

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OBJECTIVE The clinical results of reoperation for recurrent or persistent ulnar nerve compression at the elbow have not been clearly determined. The aim of this review was to determine overall improvement, residual pain, and sensory and motor deficits following reoperation regardless of the type of primary surgery performed for this condition.

METHODS In accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations, a systematic review and meta-analysis of studies was performed. An independent librarian performed a literature search using Ovid MEDLINE, Embase, CINAHL, and the Cochrane Central Register of Controlled Trials (CENTRAL). The Newcastle-Ottawa Scale and the quality appraisal tool described by Moga et al. were used to assess the quality of included case series.

RESULTS Of the 278 retrieved studies, 16 were eligible for analysis and included a total of 290 patients with failed surgery for ulnar nerve entrapment at the elbow. Relief of symptoms after reoperation was reported in 85% of patients. A decrease in pain was noted in 85% of the patients (95% CI 75%–93%). Only 2.4% of patients with preoperative pain experienced worse pain after reoperation. Motor and sensory function improvement was noted in 77% (95% CI 63%–88%) and 77% (95% CI 61%–90%) of cases, respectively. Complete recovery from signs and symptoms at the final follow-up was noted in 23% of elbows (95% CI 16%–31%).

CONCLUSIONS Although the level of evidence of the included studies was low, the majority of patients had relief from their complaints after reoperation for recurrent or persistent ulnar nerve compression at the elbow following a previous surgery. The success rate of surgical treatment for a failed surgery was quite remarkable since almost a quarter of the patients completely recovered. Therefore, the authors recommend reoperation as a serious option for patients with this condition.

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KEYWORDS compression; persistent; recurrent; reoperation; ulnar nerve; peripheral nerve

THE average annual crude incidence rate of ulnar nerve entrapment at the elbow is 24.7 cases per 100,000 person-years.¹⁶ It is the second most common nerve compression syndrome of the upper extremity after carpal tunnel syndrome. Surgery is indicated if conservative treatment fails or in cases of more severe sensory and/or motor dysfunction. Despite a variety of surgical options for ulnar nerve entrapment at the elbow, the failure of surgical treatment, expressed as the persistence, recurrence, or even worsening of symptoms, occurs in approximately 10%–25% of cases.^{1,4,20}

Recurrent or persistent ulnar nerve compression at the elbow is a challenge from a surgical point of view.¹⁷ Results of reoperation are less predictable and less favorable than those for the primary surgery regardless of the type of primary surgery performed.^{1,21} Optimal management of failed surgical treatment remains controversial, and the choice of the type of surgery to perform mostly depends on the experience of the surgeon. Because results of the reoperation in patients who suffer from persistent or recurrent ulnar compression at the elbow have never been systematically analyzed, we performed this systematic review.

ABBREVIATIONS CENTRAL = Cochrane Central Register of Controlled Trials; STROBE = Strengthening the Reporting of Observational Studies in Epidemiology.

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TABLE 1. Detailed search strategies

