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Original Research

Early Revision Rate Following Primary Carpal Tunnel Release

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Purpose: The published revision rates after carpal tunnel release (CTR) vary from 0.3% to 7%. The explanation for this variation may not be fully apparent. The purpose of this study was to determine the rate of surgical revision within 1–5 years following primary CTR at a single academic institution, compare it with rates reported in the literature, and attempt to provide explanations for these differences.

Methods: We identified all patients who underwent primary CTR at a single orthopedic practice by 18 fellowship-trained orthopedic hand surgeons from October 1, 2015, through October 1, 2020, using a combination of Current Procedural Terminology (CPT) and International Classification of Diseases (ICD), 10th Revision, codes. Patients who underwent CTR because of a diagnosis other than primary carpal tunnel syndrome were excluded. Patients who required revision CTR were identified using a practice-wide database query using a combination of CPT and ICD-10 codes. Operative reports and outpatient clinic notes were reviewed to determine the cause of revision. Data on patient demographics, surgical technique (open vs single-portal endoscopic), and medical comorbidities were collected.

Results: A total of 11,847 primary CTR procedures were performed during the 5-year period on 9,310 patients. We found 24 revision CTR procedures among 23 patients, resulting in a revision rate of 0.2%. Of 9,422 open primary CTRs performed, 22 cases (0.23%) went on to undergo revision. Endoscopic CTR was performed in 2,425 cases, with 2 cases (0.08%) ultimately undergoing revision. The average length of time from primary CTR to revision was 436 days (range, 11–1,647 days).

Conclusions: We noted a substantially lower rate of revision CTR within 1–5 years of primary release (0.2%) in our practice than that noted in previously published studies, although we accept that this does not account for out-of-area migration. There was no significant difference in the revision rates between open and single-portal endoscopic primary CTR.

Type of study/level of evidence: Therapeutic III.

Carpal tunnel syndrome (CTS) is the most common compressive neuropathy diagnosed in the upper extremities, with a prevalence of 3.7% in the general population in the United States.[1–8] Gelfman et al[4] reported an estimated annual incidence of 424 diagnoses per 100,000 person-years. Consequently, carpal tunnel release (CTR) is one of the most commonly performed upper-extremity procedures, with an estimated 400,000–600,000 annual surgical cases.[1,9]

Although the majority of CTR surgeries are effective, unsuccessful CTR can lead to patient dissatisfaction and morbidity.[10] This is most often attributed to incomplete release of the transverse carpal ligament; recurrence, with perineural scarring and/or circumferential fibrosis of the median nerve; or other related complications.[10–14] Revision surgery may be indicated in cases of persistent or recurrent CTS symptoms after other potential etiologies have been ruled out (ie, cervical radiculopathy, brachial plexopathy, and generalized peripheral polyneuropathy).[10,12]

Currently, the true revision rate after primary CTR is unclear, with the revision rates in the literature ranging from 0.3% to

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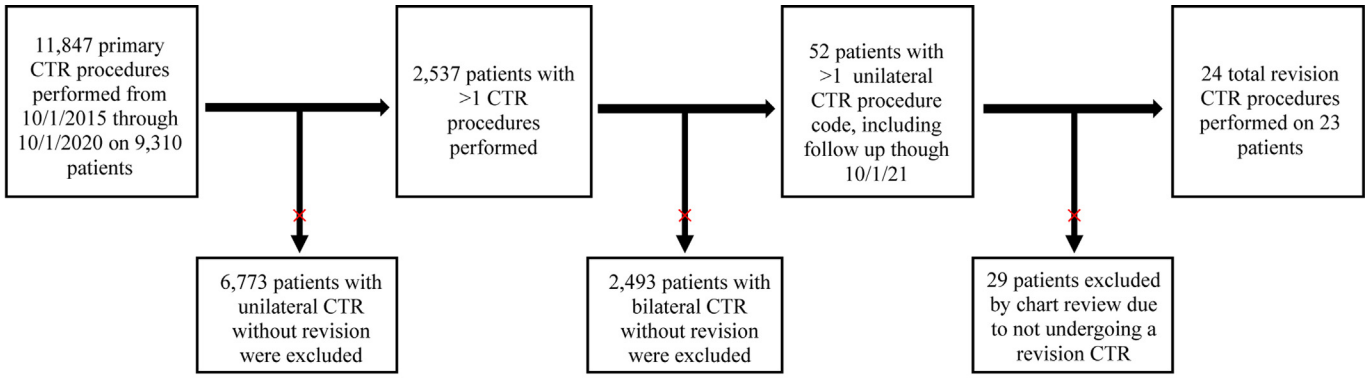

Figure. Study cohort flow diagram.

