Journal of Hand Surgery Global Online 6 (2024) 212–221

Contents lists available at ScienceDirect

Journal of Hand Surgery Global Online

journal homepage: www.JHSGO.org

Original Research

Pillar Pain After Minimally Invasive and Standard Open Carpal Tunnel Release: A Systematic Review and Meta-analysis

Annora Ai-Wei Kumar, BBioMedSc, * Matthew Lawson-Smith, BSc (Hons), MBBCh BAO *, †, ‡, §

* The University of Western Australia, Crawley, Western Australia, Australia
† The University of Notre Dame, Fremantle, Western Australia, Australia
‡ Department of Hand Surgery, Fremantle Hospital, Fremantle, Western Australia, Australia
§ Department of Orthopaedic Surgery, Fremantle Hospital, Fremantle, Western Australia, Australia

ARTICLE INFO

Article history:
Received for publication November 1, 2023
Accepted in revised form December 13, 2023
Available online January 4, 2024

Key words:
Carpal tunnel syndrome
Meta-analysis
Minimally invasive surgery
Orthopedic surgery
Pain

Purpose: Pillar pain is a recognized postoperative complication of carpal tunnel release (CTR). Minimally invasive and alternative surgical techniques can theoretically prevent pillar pain, and the aim of this review was to compare the incidence of pillar pain after standard open CTR and alternative surgical techniques.

Methods: MEDLINE, Embase, and Scopus databases were thoroughly searched. Randomized controlled trials comparing minimally invasive surgical techniques to standard open CTR were identified. Data, including surgical technique, number of hands, incidence of pillar pain, and follow-up intervals, were extracted. Odds ratios (OR) were expressed as pillar pain incidence in the intervention group relative to standard open CTR.

Results: There were 12 studies included. No statistically significant differences were noted among endoscopic (OR = 0.53, $P = .20$), flexor retinaculum lengthening (OR = 1.00, $P = 1.00$), short incision (OR = 0.41, $P = .07$) or illuminated knife techniques (OR = 0.18, $P = .16$). There was a statistically significant decrease in pillar pain after minimally invasive CTR (OR = 0.41, 95% confidence interval 0.20–0.86, $I^2 = 0\%$, $P = .02$) between 3- and 6-months follow-up; however, analyses at all other follow-up periods failed to reach statistical significance.

Conclusions: Although our findings suggest that standard open CTR may be associated with an increased duration of pillar pain between 3 and 6 months postoperatively, our results suggest that minimally invasive CTR techniques do not affect either the initial development or persistence of pillar pain.

Clinical relevance: Our results illustrate the natural history of pillar pain with the majority of cases resolving after 6 months, highlighting the utility of symptomatic and conservative treatments and patient education in the management of pillar pain.

Carpal tunnel release (CTR) is one of the most common surgical procedures performed, with 11,512 public hospital admissions for CTR in Australia from 2017 to 2018.[1] The complications of CTR include anesthetic events, intraoperative bleeding, postoperative infection, pain, scar tenderness, and persistent or recurring symptoms.[2,3] Another complication of CTR is pillar pain, which has been estimated to persist in 12.7% of patients.[4] This is described as deep-seated pain in the heel of the palm worsened by applying pressure to the area and includes pain or tenderness over the hypothenar or thenar eminences that is separate from scar tenderness and usually resolves after the third postoperative month.[5]

Although the first surgical techniques for carpal tunnel syndrome were described by Learmonth[6] in 1933 and Cannon et al[7] in 1946, it was not until 1994 that pillar pain was described by Kenneth Wilson[8] in his illustration of the "critical pillar rectangle" containing small transverse nerve fibers, which characterizes pillar pain as a neurogenic phenomenon. Dissection of the palmar cutaneous branch of the median nerve (PCBMN) is commonly thought to be the cause of pillar pain.[9] The neurogenic theory of pillar pain as a result of nerve damage and entrapment have been supported

Declaration of interests: No benefits in any form have been received or will be received related directly to this article.

Corresponding author: Annora Ai-Wei Kumar, BBioMedSc, The University of Western Australia, 35 Stirling Hwy, Crawley Western Australia 6009, Australia.
E-mail address: 22711021@student.uwa.edu.au (A.A.-W. Kumar).

https://doi.org/10.1016/j.jhsg.2023.12.003

by cadaveric anatomical and histomorphological research demonstrating an abundance of free nerve endings in the transverse carpal ligament that are transected during CTR.[10–12] However, modern research has challenged this original theory by showing that preservation of the superficial nerve branches during CTR does not result in a decrease in local postoperative pain.[13] Furthermore, rather than damage to the PCBMN and local free nerve endings, the work by Vanhees et al[14] suggests a biomechanical etiology of pillar pain, citing the division of the flexor retinaculum as the cause. Other explanations for pillar pain include inflammatory, pisotriquetral dysfunction, and sympathetic dystrophy.[15–17]

Since the advent of the technique described by Learmonth[6] in 1933, advances in the field of orthopedic surgery have resulted in the emergence of minimally invasive techniques for CTR. These techniques, including endoscopic CTR, illuminated knife, or short incision techniques, can reduce scar length.[18–21] Modern techniques can also avoid completely severing the transverse carpal ligament or avoid dissecting the area traversed by the PCBMN as demonstrated in the double incision and double tunnels techniques.[22–24]