Ovid MEDLINE In-Process & Other Non-Indexed Citations, Ovid MEDLINE Daily, Ovid MEDLINE and Ovid OLDMEDLINE 1946 to Present										
Search		Embase 1974 to 2015 July 17				CINAHL		CENTRAL		
No.	Search	Results	Search	Results	Search	Results	Search	Results	Search	Results
1	Ulnar nerve	6463	Exp ulnar nerve	8428	(MH "Ulnar Nerve")	511	Ulnar nerve	874		
2	Ulnar nerve.mp.	9147	Ulnar nerve.mp.	11,009	(MH "Ulnar Nerve Compression Syndromes+")	44	Ulnar next nerve next compress*	21		
3	Ulnar nerve compression syndromes	465	Ulnar nerve.ti. or ulnar nerve.ab.	6343	(MH "Ulnar Neuropathies+")	80	Entrapment or compress*	6162		
4	Nerve compression syndromes/	9399	Exp nerve compression	11,656	(MH "Cubital Tunnel Syndrome")	23	Cubital Tunnel Syndrome	39		
5	Cubital tunnel syndrome	390	Nerve compression.ti. or nerve compression.ab.	2983	"cubital tunnel syndrome"	81	Elbow	2050		
6	Ulnar adj5 nerve adj5 compress*.tw.	505	Ulnar adj3 nerve.mp.	11,231	(MH "Elbow") OR "elbow"	5434	Ulnar next nerve next compress*	21		
7	Ulnar adj5 nerve adj5 entrapment*.tw.	232	Ulnar adj5 nerve adj5 compress*.tw.	580	"ulnar nerve"	714	Elbow or cubital	2157		
8	((ulnar adj3 neuropat*) or (Ulnar adj3 Nerve adj3 Entrap*)) .tw.	1005	Ulnar adj5 nerve adj5 entrapment.tw.	305	"ulnar nerve compression"	44	MeSH descriptor: [Ulnar Nerve] explode all trees	247		
9	Exp Ulnar Neuropathies	1303	Ulnar adj3 neuropat*.tw.	1010	"ulnar nerve entrapment"	12	MeSH descriptor: [Cubital Tunnel Syndrome] explode all trees	15		
10	Ulnar adj3 neuropath*.ti.ab.	836	Ulnar neuropathies.kw.	15	S1 OR S2 OR S3 OR S7 OR S8 OR S9	746	MeSH descriptor: [Ulnar Nerve Compression Syndromes] explode all trees	28		
11	Compression neuropathy.mp.	365	Compression neuropathy.tw.	412	S6 AND S10	301	MeSH descriptor: [Nerve Compression Syndromes] explode all trees	522		
12	Cubital tunnel syndrome*.ti.ab.	499	Exp cubital tunnel syndrome/	1856	S4 OR S5 OR S11	338	MeSH descriptor: [Elbow] explode all trees	141		
13	Entrapment.mp.	12,424	Exp nerve compression/	11,656	(MH "Repeat Procedures+") OR (MH "Reoperation+")	6720	#5 or #7 or #12	2157		
14	Exp Elbow/	5760	Entrapment.mp.	16,975	(MH "Treatment Failure")	6188	Reoperat*	3217		
15	Elbow or cubital or ulnar.ti.ab.	37,381	Exp elbow/	14,979	"revision"	7460	Re-operat*	594		
16	Exp Reoperation	70,470	Elbow or cubital.kw.	3369	"reoperation"	6474	Reoperat* or revis* near surg*	3913		
17	Re-operation.mp.	2870	Elbow or cubital.ab.	26,933	"failure"	81,326	Failure next surgery	46		
18	((Reoperat* or revis*) adj3 surg*).mp.	12,289	Reoperation/	56,170	S13 OR S14 OR S15 OR S16 OR S17	91,373	Surg* next fail*	145		
19	Surg* adj3 failure.mp.	5208	Re-operation.mp.	4759	S12 AND S18	42	Treatment failure	32,747		
20	Surg* adj3 failure.tw.	5121	Reoperat* or revis*.mp.	238,319			Suraiq* or operat*	91,115		

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TABLE 1. Detailed search strategies

Ovid MEDLINE In-Process & Other Non-Indexed Citations, Ovid MEDLINE Daily, Ovid MEDLINE and Ovid OLDMEDLINE 1946 to Present				Embase 1974 to 2015 July 17		CINAHL		CENTRAL	
Search No.	Search	Results	Search	Results	Search	Results	Search	Results	Search
21	Treatment failure	28,395	Reoperat* or revis* .kw.	5874			Simple decompress*	132	
22	(Surgery or surgic* or operat*),ti,ab. Or su.fs.	2,751,579	Reoperat* or revis* .sh.	57,032			Anterior next transposit*	26	
23	((Simple adj5 decompress*) or (anterior adj5 transposit*) or (anterior adj5 subcutaneous adj5 transposition) or (anterior adj5 submuscular adj5 transposition) or (anterior adj5 intramuscular adj5 transposition) or (medial adj5 epicondylectomy)).af.	848	Failure adj3 surgery.mp.	3790			Anterior subcutaneous transposition	16	
24	14 or 15	39,420	Surg* adj3 failure.mp.	7085			Anterior submuscular transposition	9	
25	(1 or 2) and (4 or 10 or 13)	1529	Surg* adj3 failure.tw.	6948			Anterior intramuscular transposition	3	
26	3 or 6 or 7 or 8 or 9 or 10	2128	Exp treatment failure/	91,995			Medial epicondylectomy	11	
27	(25 or 26) and 24	2329	Surgery or surgic* or operat*.ab.	2,107,133			MeSH descriptor: [Reoperation] explode all trees	1671	
28	27 or 5 or 12	2443	((simple adj5 decompress*) or (anterior adj5 transposit*) or (anterior adj5 subcutaneous adj5 transposition) or (anterior adj5 submuscular adj5 transposition) or (anterior adj5 intramuscular adj5 transposition) or (medial adj5 epicondylectomy)).af.	1007			MeSH descriptor: [Microvascular Decompression Surgery] explode all trees	6	
29	16 or 17 or 18 or 19 or 20 or (21 and (22 or 23))	91,497	15 or 16 or 17	33,625			MeSH descriptor: [Decompression, Surgical] explode all trees	479	
30	28 and 29	80	(1 or 2 or 3 or 6) and (4 or 5)	1395			(#1 or #8) and (#3 or #11)	106	
31			30 or 7 or 8 or 9 or 10 or 11 or 13	13,012			#29 or #2 or #6 or #10	109	
32			29 and 31	1551			(#13 and #30) or #4 or #9	71	
33			12 or 32	2785			#14 or #15 or #16 or #17 or (#18 or #26) and (#19 or #20 or #21 or #22 or #23 or #24 or #25 or #27 or #28))	9594	
34			(26 and 27) or (26 and 28) or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25	262,308			#31 and #32	23	
35			33 and 34	133					

ab = abstract; adj = adjacency; af = all searchable fields; Exp = exploded; fs = floating subheading; kw = keyword; MeSH = medical subject heading; MH = major and minor heading; mp = multipurpose; S1, S2, etc. = search 1, search 2, etc.; sh = subject heading; su = surgery; ti = title; tw = textword.