7%.[15–25] In fact, 2 recent large retrospective studies noted overall CTR revision rates of 4.8% and 1.5%.[23,24] Therefore, the purpose of the present study was to determine the early revision rate following primary CTR at a single, academic orthopedic hand surgery practice. "Early" was defined as revision surgery within 1–5 years of primary CTR. We hypothesized that the rate of revision CTR would be lower than other recently reported rates, with comparable follow-up (median, 1 year and 4.79 years, respectively).[23,24]

Methods

Institutional review board approval was obtained, including a waiver of informed consent per institutional protocol, and we adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines. We performed a search of a database of patients at a single academic orthopedic practice from October 1, 2015, through October 1, 2020. This search collected data on all patients who underwent CTR surgery during this time, determined based on the presence of the Current Procedural Terminology (CPT) codes 64721 (open CTR), 29848 (endoscopic CTR), or 64708 (open neuroplasty of peripheral nerve), performed by 1 of 18 board-certified, fellowship-trained, orthopedic hand surgeons. The CPT code 64708 was included to potentially identify revision surgeries; only cases with the CPT codes 64721 or 29848 were considered primary CTR. Only procedures with the corresponding laterality-specific International Classification of Diseases, 10th Revision (ICD-10) codes of G56.01, G56.02, or G56.03 (CTS of the right, left, or bilateral upper limbs) were included. Patients who underwent CTR secondary to acute trauma (radius fracture, perilunate dislocation, etc) were excluded. The remaining group of patients represented our cohort of primary CTR cases.

Patients who required revision CTR were identified in a stepwise fashion using a practice-wide electronic medical record data query. This process is outlined in the Figure. All patients had a minimum of 1 year and a maximum of 5 years of chart follow-up, which was used as the working definition of the "early" postoperative period. In cases in which the query identified potential revisions, a complete review of the patient's electronic medical records (including operative reports) was performed.

Data on patient demographics were collected, including age, sex, race, smoking status, and medical history. The specific comorbidities recorded included history of diabetes mellitus (type I or II), thyroid disease, psychiatric conditions (defined as diagnoses of anxiety, depression, or "other mental illness"), and rheumatoid arthritis (RA) because all these represent potential risk factors for CTS.[26–30] Additionally, we performed a query of patients who underwent CTR for a history of cervical spine disease, ulnar neuropathy, or other median neuropathy based on their ICD-10 codes. The surgical technique used in each CTR was determined based on the CPT code associated with the procedure, 64721 for open surgery and 29848 for endoscopic surgery. All endoscopic CTR surgeries were performed using the single-portal technique.

In the overall cohort, continuous data were compared using 2-sample *t* tests, and categorical data were compared using chi-square tests. Multivariate logistic regression was planned to determine the potential associations of risk factors with revision. Additionally, patients who did not undergo revision were demographically matched with those who underwent revision at a ratio of 4:1. Propensity score matching based on age, sex, and body mass index was chosen in order to control for potentially confounding variables when analyzing risk factors for undergoing revision CTR. The 4:1 ratio to control for patients who underwent revision was chosen because the size of the control cohort allowed it, and a greater ratio would not provide additional statistical power. Odds ratios were calculated, with significance set at $P < .05$. All statistical analyses were performed using R Studio (version 3.6.3).

Results

Study cohort

From October 1, 2015, to October 1, 2020, 11,847 primary CTR operations were performed on 9,310 unique patients. Of these patients, 41% were men and 59% were women. The average patient age at the time of surgery was 65 years (range, 21–103 years). There were 9,422 open primary CTRs among 7,486 patients (79.5% of the total cases and 80.4% of the total patients) and 2,425 endoscopic primary CTRs among 1,824 patients (20.5% of the cases and 19.6% of the total patients). Additional demographic and comorbidity data are presented in Table 1.