Theoretically, these techniques have the potential to reduce the risk of pillar pain. If pillar pain is neurogenic in origin and caused by injury to small branches of nerve fibers, the short incision, endoscopic, and illuminated knife techniques should result in a decreased incidence of pillar pain.[8,25] Similarly, if pillar pain is due to the immediate biomechanical disruption following dissection of the transverse carpal ligament, flexor retinaculum lengthening techniques should decrease the incidence of pillar pain.[14] Given that the endoscopic and illuminated knife techniques minimize local inflammation, if pillar pain is inflammatory in origin, a reduction in pillar pain would be expected after these techniques.[25–27]

Research on the efficacy of minimally invasive and alternative techniques in carpal tunnel surgery have yielded mixed results, and there is a lack of research specifically investigating the cause of pillar pain.[5,22,25] Therefore, we performed a systematic review and meta-analyses to investigate the incidence of pillar pain after minimally invasive and alternative surgical techniques. This review seeks to address the following primary research question: In patients undergoing CTR, is there a significant difference in the incidence of postoperative pillar pain in those undergoing standard open CTR compared to those who have undergone minimally invasive and alternative surgical techniques?

Materials and Methods

This systematic review was registered on the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD42022359701). This review was performed in accordance with the Quality of Reporting of Meta-analyses (QUOROM) guidelines and the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines (http://www.prisma-statement.org/).[28]

Literature search

Two independent reviewers searched the MEDLINE, Embase, and Scopus databases to identify relevant records published up to October 2023 using the search terms “carpal tunnel syndrome,” “carpal tunnel release,” and “pillar pain.” Appendix A (available online on the Journal’s website at https://www.jhsgo.org) outlines the search strategy in detail. Reference lists were also manually scanned to identify additional studies eligible for inclusion using these search terms.

Inclusion and exclusion criteria

Published randomized controlled trials (RCTs) of adult patients with pillar pain receiving CTR measured as an outcome after surgery were included. RCTs were included only if the study contained isolated standard open CTR as the control group. Eligible studies included those that contained qualitative data on the incidence of pillar pain in control and intervention groups as well as described the surgical technique used in the CTR procedure and specified the follow-up period. Articles that measured pillar pain only in the presence of other outcome measures (recorded only the number of patients with pillar pain ± scar tenderness, without specifying the exact number of patients that had isolated pillar pain) were excluded. Articles that combined CTR with another surgery (eg, basal joint arthroplasty, trapeziectomy) were excluded. Gray literature and articles in languages other than English were excluded.

Data extraction

The time frame of pillar pain was extracted and classified as early (during the first 6 weeks postoperatively), intermediate (between 6 and 12 weeks), late (between 3 and 12 months), and persistent (at 6 months and 1 year). Additionally, the following data were extracted from each study: author, publication year, region, surgical technique, number of participants and hands in control and intervention groups, and number of events (pillar pain) in control and intervention groups. Whether participants had unilateral or bilateral CTR was also noted. Information about funding sources was not sought. As only adult participants were included, other participant characteristics were not extracted.

Quality assessment and risk of bias

Quality and validity assessment was undertaken according to the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) guidelines, with a focus on the following constructs: inconsistency, indirectness, imprecision, and publication bias.[29] Risk of bias assessment was appraised using the Cochrane Collaboration’s tool.[30] This is a seven-item checklist that includes selection, performance, detection, attrition, reporting, and other biases and codes the level of bias as unknown (?), present (+), or absent (-). Quality assessment and risk of bias were undertaken by two investigators (AAK and MLS).

Statistical analysis

Data organization and analysis were conducted using Review Manager (version 5.3; The Nordic Cochrane Center, Cochrane Collaboration, Copenhagen, Denmark.[31] Dichotomous data were analyzed using the Mantel–Haenszel statistical method, reporting odds ratios (OR) and using 95% confidence interval (CIs), with the control group being the standard open CTR. Due to variations in surgical technique between RCTs, the pooled results of the outcome were calculated using the random effects model as it could not be assumed that the studies were functionally identical. Statistical heterogeneity was assessed using chi-square and I^2 statistics. An I^2 value of <40% was interpreted to contain negligible heterogeneity, 30% to 60% moderate heterogeneity, 50% to 90% substantial heterogeneity, and 75% to 100% considerable heterogeneity. A P value of less than .05 was considered statistically significant. When the P value from the chi-square test was less than 0.05 in conjunction with an I^2 value greater than 50%, the authors closely examined the relevant studies to identify the source of the heterogeneity. Finally, publication bias was subjectively assessed by visualizing the funnel