FIG. 1. Study identification process. N = number of studies; P = surgery for recurrent or persistent symptoms of ulnar nerve entrapment at the elbow after previous surgical treatment for ulnar nerve entrapment at the elbow.

Methods

This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations.¹⁵

Search Methods for the Identification of Studies

An experienced, independent librarian performed a search of the literature in MEDLINE, Embase, CINAHL, and the Cochrane Central Register of Controlled Trials (CENTRAL). The search was last updated on July 2015. Geographic or language restrictions were not formulated. The detailed search strategies are described in Table 1. Two authors reviewed the abstracts and titles, and once the studies were selected they also reviewed the full-text articles. In cases of disagreement the reviewers discussed the reason, and if the discussion was not closed a third reviewer intervened. Reference lists were screened for addi-

tional studies. Authors were not contacted for unpublished results.

Eligibility Criteria

Studies were considered eligible for inclusion if they met the following criteria. The study group included at least five patients who were 18 years or older and had undergone surgery for recurrent or persistent symptoms of ulnar nerve entrapment at the elbow following previous surgical treatment of the condition, regardless of the type of primary and repeat surgery performed. The study included well-described outcomes measurement with a minimal description of the postoperative outcome for ulnar nerve entrapment symptoms as “improved” or “not improved.” If we found the same data in more than one article, the article with the most complete data set was included.

TABLE 2. Summary of characteristics of studies included in the systematic review

Authors & Year	Title	Journal	Country	Type of Study	Level of Evidence	Funding or Conflict of Interest	Methodological Quality Assessment	STROBE Score
Aleem et al., 2014	Outcomes of revision surgery for cubital tunnel syndrome	<i>J Hand Surg Am</i>	US	Case control	III	No	Mod	High
Antoniadis & Richter, 1997	Pain after surgery for ulnar neuropathy at the elbow: a continuing challenge	<i>Neurosurgery</i>	Germany	Case series	IV	NM	Low	Low
Bartels & Grotenhuis, 2004	Anterior submuscular transposition of the ulnar nerve. For post-operative focal neuropathy at the elbow	<i>J Bone Joint Surg Br</i>	Netherlands	Case series	IV	No	High	High
Broudy et al., 1978	Technical problems with ulnar nerve transposition at the elbow: findings and results of reoperation	<i>J Hand Surg Am</i>	US	Case series	IV	NM	Mod	Mod
Caputo & Watson, 2000	Subcutaneous anterior transposition of the ulnar nerve for failed decompression of cubital tunnel syndrome	<i>J Hand Surg Am</i>	US	Case series	IV	No	Mod	Mod
Dagregorio & Saint-Cast, 2004	Simple neurolysis for failed anterior submuscular transposition of the ulnar nerve at the elbow	<i>Int Orthop</i>	France	Case series	IV	NM	Mod	Mod
Filippi et al., 2001	Recurrent cubital tunnel syndrome. Etiology and treatment	<i>Minim Invasive Neurosurg</i>	Germany	Case series	IV	NM	Mod	Mod
Gabel & Amadio, 1990	Reoperation for failed decompression of the ulnar nerve in the region of the elbow	<i>J Bone Joint Surg Am</i>	US	Case series	IV	Yes	Mod	Mod
Goldfarb et al., 2009	Incidence of re-operation and subjective outcome following in situ decompression of the ulnar nerve at the cubital tunnel	<i>J Hand Surg Eur Vol</i>	US	Case series	IV	Yes	Mod	High
Holmberg, 1991	Reoperation in high ulnar neuropathy	<i>Scand J Plast Reconstr Surg Hand Surg</i>	Sweden	Case series	IV	NM	Mod	Low
Kokkalis et al., 2010	Vein wrapping at cubital tunnel for ulnar nerve problems	<i>J Shoulder Elbow Surg</i>	US	Case series	IV	No	Mod	Mod
Papatheodorou et al., 2015	Preliminary results of recurrent cubital tunnel syndrome treated with neurolysis and porcine extracellular matrix nerve wrap	<i>J Hand Surg Am</i>	US	Case series	IV	Yes	Mod	Mod
Rogers et al., 1991	The failed ulnar nerve transposition. Etiology and treatment	<i>Clin Orthop Relat Res</i>	US	Case series	IV	NM	Mod	Mod
Sarris et al., 2002	Medial brachial and antebrachial cutaneous nerve injuries: effect on outcome in revision cubital tunnel surgery	<i>J Reconstr Microsurg</i>	US	Case series	IV	NM	Mod	Mod
Soltani et al., 2014	Revision decompression and collagen nerve wrap for recurrent and persistent compression neuropathies of the upper extremity	<i>Ann Plast Surg</i>	US	Case series	IV	NM	Mod	Mod
Vogel et al., 2004	Revision anterior submuscular transposition of the ulnar nerve for failed subcutaneous transposition	<i>Br J Plast Surg</i>	US	Case series	IV	NM	Mod	Mod

Mod = moderate; NM = not mentioned.