Revision CTR rate and cohort characteristics

The overall revision rate for all primary CTR surgeries was 0.2% (24/11,847). The revision rate for primary open CTR was 0.23% (22/9,422) compared with 0.08% (2/2,425) for primary endoscopic CTR ($P = .14$). All 24 revision CTR operations were performed using an open technique. The mean time to revision was 436 days (range, 11–1,647 days), with a median of 293.5 days. Thirteen revisions (54%) were performed within 1 year of primary CTR. One patient

Table 1
Patient Demographics and Risk Factors in Overall Cohort

CTR Data Per Patient	Primary CTR Without Revision		Primary CTR With Revision CTR	
Total Patients	n = 9,287		n = 23	
Variable	n	%	n	%
Sex				
Male	3,817	41.1	13	56.5
Female	5,470	58.9	10	43.5
Age				
Average	64.8	-	59.1	-
Range	21–103	-	33–80	-
BMI, kg/m^2				
<25	1,636	17.6	6	26.1
25–29.9	2,926	31.5	3	13.0
>29.9	4,345	46.8	10	43.5
Surgical approach				
Open	7,465	80.4	21	91.3
Endoscopic	1,822	19.6	2	8.7
Tobacco use				
Current	1,310	14.1	7	30.4
Former	1,929	20.8	1	4.3
Nonsmoker	3,730	40.2	8	34.8
Comorbidities				
DM (type 1 or 2)	1,424	15.3	5	21.7
Thyroid disease	1,239	13.3	3	13.0
Psychiatric conditions	2,046	22.0	10	43.5
Rheumatoid arthritis	892	9.6	4	17.4
Cervical disease	304	3.3	2	8.7
Ulnar neuropathy	740	8.0	4	17.4
Other median neuropathy	30	0.3	1	4.3

BMI, body mass index; DM, diabetes mellitus.

underwent bilateral revision surgeries following bilateral primary CTRs. Twenty-two patients (96%) had their revision surgery performed by the same surgeon as that who performed the primary CTR, and the other patient underwent revision performed by a different surgeon within the same practice.

Of the 23 patients who went on to undergo revision, 14 (61%) had recurrent CTS symptoms, 7 (30%) had persistent symptoms, and 2 (9%) had worsening symptoms with associated pain immediately following their primary surgery.

The indication for revision in each of the 24 cases is described in Table 2. The intraoperative findings from 21 of the 24 cases are detailed in Table 2. The operative reports for the remaining 3 cases were unavailable, and data were gathered from office notes primarily. During their revision surgery, 7 patients (29%) underwent a concomitant soft-tissue flap procedure, 5 patients required flexor tendon tenosynovectomy (20.8%), and 4 patients (16.7%) underwent a median nerve wrap for prevention of recurrent perineural scarring and adhesion formation. The decision to perform 1 or more of these additional procedures was made during surgery on a case-by-case basis because of the degree of perineural scarring, adhesions, transverse carpal ligament reformation, and flexor tenosynovial hypertrophy. Depending on surgeon preference, it may be reasonable to have nerve wraps available during revision CTR cases.

Prior to primary CTR, each of these patients underwent electromyography (EMG) and nerve conduction study (NCS) testing and met the American Association of Electrodiagnostic Medicine's diagnostic criteria for CTS.[31,32] Sixteen patients (67%) underwent repeat prerevision EMG and NCS. Of these patients, 12 (75%) had equivalent results compared with the results of their original preoperative testing, whereas 3 (19%) had more severe findings, and 1 patient (6%) was noted to have mildly improved EMG and NCS measurements. The decision to repeat EMG and NCS testing was made by the treating surgeon.