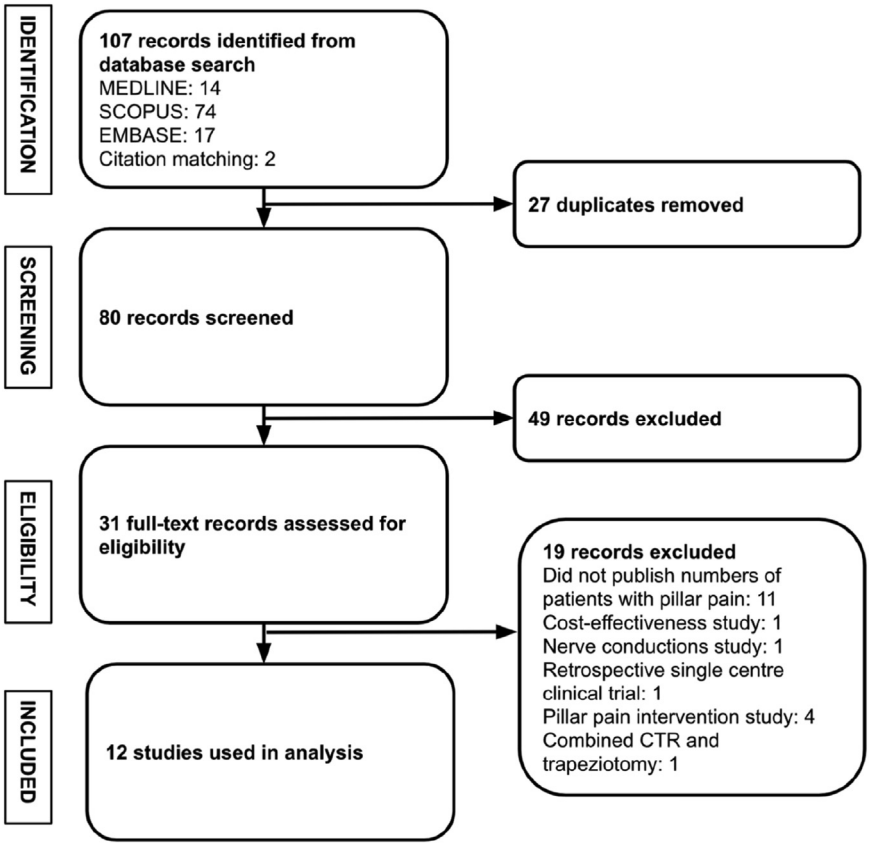

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement of search results. PRISMA statement detailing the studies included after identification, screening and eligibility stages of selection.

plot created in RevMan and objectively assessed using Egger's test in JASP (JASP Team (2022), Version 0.16.3).[31,32]

Results

Characteristics of included studies

There were 12 RCTs included in the final analysis (Fig. 1). Follow-up periods ranged from 2 weeks to 10 years. The average follow-up period was 15.3 months (Table).[20,21,24–26,33–39]

Risk of bias assessment

Among all included studies, none were deemed to be at risk for reporting bias. Random sequence generation (selection bias) and performance bias were the most common forms of bias encountered. Due to differences in scar length and operation time, patients and personnel were often aware of the type of surgery that had occurred. Therefore, five of the studies were deemed to be at high risk for performance bias with one having indeterminate risk. Figure 2 illustrates the risk of bias assessment conducted using the Cochrane Collaboration's tool.[27]

Publication bias

Publication bias was assessed using the funnel plot method, and this was formally tested using the regression test for funnel plot asymmetry (Egger's test). Both the shape of the funnel plot (Fig. 3) and the result of Egger's test ($P = .67$) indicated a lack of significant publication bias in the included studies.

Pillar pain 0–6 weeks after CTR (early)

The prevalence pillar pain between 0 and 6 weeks following CTR was 21.3% after minimally invasive CTR and 24.4% after standard open CTR. There was no significant difference in pillar pain during this period (OR = 0.87, 95% CI 0.50–1.52, $I^2 = 0\%$, $P = .64$) (Fig. 4).

Pillar pain 6–12 weeks after CTR (intermediate)

The prevalence of pillar pain between 6 and 12 weeks following CTR was 26.3% after minimally invasive CTR and 32.5% after standard open CTR. There was no significant difference in pillar pain during this period (OR = 0.53, 95% CI 0.12–2.38, $I^2 = 76\%$, $P = .39$) (Fig. 5).

Pillar pain 3–6 months after CTR (late)

The prevalence of pillar pain between 3 and 6 months following CTR was 11.6% after minimally invasive CTR and 23.6% after standard open CTR. During this time period, there was a statistically significant decrease in pillar pain after minimally invasive CTR (OR = 0.41, 95% CI 0.20–0.86, $I^2 = 0\%$, $P = .02$) (Fig. 6).

Pillar pain 6 and 12 months after CTR (persistent)

At 6 months of follow-up, pillar pain persisted in 11.4% of patients after minimally invasive CTR and 16.8% of patients after standard open CTR. This decrease in the prevalence of persistent pillar pain at six months follow-up failed to reach statistical significance (OR = 0.66, 95% CI 0.15-2.92, $I^2 = 58\%$, $P = .59$) (Fig. 7).

One year following CTR, pillar pain persisted in 5.5% of patients after minimally invasive CTR and 14.1% of patients after standard open CTR. This was not statistically significant (OR = 0.49, 95% CI 0.03–9.21, $I^2 = 77\%$, $P = .64$) (Fig. 8).