All studies had a retrospective design.

TABLE 3. Summary of data in studies included in the systematic review

Authors & Year	Database Yrs/Study Period	No. of Patients in Revision Group/ No. of Elbows	Males (no. [%])/ Females (no. [%])	Mean Age in Yrs (range)	Interval to Reoperation in Mos	Mean FU in Yrs (range)	Complications
Aleem et al., 2014	January 2006–July 2011	28/28	11(39)/17(61)	55 (32–72)	NA	3.4 (2.0–6.2)	NA
Antoniadis & Richter, 1997	October 1989–March 1995	25/25	NA	45 (22–87)	NA	1.4 (0.2–4.6)	No postop infections, 1 evacuation of subcutaneous hematoma w/o nerve compression
Bartels & Grotenhuis, 2004	November 1997–November 2002	40/41	15(37.5)/25(62.5)	50 (25–75)	17	1.0 (0.2–4.2)	8 patients (21%); pain in 4th & 5th fingers, numbness, cold intolerance, pain at elbow
Broudy et al., 1978	NA	10/10	3(30)/7(70)	42 (18–71)	13	1.2 (0.5–2.5)	NA
Caputo & Watson, 2000	1980–1993	20/20	13(65)/7(35)	47 (24–70)	13	2.7 (2.0–7.0)	NA
Dagregorio & Saint-Cast, 2004	1996–2000	9/9	7(78)/2(22)	47 (32–66)	NA	2.0 (NA)	1 patient; lat epicondylitis, pain on palpation of transposed ulnar nerve or when flexing elbow
Filippi et al., 2001	NA	22/22	9(41)/13(59)	42 (27–76)	4–108	0.6 (0.2–1.7)	No postop infections, other complications not mentioned
Gabel & Amadio, 1990	1979–1985	30/30	18(60)/12(40)	40 (18–75)	46	3.6 (2.0–9.4)	No postop infections
Goldfarb et al., 2009	1996–2006	5/5	NA	52 (20–80)	NA	4.1 (1.1–7.8)	NA
Holmberg, 1991	NA	14/16	NA	52 (15–74)	18	1.7 (0.3–2.5)	NA
Kokkalis et al., 2010	1995–2007	17/17	8(47)/9(53)	51 (30–67)	NA	3.7 (2.0–7.3)	No complications of upper extremity, 1 patient w/ transient leg swelling caused by harvesting saphenous vein graft from leg
Papatheodorou et al., 2015	May 2009–June 2012	12/12	8(67)/4(33)	45 (30–58)	18	3.4 (2.0–5.1)	No complications
Rogers et al., 1991	NA	14/14	8(57)/6(43)	36 (16–59)	9	1.6 (0.8–4.0)	NA
Sarris et al., 2002	1992–1999	20/20	NA	NA	18	2.2 (1.1–7.0)	NA
Soltani et al., 2014	September 2007–January 2013	6/6	NA	57 (47–66)	44	1.1 (NA)	NA
Vogel et al., 2004	1989–2000	18/18	9(50)/9(50)	44 (NA)	54	2.8 (0.5–7.0)	NA

NA = information not available.

Excluded studies involved animals or other nonhuman experiments or were single case reports, letters, or reviews. Studies in which the initial surgery was not primarily for ulnar nerve entrapment were also excluded, as were studies including more than 30% of patients in the group with bone fracture of the elbow on the side of nerve entrapment. Studies were also excluded if the ulnar nerve surgery was not the main procedure performed during the same operative session. If more studies were published based on the same data, the article with the most extensive data was included.

Quality Assessment

The quality of included case-control studies was assessed using the Newcastle-Ottawa Scale (NOS). This scale looks at three elements: selection of the study groups, comparability of the groups, and evaluation of the exposure. Quality assessment is performed using a star system with 9 stars as the maximum possible star score for case-control studies.²³ Studies with a score of 7–9 stars were defined as high quality, 4–6 stars as moderate quality, and 0–3 as low quality.