Overall, the revision group was predominantly comprised of men (57% compared with 41% of the patients in the overall cohort) and had a greater proportion of active smokers (30% vs 14%, respectively) as well as patients with psychiatric conditions (44% vs 22%, respectively), diabetes mellitus (22% vs 15%, respectively), RA (17% vs 10%, respectively), cervical spine disease (9% vs 3%, respectively), and other median neuropathy (4.3% vs 0.3%, respectively). Unfortunately, the small size of the revision cohort (n = 23) precluded the use of multivariate analysis to describe the effect of surgical technique and comorbidities on the revision rate. The results of the analysis of the 4:1 matched revision versus nonrevision cohort are presented in Table 2. Following the matching calculation, no significant differences were present in age, sex, or body mass index between the control and revision cohorts, and significantly greater odds of progression to revision CTR existed only for patients with a history of psychiatric conditions (43.5% vs 20.7%; odds ratio, 2.93 [95% confidence interval, 1.09–7.81]; $P = .047$).

Discussion

Primary CTR is typically successful; however, unfortunately, complications can occur that necessitate revision surgery.[10–14] The impetus for our study was the meaningful discrepancy in revision rates between the 2 most contemporary, retrospective studies to date (Wessel et al[23] 4.8% vs Westenberg et al[24] 1.3%). Additionally, we sought to compare the revision rates between open and endoscopic CTR in our own study cohort. Overall, the revision rate in our cohort (n = 11,847) was 0.2%, which is substantially lower than those recently reported in the literature. Additionally, no statistically significant difference in revision rate was noted between open (0.23%) and endoscopic (0.08%) primary CTR.

A number of studies have sought to clarify the revision rate following CTR (Table 3). Over a 14-year period (2002–2015), Westenberg et al[24] conducted a large retrospective review of 9,417 primary open and endoscopic CTR surgeries in 7,464 patients. Their overall revision rate was 1.3%, performed at a median of 1.23 years after primary CTR. In contrast to our results, their rate of revision CTR was greater after endoscopic CTR (2.8%) compared with that after open CTR (1.4%), and they reported this as a risk factor. However, only 425 patients (6% of the cases) underwent endoscopic release in this group. Given that this only amounts to an average of 30 endoscopic CTR cases per year over a 14-year period, the relatively low volume could have potentially contributed to the higher revision rate for the endoscopic technique.[24] In contrast, our study included 2,425 endoscopic CTRs over 5 years which averages to 485 per year.

In 2021, Wessel et al[23] performed a retrospective review of an insurance database, including 4,549 patients, over a 3-year period (2015–2017), with a focus on revision CTR rate within 1 year of the index procedure. They reported an overall 1-year revision rate of 4.8%. The open and endoscopic CTR subgroups had revision rates of 4.4% and 6.5%, respectively. These rates are substantially higher than those found in our study and other studies in the literature.[16,18–21,24,25,33,34] Because of complete reliance on accurate coding and the inability to manually review individual patient charts and operative reports, it is likely that these results overestimated the true revision rate within 1 year of CTR.[23]

Using England's National Health Service database, Lane et al[34] analyzed all CTR cases performed over a 19-year period (1998–2017) using a combination of Office of Population Censuses and Surveys Classification of Interventions and Procedures codes and ICD codes. A total of 855,832 cases were included, with a median follow-up duration of 7.5 years. However, no distinction between open or endoscopic CTR techniques was made, and patient charts and/or operative reports were not reviewed. Despite this, the authors identified 17,956 presumed paired primary and revision surgeries, resulting in a revision rate of 2.1%. The median time to

Table 2
Patient Demographics and Risk Factors in Matched Cohort

CTR Data Per Patient	Primary CTR Without Revision		Primary CTR With Revision CTR			
Total Patients	n = 92		n = 23			
Variable	n	%	n	%	Odds Ratio (95% Confidence Interval)	*P* Value
Sex					1 (0.39–2.54)	1
Male	40	56.5	13	56.5		
Female	52	43.5	10	43.5		
Age					1 (0.97–1.03)	1
Average	60.1	-	60.1	-		
BMI					1.01 (0.94–1.08)	1
Average	30.8	-	31.2	-		
Surgical approach					1.89 (0.57–9.0)	.397
Open	71	77.2	21	91.3		
Endoscopic	21	22.8	2	8.7		
Tobacco use						.094
Current	16	21.9	7	41.2	1.79 (0.54–5.76)	
Former	20	27.4	1	5.9	0.23 (0.01–1.41)	
Nonsmoker	37	50.7	9	52.9		
Comorbidities						
DM (type 1 or 2)	19	20.7	5	21.7	1.08 (0.32–3.18)	1
Thyroid disease	10	10.9	3	13	1.26 (0.25–4.70)	.72
Psychiatric conditions	19	20.7	10	43.5	2.93 (1.09–7.81)	.047
RA	3	9.8	4	17.4	1.96 (0.47–6.89)	.289
Cervical disease	5	5.4	2	8.7	1.71 (0.21–8.99)	.626
Ulnar neuropathy	11	12	5	21.7	2.06 (0.56–6.55)	.309
Other median neuropathy	0	0	1	4.4	-	.2