Table
Characteristics of Included Randomized Controlled Trials

Study	Year	Region	Surgical techniques in control and intervention groups	Number of hands	Total number of participants	Total number of hands	Follow-up period(s)
Bhattacharya et al[25]	2004	United Kingdom	Control: Conventional open release, 2.5 cm incision in line with the ring finger	26	26	52	2 weeks
			Intervention: KnifeLight - 1–1.5 cm incision made at the distal edge of the flexor retinaculum	26			
Castro-Menendez et al[36]	2016	Spain	Control: Complete resection - longitudinal incision in line with cubital edge of carpi radialis flexor	40	80	80	15 days, 1 month, 3 months, 1 year
			Intervention: Z-Elongation of the transverse carpal ligament, two parallel incisions 0.5 cm apart	40			
Elsharif et al[33]	2014	United Kingdom	Control: conventional open release, 2–3 cm palmar incision over the heel of the hand	43	82	82	10 years
			Intervention: KnifeLight - 0.5 cm palmar incision between the middle of the wrist and the 3rd web space	39			
Hamed et al[39]	2009	United Kingdom	Control: Single incision - longitudinal straight incision along the axis of the ring finger just ulnar to the thenar crease	21	40	40	6 weeks, 3 months, 6 months
			Intervention: Double incision - 2–3 cm longitudinal incision was made along the proximal palmar crease, with a second incision at the distal wrist crease between the palmaris longus and flexor carpi ulnaris tendons	19			
Jugovac et al[38]	2002	Croatia	Control: Traditional open technique - Eversmann technique	36	72	72	3 months
			Intervention: Limited palmar incision - 2.5 cm incision above the distal part of the transverse carpal ligament	36			
Larsen et al[34]	2013	Denmark	Control: Classic incision - 7 cm curved incision just ulnar to the thenar crease	30	90	90	6 weeks, 24 weeks
			Intervention 1: Short incision - 3cm incision in the midpalm distal to the flexion crease of the wrist	30			
			Intervention 2: Endoscopic procedure - using the Linvatec system	30			
Wong et al[26]	2003	Hong Kong	Control: Limited open carpal tunnel release (Lee and Strickland)	30	30	60	2 weeks, 8 weeks, 6 months, 1 year
			Intervention: Two-portal endoscopic release (Modified from Chow)	30			
Rojcharoenngam[35]	2020	Thailand	Control: Standard open release - 5–6 cm skin incision	20	40	40	1 month
			Intervention: Minimally invasive Wongsiri technique - 1.0–1.5 cm incision	20			
Dias et al[37]	2004	United Kingdom	Control: Standard release of the flexor retinaculum	26	52	52	2 weeks, 6 weeks, 12 weeks, 25 weeks
			Intervention: Z-elongation of the retinaculum as described by Simonetta (1977)[22]	26			
Mackenzie et al[21]	2000	United States	Control: 2.5 cm incision	14	26	36	4 weeks
			Intervention: Endoscopic - 3M Agee system	22			
Helm and Vaziri[20]	2003	United Kingdom	Control: Conventional open release – 2–3 cm palmar incision over the heel of the hand	43	82	82	6 weeks
			Intervention: KnifeLight - 0.5 cm palmar incision between the middle of the wrist and the 3rd web space	39			
Vanni et al[24]	2015	Italy	Control: 3 cm longitudinal incision from distal wrist crease to third web space to the wrist	110	220	220	12 months
			Intervention: Double tunnels technique - 0.6 cm longitudinal skin incision from proximal wrist crease to third finger web space; then, a 5 mm incision is made where the anebrachial fascia continued with the palmar fascia	110			

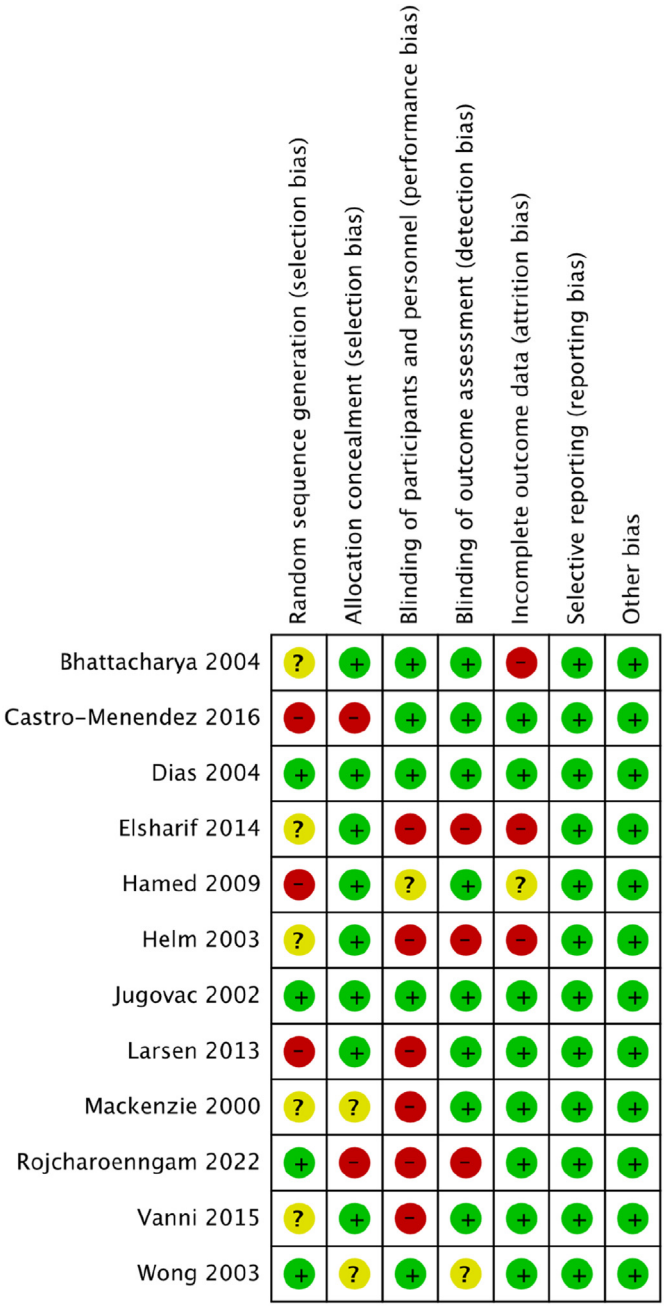

Figure 2. Risk of bias assessment for included studies. Assessment of selection, performance, detection, attrition, reporting, and other biases present among included studies. A high risk of bias is indicated by the minus sign, a low risk of bias is indicated by the plus sign, and studies with an indeterminate risk of bias are indicated by the question mark.