The quality of included case series was assessed with

TABLE 4. Primary operation and reoperation types per study

Authors & Year	Failed Surgical Procedure (%)	Type of Revision Surgery (%)
Aleem et al., 2014	ISD 26 (92.9%), SCT 2 (7.1%)	ISD 1 (3.6%), SCT 5 (17.9%), IMT 1 (3.6%), SMT 21 (75.0%)
Antoniadis & Richter, 1997	ISD 10 (40.0%), AT 15 (60.0%)	AT 7 (28.0%), AT & EN 3 (12.0%), nerve replaced in its original bed 5 (20.0%), EN 5 (20.0%), EpN 1 (4.0%), IN 4 (16.0%)
Bartels & Grotenhuis, 2004	ISD 20 (48.8%), SCT 12 (29.3%), ISD & SCT 3 (7.3%), ME 4 (9.8%), EN after SCT 2 (4.9%)	SMT & EN 41 (100%)
Broudy et al., 1978	SCT 5 (50%), SMT 1 (10%), nerve located in channel cut into muscle 4 (40%)	N 2 (20%), N & EpN 8 (80%)
Caputo & Watson, 2000	SMT 4 (20%), SCT 12 (60%), N 4 (20%)	SCT 20 (100%)
Dagregorio & Saint-Cast, 2004	Subfascial-submuscular ant transposition 9 (100%)	EN 9 (100%)
Filippi et al., 2001	AT 10 (45.5%), ISD 5 (22.7%), NA 7 (31.8%)	EN 10 (45.5%), repositioning of nerve 7 (31.8%), ISD 4 (18.2%), AT 1 (4.5%)
Gabel & Amadio, 1990	INA	SMT 24 (80%), SCT 5 (17%), IMT 1 (3%)
Goldfarb et al., 2009	ISD 5 (100%)	SMT 5 (100%)
Holmberg, 1991	N 10 (62.5%), SCT 6 (37.5%)	SMT 12 (75%), SCT 4 (25%)
Kokkalis et al., 2010	INA	Vein wrapping 17 (100%) & IN NA
Papatheodorou et al., 2015	SMT 6 (50%), SCT 2 (16.7%), ME 4 (33.3%)	N & porcine extracellular matrix nerve wrap 12 (100%)
Rogers et al., 1991	INA	EN & SMT 14 (100%)
Sarris et al., 2002	SCT 8 (40%), SMT 4 (20%), ISD 2 (10%), ME 2 (10%), NA 4 (20%)	N w/ SCT or SMT; no description of distribution available 20 (100%)
Soltani et al., 2014	INA	SMT 3 (50%), EN 3 (50%)
Vogel et al., 2004	SCT 14 (77.8%), ME 2 (11.1%), SMT 1 (5.6%), SCT 1 (5.6%)	EN + SMT 18 (100%), in combination w/ IN NA

ant = anterior; AT = anterior transposition; EN = external neurolysis; EpN = epineurectomy; IMT = intramuscular transposition; IN = internal neurolysis; INA = no information about precise failed procedure before revision; ISD = in situ decompression; ME = medial epicondylectomy; N = neurolysis; NA = information not available; SCT = subcutaneous transposition; SMT = submuscular transposition.

a tool developed by Moga et al. in 2002 using a modified Delphi technique. The tool consists of 18 items, and scores range from 0 to 18. Studies receiving a score of 13 or more of the possible 18 points were rated as high quality, studies with 7–12 points as moderate quality, and studies with 0–6 points as low quality.¹⁴

To ensure clear presentation of reporting, included studies were scored using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement.²²

Two reviewers conducted the quality appraisal. Any disagreements during the process were discussed and resolved by adjudication by a third reviewer.

Data Extraction

Data were independently extracted by two reviewers. The following data were extracted from the studies: total number of patients, demographics, type of previous surgery, type of revision procedure, type of symptoms (for example, recurrent or persistent symptoms), subjective and objective outcome measurements for pain, sensory or motor function improvement after reoperation. In cases of different interpretations, the results were discussed again by the two reviewers and resolved by adjudication by a third reviewer.

Motor improvement was defined as improvement based on one of the following: McGowan scale, Medical Research Council grade, weakness, strength, and grip strength. Preoperative and postoperative data on motor function were compared, and the percentage of improvement in comparison with the entire group of patients with preoperative motor dysfunction was calculated. Information about sensation in the hand, numbness, and 2-point discrimination was used to calculate the number of patients with sensory improvement. As for sensory function, pre- and postoperative data on sensation were compared and the percentage of improvement in comparison with the entire group of patients with preoperative sensory dysfunction was calculated.

Improvement in pain was calculated as the proportion of patients with measured improvement in pain from the number of patients with preoperative pain. Data about pain worsening after reoperation was calculated as the proportion of patients with worsening pain from the number of patients with preoperative hand pain.

Symptom recurrence was defined as the return of symptoms of ulnar nerve compression after a symptom-free period following operation. Persistence of symptoms of ulnar nerve compression at the elbow was defined as symptoms that did not change and remained the same after operation for ulnar nerve compression at the elbow.

FIG. 2. Forest plot (A) and funnel plot (B) showing pooled results of overall symptomatic improvement in proportions of improved patients with 95% CIs per included study and table (C) indicating heterogeneity data.