BMI, body mass index; DM, diabetes mellitus.

reoperation was 331 days.[34] Apart from these 3 large studies, other smaller prospective and retrospective studies have described varying rates of revision surgery following primary CTR, as detailed in Table 4.[18–20,25,33,35–37]

An additional goal of our study was to compare the rates of previously described risk factors for CTS in patients who underwent revision versus those in the remainder of the study cohort patients (those who did not undergo revision). Patients who required revision CTR were associated with higher percentages of the following risk factors: current smokers (30.4% vs 14.1%), diabetes mellitus (21.7% vs 15.3%), RA (17.4% vs 9.6%), cervical spine disease (8.7% vs 3.3%), psychiatric conditions (43.5% vs 22%), and other median neuropathy (4.4% vs 0.3%).[24,28–30] Demographic matching revealed significantly greater odds of requiring revision CTR only for patients with a history of psychiatric diagnosis, although all risk factors analyzed trended toward increased odds of requiring revision in the matched analysis. Unfortunately, we were unable to use multivariate analysis to describe the effect of these comorbidities on the revision rate because of the limited sample size, representing a distinct weakness. However, our results are grossly comparable with those of Westenberg et al,[24] who also reported higher rates of diabetes mellitus (29.2% vs 21.7%, respectively), RA (16.8% vs 7.7%, respectively), smoking (27.4% vs 12.5%, respectively), and cervical radiculopathy (23.9% vs 16.4%, respectively) in their revision group versus those in a matched case-control cohort of patients who underwent primary release only.

Previous studies have demonstrated that psychological status and illness behavior can play a role in the severity of perceived preoperative CTS symptoms and diminished postoperative patient satisfaction following CTR.[30,38–41] A significant portion of our patients who underwent revision CTR carried a psychiatric diagnosis (43.5%). Although it is possible that patients with a psychiatric history were less likely to be satisfied with CTR and more likely to catastrophize recurrent or persistent symptoms, no definitive conclusions can be made from this retrospective study.

Our study has a number of strengths. First, the use of the original ICD-10 implementation date (October 1, 2015) as the start date for our data collection period, in conjunction with the CPT code queries, allowed for more accurate filtering of all primary CTR data, particularly with regard to laterality.[42] Despite this meticulous protocol, a substantial number of false positives were noted, as shown in the Figure. After careful manual review of available operative reports and clinical notes from 52 identified potential revision cases, only 24 represented true revisions. The majority of these false positives were due to inaccurately coded laterality; these patients were initially identified as having undergone 2 CTR procedures coded with the same laterality; however, they actually underwent a staged bilateral procedure. The ability to manually review all pertinent patient medical records represents a distinct advantage in terms of accuracy and validity when compared with insurance database studies.[23,34] Second, our query included nearly 12,000 consecutive primary CTR cases at a single institution over a relatively condensed time frame (5 years: 2015–2020). This total number is substantially larger than those in recent large, retrospective studies in the United States. Furthermore, we used a more condensed time frame (5 years; 2015–2020) compared with those in other large retrospective reviews, with access to individual patient charts, by Westenberg et al[24] (9,417 cases over 14 years; 2002–2015) and Hankins et al[25] (14,722 patients over 13 years; 1993–2005). Our shorter time frame increased the likelihood that the experience level of the surgeons was similar. Moreover, the timing of our study ensured that our data reflect our current revision rate. Because of the learning curve for endoscopic CTR, studies that included this technique from the 1990s and early 2000s, when it was first described, may have had a higher revision rate. The 2-portal endoscopic technique is no longer frequently used.[43] In 2011, Leinberry et al[43] surveyed the members of the American Society for Surgery of the Hand regarding their current CTS management. Of the participating members who predominantly use an endoscopic technique (in more than two-thirds of their primary cases), a single-portal technique was preferred by 82% of surgeons. Our study included single-portal endoscopic CTR cases only, whereas other similar studies either included 2-portal techniques (Westenberg et al,[24] Hankins et al,[25] Atroshi et al,[19] and