Figure 9 illustrates the prevalence of pillar pain during the early, intermediate, late, and persistent time periods. The majority of cases of pillar pain occurred during the intermediate period (6–12 weeks), and most cases resolved by 6 months.

Endoscopic CTR

There were four studies consisting of 102 patients in the intervention group and 94 in the control group that investigated pillar pain after endoscopic CTR. No statistically significant difference was found between the two groups (OR = 0.84, 95% CI 0.33–2.11, I^2 = 0%, P = .71) (Fig. 10).

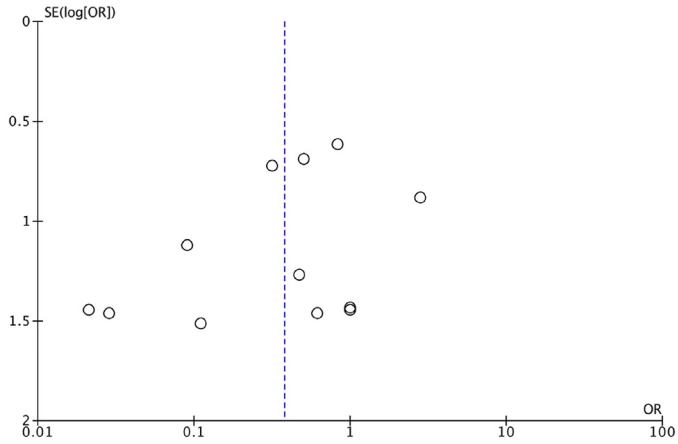

Figure 3. Funnel plot showing the pooled estimate from the meta-analysis and study odds ratios (OR) against the standard error (SE). The shape of the funnel plot and lack of funnel plot asymmetry indicate a lack of evidence of statistically significant publication bias.

Flexor retinaculum lengthening

Two studies investigated pilar pain after flexor retinaculum lengthening (both using Z-type lengthening). There were 66 patients in each of the intervention and control groups in these two studies. There was no observed reduction in the incidence of pillar pain after flexor retinaculum lengthening, as indicated by the OR and P value (OR = 1.00, 95% CI 0.14–7.33, I^2 = 0%, P = 1.00) (Fig. 11).

Short incision

Two studies investigated pillar pain following short incision with 66 patients in the intervention and control groups. The incidence of pillar pain was decreased after short incision; however, this failed to reach statistical significance (OR = 0.41, 95% CI 0.15–1.08, I^2 = 0%; P = .07) (Fig. 12).

Illuminated knife

Three studies investigated pillar pain after CTR using the illuminated knife technique (Knifelight®). There were 104 patients in the intervention group and 112 in the control group. There was no statistically significant reduction in pillar pain after CTR with the illuminated knife technique (OR = 0.18, 95% CI 0.02–1.92, I^2 = 68%, P = .16). An I^2 statistic of 68% represents substantial heterogeneity, and the P value from the chi-square test was 0.04, which confirms statistical heterogeneity (Fig. 13).

Discussion

The results of our review demonstrate a decreased prevalence of pillar pain after minimally invasive CTR compared to standard open CTR across all specified follow-up periods (early, intermediate, late, and persistent); however, this failed to reach statistical significance in all cases except for the late follow-up period (between 3 and 6 months). Furthermore, we found no significant reduction in pillar pain after endoscopic, flexor retinaculum lengthening, short incision, or illuminated knife techniques.

Although current strategies for the treatment of pillar pain include hand therapy, anti-inflammatory injections, such as alpha-lipoic acid

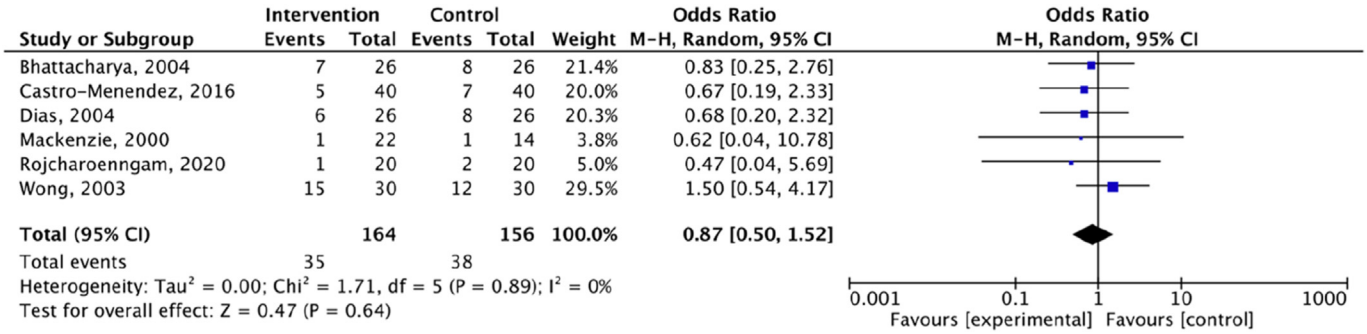

Figure 4. Pillar pain 0–6 weeks after CTR. Forest plot illustrating the odds of pillar pain after minimally invasive versus standard open CTR between 0 and 6 weeks of follow-up. There was no significant difference in pillar pain during this period (OR = 0.87, 95% CI 0.50–1.52, $I^2 = 0\%$, $P = .64$). CI, confidence interval; df, degrees of freedom; M-H, Mantel-Haenszel.