FIG. 3. Forest plot (A) and funnel plot (B) showing pooled results of pain decrease in proportions of improved patients with 95% CIs per included study and table (C) indicating heterogeneity data.

TABLE 5. Preoperatively present pain worsening after reoperation

Authors & Year	No. of Patients w/ Pain Worsening After Reoperation	Total No. of Patients w/ (Hand) Pain Preoperatively	Total No. of Patients
Aleem et al., 2014	NA	NA	28
Antoniadis & Richter, 1997	1	25	25
Bartels & Grotenhuis, 2004	1	22	38*
Broudy et al., 1978	0	7	10
Caputo & Watson, 2000	0	19	20
Dagregorio & Saint-Cast, 2004	1	NA	9
Filippi et al., 2001	0	22	22
Gabel & Amadio, 1990	2	30	30
Goldfarb et al., 2009	0	5	5
Holmberg, 1991	0	14	14
Kokkalis et al., 2010	0	17	17
Papatheodorou et al., 2015	0	12	12
Rogers et al., 1991	0	14	14
Sarris et al., 2002	NA	NA	20
Soltani et al., 2014	0	4	6
Vogel et al., 2004	0	18	18
Total	5 (2.4%)	209	288

NA = information not available.

* Two patients were lost to follow-up.

Statistical Analysis

Given the obvious differences across the included studies, a random-effects model was used to pool the proportions found in the included studies. To measure the degree of inconsistency across the results of the studies, the I² statistic was calculated. The I² of < 25%, 50%, and 75% represent low, moderate, and high heterogeneity, respectively.¹¹ Increasing values of I² are associated with greater heterogeneity. When possible and appropriate, results of individual studies were combined to produce a meta-analysis. A pooled proportion of patients with 95% confidence intervals of proportion was calculated. Results are presented as mean values or 95% confidence intervals. A p value ≤ 0.05 was considered statistically significant. Forest and funnel plots for each calculation were created for optimal visualization of the results. No additional analyses (for example, subgroup analyses) were done. Statistical analyses were performed using MedCalc for Windows (MedCalc Software) and IBM SPSS Statistics for Windows version 22 (IBM Corp.).

Results

Two hundred seventy-eight published studies were retrieved. After removing 64 duplicates, 214 abstracts were screened for content, and 16 papers were included in the final analysis. The search for additional studies by screening the reference lists did not produce any additional re-

sults. The study identification flow diagram with reasons for exclusion is shown in Fig. 1.

Fifteen included studies had level IV evidence^{2,3,5–10,12,13,17–21} and one had level III evidence¹ (Table 2). Methodological quality varied among the studies with 1 study scored as high quality, 14 studies as moderate quality, and 1 as low quality. Fifty-six percent (9) of the studies did not mention if they were funded. Only 19% (3) of the studies were funded and 25% (4) were not.

The total number of patients in the included studies was 290. Mean age was 47 years (1 study provided no information about patient age). Some patients underwent surgery on both sides, resulting in a total of 293 involved elbows. Recurrent symptoms were present in 77 patients (26.6%), persistent symptoms in 132 patients (45.5%), and information about recurrence or persistence of symptoms was not available in 81 patients (27.9%). The dominant side was involved in 61% of patients (71 of 117) for whom we had data. The mean time until reoperation was only mentioned in 10 studies and consisted of 25 months. The mean follow-up duration for the 16 studies was 2.3 years. More study characteristics are summarized in Table 3. Table 4 lists the primary operation and reoperation types per study. The most common primary procedure was in situ decompression, and the most common reoperation was anterior submuscular transposition.

Meta-Analysis

Pooled results of the 16 studies showed that 85% of the patients (95% CI 76%–92%) had relief of symptoms after reoperation. The I² was 74% (95% CI 57%–84%; Fig. 2). Because the I² disclosed high heterogeneity, a random-effects model was used for further analyses.

Thirteen studies^{2,3,5,6,8–10,12,13,17,18,20,21} described changes in pain level. At the final follow-up of 211 elbows, 85% of the patients (95% CI 75%–93%) had a decrease in pain (Fig. 3). The I² was 70% (95% CI 48%–83%). Five (2.4%) of 209 patients had worsening of preoperatively present pain following reoperation (Table 5).

Sensory and motor function improvement were described in 11^{3,5–10,13,17,18,21} and 13 studies^{2,3,5–10,12,13,17,18,21} representing a total of 183 and 221 elbows, respectively. Sensory improvement occurred in 77% (95% CI 61%–90%) and motor function improvement in 77% (95% CI 63%–88%) of elbows (Figs. 4 and 5). The I² for sensory improvement was 83%, and for motor improvement it was 81%.