Table 3
Details of Patients Who Underwent Revision CTR

Patient ID	Laterality	Days to Revision	Preop EMG/ NCS	Preop EMG/ NCS Grade	Prerevision EMG Result	Same Surgeon?	Primary Approach	Revision Approach	Reason for Revision	Revision Surgery Intraop Findings	Concomitant Procedures
1	Right	421	Yes	Moderate-to-severe	Equivalent (moderate-to-severe)	No	Open	Open	Recurrent symptoms	1. Incomplete release of TCL 2. Median n. severely compressed, w/ hourglass appearance	N/a
2	Left	43	Yes	Severe	N/a	Yes	Open	Open	Worsening symptoms with pain	1. Median n. compressed under distal forearm fascia 2. Flexor tenosynovial hypertrophy	Forearm flexor tenosynovectomy
3	Right	1647	Yes	Moderate	Equivalent (moderate)	Yes	Open	Open	Recurrent symptoms	1. Reformation and thickening of TCL 2. Median n. flattened and atrophied	CuTR, Ulnar nerve release at wrist, flexor pronator lengthening
4	Left	840	Yes	Severe	Equivalent (severe)	Yes	Open	Open	Recurrent symptoms	1. Perineural scarring w/ adhesions and tethering causing compression	Pedicled synovial flap
5	Right	434	Yes	Severe	Equivalent (severe)	Yes	Open	Open	Recurrent symptoms	1. Reformation and thickening of TCL 2. Flexor tenosynovial hypertrophy	Hypothenar fat flap, Forearm flexor tenosynovectomy
6	Right	112	Yes	Moderate	N/a	Yes	Endoscopic	Open	Recurrent symptoms	Full operative report unavailable	N/a
7	Right	805	Yes	Severe	Equivalent (severe)	Yes	Open	Open	Persistent symptoms	1. Perineural scarring w/ adhesions and tethering causing compression	Nerve wrap
8	Right	175	Yes	Severe	Equivalent (severe)	Yes	Endoscopic	Open	Persistent symptoms	1. Thin, scarred in portion of TCL causing compression	Hypothenar fat flap, CuTR
9	Left	1125	Yes	Severe	Mild improvement in conduction (moderate)	Yes	Open	Open	Recurrent symptoms	1. Thin, scarred in portion of TCL causing compression	Long TFR, Revision Ulnar n. transposition
10	Right	134	Yes	Severe	Equivalent (severe)	Yes	Open	Open	Persistent symptoms	1. Flexor tenosynovial hypertrophy	Forearm flexor tenosynovectomy
11	Right	302	Yes	Moderate-to-severe	More severe (severe)	Yes	Open	Open	Persistent symptoms	1. Reformation and thickening of TCL 2. Perineural scarring w/ adhesions 3. Median n. severely compressed w/ hourglass appearance	Hypothenar fat flap
12	Right	425	Yes	Moderate-to-severe	Equivalent (moderate-to-severe)	Yes	Open	Open	Persistent symptoms	1. Flexor tenosynovial hypertrophy	Forearm flexor tenosynovectomy, Median nerve neurolysis at elbow, Lacertus release
13	Right	168	Yes	Severe	Equivalent (severe)	Yes	Open	Open	Persistent symptoms	1. Perineural scarring w/ adhesions 2. Flexor tenosynovial hypertrophy	Nerve wrap, Forearm flexor tenosynovectomy
14	Left	90	Yes	Moderate	More severe (severe)	Yes	Open	Open	Recurrent symptoms	1. Thin, scarred in portion of TCL causing compression 2. Median n. severely compressed w/ hourglass appearance	Hypothenar fat flap
15	Left	427	Yes	Moderate	N/a	Yes	Open	Open	Recurrent symptoms	Full operative report unavailable	N/a
16	Left	131	Yes	Moderate	More severe (moderate-to-severe)	Yes	Open	Open	Recurrent symptoms	1. Thin, scarred in portion of TCL causing compression 2. Perineural scarring w/ adhesions	Pedicled synovial flap
17	Left	11	Yes	Moderate-to-severe	N/a	Yes	Open	Open	Worsening symptoms with pain	1. Compressive superficial band of distal forearm fascial tissue	N/a
18	Right	245	Yes	Moderate	Equivalent (Moderate)	Yes	Open	Open	Persistent symptoms	1. Perineural scarring w/ adhesions and tethering causing compression	Nerve wrap
19	Right	90	Yes	Moderate	N/a	Yes	Open	Open	Recurrent symptoms	1. Perineural scarring w/ adhesions and tethering causing compression	Nerve wrap
20 Left	Left	285	Yes	Moderate	N/a	Yes	Open	Open	Recurrent symptoms	1. Thin, scarred in portion of TCL causing compression 2. Perineural scarring w/ adhesions	N/a