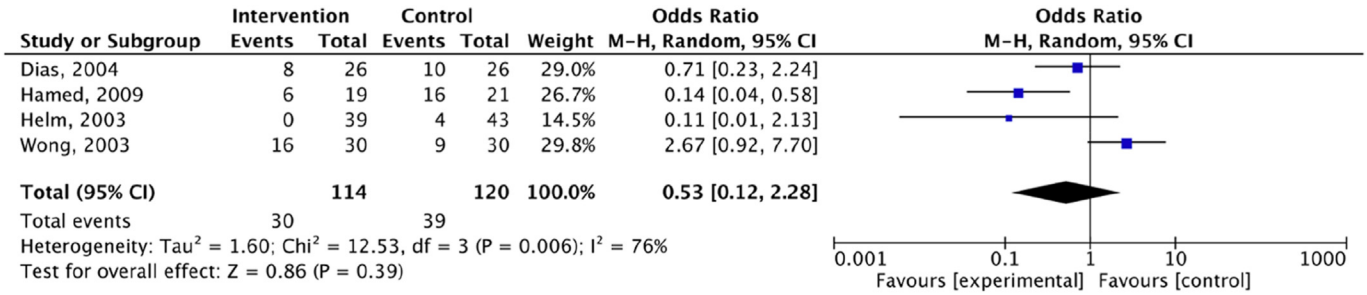

Figure 5. Pillar pain 6–12 weeks after CTR. Forest plot illustrating the odds of pillar pain after minimally invasive versus standard open CTR between 6 and 12 weeks of follow-up. There was no significant difference in pillar pain during this period (OR = 0.53, 95% CI 0.12–2.38, $I^2 = 76\%$, $P = .39$). CI, confidence interval; df, degrees of freedom; M-H, Mantel-Haenszel.

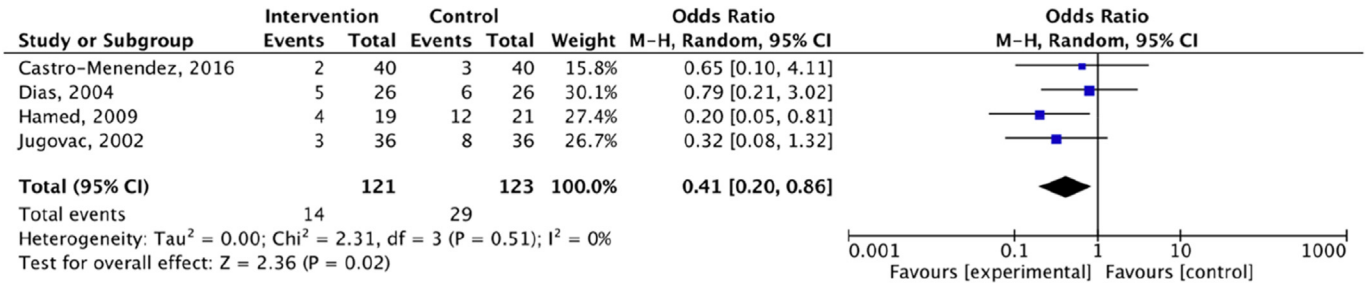

Figure 6. Pillar pain 3–6 months after CTR. Forest plot illustrating the odds of pillar pain after minimally invasive versus standard open CTR between 3 and 6 months of follow-up. There was a statistically significant decrease in pillar pain after minimally invasive CTR (OR = 0.41, 95% CI 0.20–0.86, $I^2 = 0\%$, $P = .02$). CI, confidence interval; df, degrees of freedom; M-H, Mantel-Haenszel.

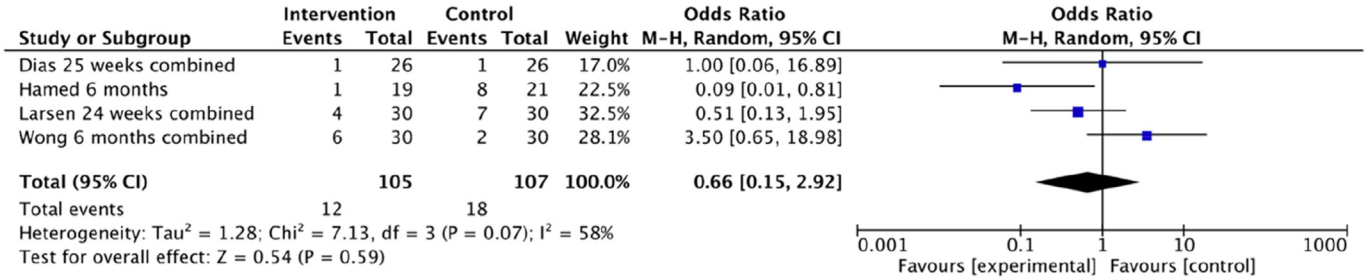

Figure 7. Pillar pain 6 months after CTR. Forest plot illustrating the odds of pillar pain after minimally invasive versus standard open CTR at 6 months of follow-up. There was no statistically significant difference in pillar pain at 6 months (OR = 0.66, 95% CI 0.15–2.92, $I^2 = 58\%$, $P = .59$). CI, confidence interval; df, degrees of freedom; M-H, Mantel-Haenszel.