Ten studies^{1,2,3,6,7,9,12,18,19,21} reported on patients with complete relief of symptoms after reoperation. Patients were considered asymptomatic when the signs and symptoms were completely resolved. Forty-nine of 215 elbows or 23% of patients (95% CI 16%–31%) were asymptomatic at the final follow-up (Fig. 6). The I² was 47% (95% CI 0%–74%).

See Table 6 for detailed calculations for Figs. 2–6.

Discussion

In our meta-analysis of the outcomes of reoperation for ulnar nerve compression at the elbow, a significant proportion of patients improved and even 23% of patients were

TABLE 6. Exact calculations and tests for heterogeneity corresponding with Figs. 2–6

Authors & Year	Sample Size (no. of cases)	Proportion (%)	95% CI	Weight (%) Random Effects
Fig. 2: pooled results of overall symptomatic improvement in proportions of improved patients				
Aleem et al., 2014	28	78.571	59.047 to 91.704	7.2
Antoniadis & Richter, 1997	25	76	54.871 to 90.644	7.05
Bartels & Grotenhuis, 2004	38*	42.105	26.310 to 59.179	7.56
Broudy et al., 1978	10	100	69.150 to 100.000	5.51
Caputo & Watson, 2000	20	75	50.895 to 91.343	6.72
Dagregorio & Saint-Cast, 2004	9	88.889	51.750 to 99.719	5.31
Filippi et al., 2001	22	81.818	59.715 to 94.813	6.86
Gabel & Amadio, 1990	30	80	61.433 to 92.286	7.29
Goldfarb et al., 2009	5	100	47.818 to 100.000	4.2
Holmberg, 1991	16	75	47.623 to 92.734	6.36
Kokkalis et al., 2010	17	100	80.494 to 100.000	6.46
Papatheodorou et al., 2015	12	100	73.535 to 100.000	5.85
Rogers et al., 1991	14	100	76.836 to 100.000	6.13
Sarris et al., 2002	20	95	75.127 to 99.873	6.72
Soltani et al., 2014	6	83.333	35.877 to 99.579	4.54
Vogel et al., 2004	15†	93.333	68.052 to 99.831	6.25
Total (random effects)	287	85.21	76.361 to 92.269	100
Fig. 3: pooled results of pain decrease in proportions of improved patients				
Antoniadis & Richter, 1997	25	76	54.871 to 90.644	8.99
Bartels & Grotenhuis, 2004	22	40.909	20.709 to 63.645	8.74
Broudy et al., 1978	7	85.714	42.128 to 99.639	6.06
Caputo & Watson, 2000	19	94.737	73.972 to 99.867	8.44
Filippi et al., 2001	22	81.818	59.715 to 94.813	8.74
Gabel & Amadio, 1990	30	86.667	69.278 to 96.245	9.31
Goldfarb et al., 2009	5	80	28.358 to 99.495	5.24
Holmberg, 1991	16	75	47.623 to 92.734	8.07
Kokkalis et al., 2010	17	100	80.494 to 100.000	8.2
Papatheodorou et al., 2015	12	100	73.535 to 100.000	7.4
Rogers et al., 1991	14	100	76.836 to 100.000	6.7
Soltani et al., 2014	4	75	19.412 to 99.369	2.23
Vogel et al., 2004	18	94.444	72.706 to 99.859	8.48
Total (random effects)	211	84.758	74.845 to 92.534	100
Fig. 4: pooled results of sensory improvement in proportions of improved patients				
Bartels & Grotenhuis, 2004	34	26.471	12.882 to 44.362	10.23
Broudy et al., 1978	10	80	44.390 to 97.479	8.52
Caputo & Watson, 2000	19	68.421	43.450 to 87.424	9.57
Dagregorio & Saint-Cast, 2004	9	88.889	51.750 to 99.719	8.31
Filippi et al., 2001	22	68.182	45.128 to 86.135	9.76
Gabel & Amadio, 1990	26	65.385	44.333 to 82.786	9.95
Goldfarb et al., 2009	5	100	47.818 to 100.000	7.08
Kokkalis et al., 2010	17	100	80.494 to 100.000	9.41
Papatheodorou et al., 2015	12	100	73.535 to 100.000	8.85
Rogers et al., 1991	14	78.571	49.202 to 95.342	9.11
Vogel et al., 2004	15	66.667	38.380 to 88.176	9.22
Total (random effects)	183	76.849	60.793 to 89.662	100

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TABLE 6. Exact calculations and tests for heterogeneity corresponding with Figs. 2–6