(*continued on next page*)

Table 3 (*continued*)

Patient ID	Laterality	Days to Revision	Preop EMG/ NCS	Preop EMG/ NCS Grade	Prerevision EMG Result	Same Surgeon?	Primary Approach	Revision Approach	Reason for Revision	Revision Surgery Intraop Findings	Concomitant Procedures
20 Right	Right	273	Yes	Moderate	N/a	Yes	Open	Open	Recurrent symptoms	1. Perineural scarring w/ adhesions	N/a
21	Left	1113	Yes	Severe	Equivalent (Severe)	Yes	Open	Open	Recurrent symptoms	Full operative report unavailable	Hypothenar fat flap
22	Left	651	Yes	Severe	N/a	Yes	Open	Open	Recurrent symptoms	1. Perineural scarring w/ adhesions	Ring TFR, Revision CuTR
23	Right	524	Yes	Severe	Equivalent (Severe)	Yes	Open	Open	Recurrent symptoms	1. Reformation and thickening of TCL 2. Perineural scarring w/ adhesions	N/a

CuTR, cubital tunnel release; intraop, intraoperative; N/a, not available; preop, preoperative; TCL, transverse carpal ligament; TFR, trigger finger release.

Table 4
Review of Current Literature

Authors (Reference)	Journal	Year Published	Data Collection Period	Approach	Results and Revision Rate	Follow-up	Comments and Notes
Wessel et al[24]	*J Hand Surg Am*	2021	2015–2017	Open, endo (portal data not provided)	Combined: 217/4,549 = 4.8% Open: 170/3,829 = 4.4% Endo: 47/720 = 6.5%	1-y chart review follow-up	RR, insurance database, no direct chart/operative report review
Westenberg et al[25]	*Plast Reconstr Surg*	2020	2002–2015	Open, 1-portal Endo, 2-portal endo	Combined: 118/9,417 = 1.3% (per release) Open: 101/7,039 = 1.4% (per patient) Endo: 12/425 = 2.8% (per patient)	Median 4.8 y	RR, number of 1-portal vs 2-portal endo CTR not reported
Lane et al[38]	*Lancet Rheumatol*	2020	1998–2017	Open, endo (portal data not provided)	Combined: 17,956/8,55832 = 2.1%	Median 7.5 y	RR, National Health Service database (United Kingdom), open described as "primary technique," no direct chart/operative report review
Zhang et al[15]	*Hand*	2019	2008–2013	Open	Total: 11/1,144 = 1.0%	Min 1 mo, Median 9 mo	RR, "Mini-Open" 1.5–2 cm incision
Hankins et al[26]	*Plast Reconstr Surg*	2007	1993–2005	2-portal endo	Total: 403/14,722 = 2.7% Nonwork Comp: 322/12,494 = 2.6% Work comp: 81/2,228 = 3.6%	3 mo per protocol; subset 2,163 patients followed for 10 y	RR
Atroshi et al[20]	*BMJ*	2006	1998–2002	Open, 2-portal endo	Combined: 3/128 = 2.3% Open: 1/65 = 1.5% Endo: 2/63 = 3.2%	Min 3 mo Office visit; Questionnaire at 12 mo	RCT
MacDermid et al[23]	*J Hand Surg Am*	2003	N/a	Open, 2-portal endo	Combined: 5/123 = 4.1% Open: 0/32 = 0.0% Endo: 5/91 = 5.5%	Clinic: 12 wk; Phone call: mean 3.2 y postop	RCT, unbalanced enrollment 3:1 (endo:open)
Eichhorn et al[22]	*Chirurgische Praxis*	2003	N/a	Open, endo	Combined: 4/124 = 3.2% Open: 3/60 = 5% Endo: 1/64 = 1.6%	N/a	Abstract only
Trumble et al[19]	*J Bone Joint Surg Am*	2002	N/a	Open, 1-portal endo	Combined: 1/192 = 0.5% Open: 1/95 = 1.1% Endo: 0/97 = 0.0%	1 y	RCT
Concannon et al[16]	*Plast Reconstr Surg*	2000	1986–1996	Open, 2-portal endo	Combined: 6/191 = 3.1% Open: 0/103 = 0.0% Endo: 6/88 = 6.8%	Open: mean 29 mo.; Endo: mean 22 mo. (combination chart review and phone call)	RR, open: 35% WC Endo: 54% WC