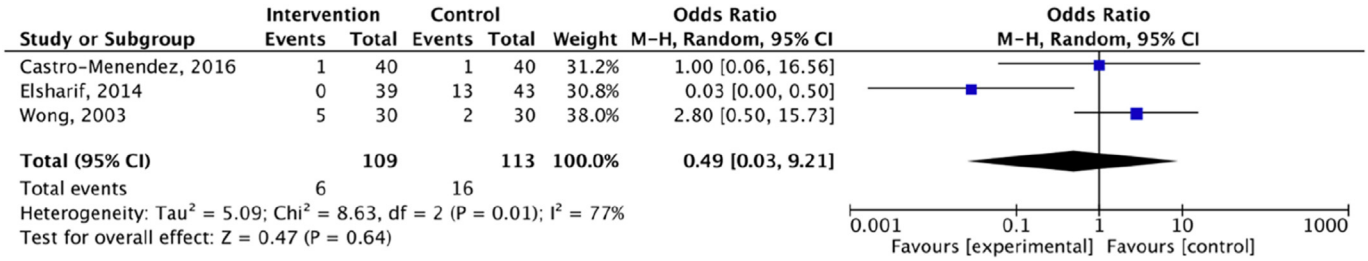

Figure 8. Pillar pain >1 year after CTR. Forest plot illustrating the odds of pillar pain after minimally invasive versus standard open CTR after 1 year of follow-up. There was no statistically significant difference in pillar pain after 1 year (OR = 0.49, 95% CI 0.03–9.21, $I^2 = 77\%$, $P = .64$). CI, confidence interval; df, degrees of freedom; M-H, Mantel-Haenszel.

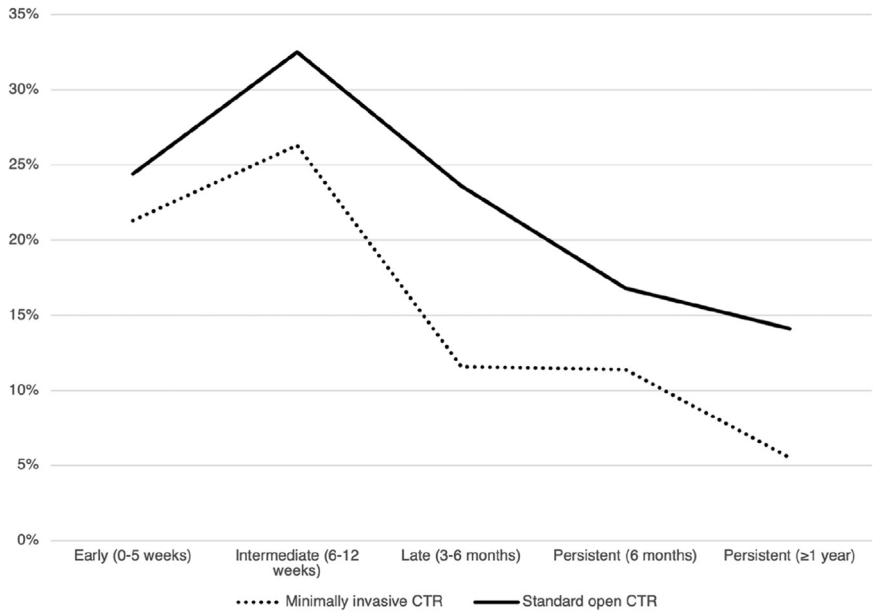

Figure 9. Pillar pain during the early, intermediate, late, and persistent time periods. Line graph illustrating the percentage of patients with pillar pain during each defined follow-up period. The majority of cases of pillar pain occurred during the intermediate period (6-12 weeks), and most cases resolved by 6 months.

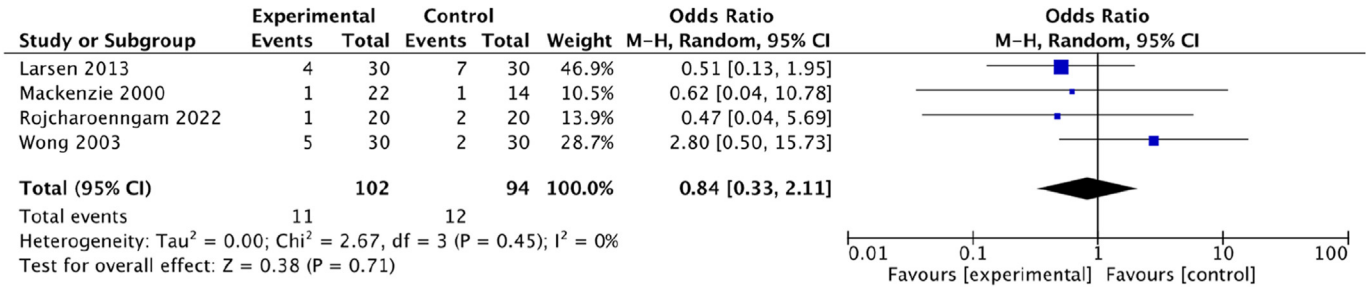

Figure 10. Pooled odds ratio of pillar pain after endoscopic CTR. Forest plot illustrating the odds of pillar pain after endoscopic CTR; the *P* value of 0.71 (OR = 0.84, 95% CI 0.33–2.11) indicates a lack of statistical significance. CI, confidence interval; df, degrees of freedom; M-H, Mantel-Haenszel.

and extracorporeal shock wave therapy, our pooled results demonstrate that the majority of cases of pillar pain arise before three months and resolve 6 months postoperatively.[15,17] Therefore, our findings function to illustrate the natural history of pillar pain (Fig. 9), suggesting that conservative symptomatic treatment and patient education may be sufficient for this condition that is often self-resolving.[5] The statistically significant decrease in pillar pain after minimally invasive CTR between 3 and 6 months suggests that standard open CTR may be associated with an increased duration of pillar pain symptoms, as it is generally accepted that most cases of pillar pain resolve by the third postoperative month.[5,40] Although minimally invasive techniques may result in a faster resolution of pillar pain, the lack of statistically significant pooled results at the other follow-up periods (early, intermediate, and persistent) suggests that minimally invasive CTR techniques do not affect either the initial development of pillar pain before 3 months or the persistence of pillar pain after 6 months.