Authors & Year	Sample Size (no. of cases)	Proportion (%)	95% CI	Weight (%) Random Effects
Fig. 5: pooled results of improvement in motor function in proportions of improved patients				
Antoniadis & Richter, 1997	25	52	31.306 to 72.203	8.45
Bartels & Grotenhuis, 2004	38	31.579	17.503 to 48.653	8.85
Broudy et al., 1978	9	88.889	51.750 to 99.719	6.92
Caputo & Watson, 2000	14	85.714	57.187 to 98.221	7.67
Dagregorio & Saint-Cast, 2004	9	88.889	51.750 to 99.719	6.92
Filippi et al., 2001	22	68.182	45.128 to 86.135	8.3
Gabel & Amadio, 1990	26	57.692	36.918 to 76.648	8.49
Goldfarb et al., 2009	5	100	47.818 to 100.000	5.79
Holmberg, 1991	15	73.333	44.900 to 92.213	7.78
Kokkalis et al., 2010	17	100	80.494 to 100.000	7.96
Papatheodorou et al., 2015	12	100	73.535 to 100.000	7.42
Rogers et al., 1991	14	78.571	49.202 to 95.342	7.67
Vogel et al., 2004	15	80	51.911 to 95.669	7.78
Total (random effects)	221	77.046	63.359 to 88.299	100
Fig. 6: pooled results of complete recovery of signs and symptoms in proportions of improved patients				
Aleem et al., 2014	28	14.286	4.034 to 32.665	11.74
Antoniadis & Richter, 1997	25	40	21.125 to 61.335	11.14
Bartels & Grotenhuis, 2004	38	21.053	9.554 to 37.319	13.32
Caputo & Watson, 2000	20	15	3.207 to 37.893	9.97
Dagregorio & Saint-Cast, 2004	9	44.444	13.700 to 78.799	6.23
Gabel & Amadio, 1990	30	23.333	9.934 to 42.284	12.1
Holmberg, 1991	16	25	7.266 to 52.377	8.83
Rogers et al., 1991	14	0	0.000 to 23.164	8.18
Sarris et al., 2002	20	20	5.733 to 43.661	9.97
Vogel et al., 2004	15	33.333	11.824 to 61.620	8.52
Total (random effects)	215	22.841	15.661 to 30.926	100

* Two patients lost to follow-up.

† Postoperative data absent for 3 patients.

completely symptom-free at the final follow-up. A minority of patients had a worsening of pain following reoperation in comparison with preoperative levels.

It should be emphasized that the results describe the proportions of patients who showed improvement but not how much they improved. This was attributable to the variety of outcome measures used in the included studies (for example, Levine-Katz questionnaire,¹ Patient-Rated Elbow Evaluation,¹ McGowan grade,¹⁸ modified Novak, Mackinnon and Stuebe questionnaire,³ Wilson and Krout classification,^{7,19} Gabel and Amadio scale,^{6,9} neurological examination,⁸ visual analog scale,^{13,17,20} and so forth), which made it impossible to compare the effect size of improvement in any symptoms caused by ulnar nerve entrapment with the findings of other studies. Particularly disappointing was the fact that in most of the reviewed studies, details on the instruments and respective cutoff points used in the studies were not even mentioned. This

may be considered as a fundamental source of heterogeneity.

Our study has some caveats. The level of evidence of the studies was low given the observational character of the included studies. It is well known that observational studies overestimate the effect size in comparison to randomized controlled trials. Because of the retrospective design of the included studies, we had to deal with biases like recall bias, selection bias, and so forth. Except for one,¹ no studies included a comparison group for the revision surgery group. There was also a lack of standardized outcome measurements to facilitate comparisons between studies. The studies also differed from each other in the number of operations performed prior to reoperation.

Altogether, we were not surprised by the finding of high heterogeneity. Given this limitation, any statement about patient selection cannot be made, nor can the optimal surgical solution be identified.

FIG. 4. Forest plot (A) and funnel plot (B) showing pooled results of sensory improvement in proportions of improved patients with 95% CIs per included study and table (C) indicating heterogeneity data.

FIG. 5. Forest plot (A) and funnel plot (B) showing pooled results of improvement in motor function in proportions of improved patients with 95% CIs per included study and table (C) indicating heterogeneity data.

FIG. 6. Forest plot (A) and funnel plot (B) showing pooled results of complete recovery of signs and symptoms in proportions of improved patients with 95% CIs per included study and table (C) indicating heterogeneity data.

Conclusions

Despite the limitations of this study, it is most likely that the majority of patients will benefit to a greater or lesser extent from surgical reexploration of the ulnar nerve after previously failed surgical treatment. However, surgeons performing a reexploration must be competent, capable, and comfortable with the procedure.

In our opinion, further research should focus on a well-designed, adequately powered prospective randomized controlled trial with long-term follow-up (> 2 years). Moreover, considering the number of patients with the recurrence of persistent symptoms of ulnar nerve compression, a multicenter approach is recommended. This should also include a combination of quantitative clinical findings for pain, motor function, sensation, and patient-related outcomes with satisfaction rates required for adequate evaluation of surgical procedures.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: all authors. Acquisition of data: Natroshvili, Walbeehm. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Natroshvili. Statistical analysis: Natroshvili, Walbeehm, Bartels. Administrative/technical/material support: van Alfen, Bartels. Study supervision: Walbeehm, van Alfen, Bartels.

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