Nancollas et al[17]	*J Hand Surg Br*	1995	1980–1985	Open	Total: 1/60 = 1.7%	Phone call questionnaire: mean 4.8 y	RR
Agee et al[21]	*J Hand Surg Am*	1992	N/a	Open, 1-portal endo	Combined: 2/147 = 1.4% Open: 0/65 = 0% Endo: 2/82 = 2.4%	26 wk	RCT

Endo, endoscopic; RR, retrospective review; RCT, randomized controlled trial; WC, Workers' Compensation patients.

MacDermid[22]) or did not describe the number of portals used during endoscopic CTR (Wessel et al[23] and Lane et al[34]).

Our study also has several limitations. First, any database query of this size is susceptible to coding errors. To mitigate this, we performed a manual review of the patients' records in potential revision cases to identify inaccuracies. Second, because the design and large cohort size of our retrospective study, we were unable to contact patients to determine whether they ultimately underwent

revision CTR at an outside institution. It was deemed unfeasible to attempt to contact 9,310 patients. Consequently, we had to make the false assumption that if any further care was sought and/or revision was performed, it was done at our own institution. It is likely that, to some degree, this assumption led to underestimation of the true revision rate in our cohort. However, we are a large referral practice in the region, and, therefore, we believe that this would be relatively uncommon. Third, although the majority of revision CTR is performed within a year of primary release, our revision rate in patients outside that time frame would be expected to increase slightly as more time for follow-up passes. We suspect that this would primarily pertain to patients in the latter portion of the database query. Fourth, not all complete EMG or NCS reports were available for review, and in many cases, repeat testing was performed by a different physician. However, the study impression (moderate, moderate-to-severe, severe, etc) was available for all EMG or NCS tests and was included. Fifth, the willingness of our surgeons to offer revision surgery and the willingness of our patients to proceed with revision CTR may not mirror that of the general population. Finally, as mentioned previously, multivariate logistic regression to determine the potential associations between risk factors for CTS and revision surgery could not be performed because of the small size of our revision cohort.

Overall, our study noted a substantially lower rate of early revision CTR (0.2% overall and 0.11% within 1 year) than previously published studies. Although the time elapsed from primary CTR to revision is variable, the overwhelming majority of revision surgeries are performed within 1–2 years of patients' primary release. No statistically significant difference in the revision rate was noted between our open CTR cohort and our single-portal endoscopic CTR cohort. These findings will allow us to better counsel patients considering CTR surgery. Finally, it is possible that large database studies that do not include manual review of patient charts and operative notes unintentionally over-report revision rates following primary CTR because of potentially inaccurate coding.

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