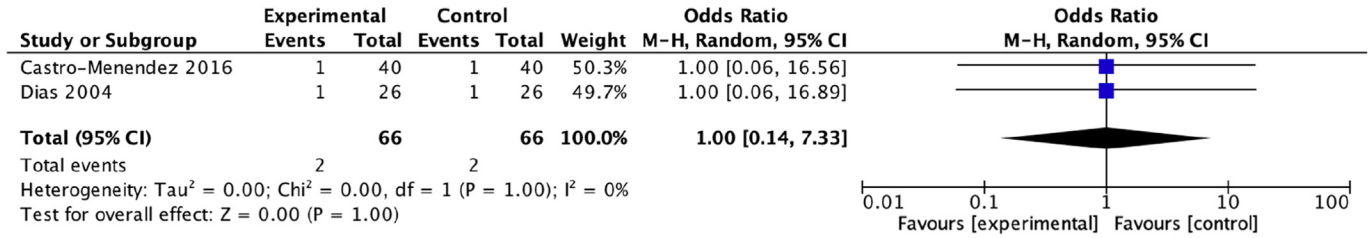

Figure 11. Pooled odds ratio of pillar pain after CTR with Z-type flexor retinaculum lengthening. Forest plot illustrating the odds of pillar pain after CTR with flexor retinaculum lengthening technique; the *P* value of 1.00 (OR = 1.00, 95% CI 0.14–7.33) indicates a lack of statistical significance. CI, confidence interval; df, degrees of freedom; M-H, Mantel-Haenszel.

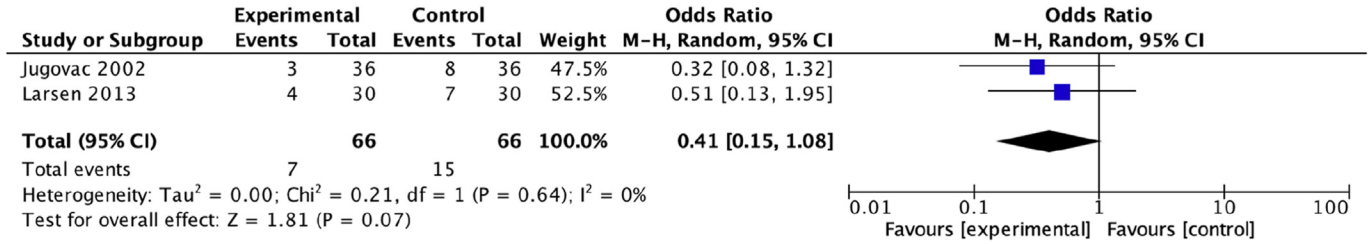

Figure 12. Pooled odds ratio of pillar pain after CTR with short incision. Forest plot illustrating the odds of pillar pain after CTR with short incision; the *P* value of 0.07 (OR = 0.41, 95% CI 0.15–1.08) indicates a lack of statistical significance.CI, confidence interval; df, degrees of freedom; M-H, Mantel-Haenszel.

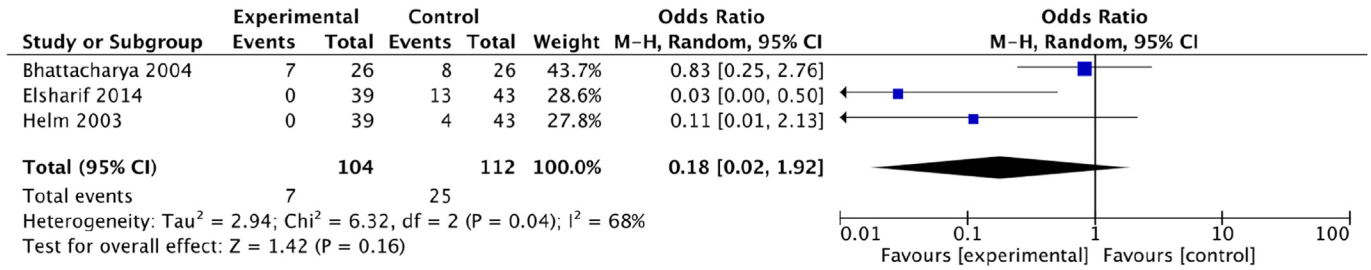

Figure 13. Pooled odds ratio of pillar pain after CTR with illuminated knife technique. Forest plot illustrating the odds of pillar pain after illuminated knife technique; the *P* value of 0.16 (OR = 0.18, 95% CI 0.02–1.92) indicates a lack of statistical significance. CI, confidence interval; df, degrees of freedom; M-H, Mantel–Haenszel.

Since its conception almost 90 years ago, standard open CTR has been the most popular surgical technique for carpal tunnel decompression.[41] Important considerations include safety, efficacy, cost, and availability; the primary aim of this review was not to change the well-established surgical techniques currently in use. Rather, we sought to gain deeper insights into the underlying cause of pillar pain. Although the literature supports the use of anti-inflammatory treatments of pillar pain suggesting an edematous etiology underlying this postoperative complication, the lack of significant reduction in pillar pain after endoscopic, flexor retinaculum lengthening, short incision, or illuminated knife techniques can be interpreted as challenging this theory.[15,17] In order to understand this, it is important to consider the collective effect of releasing the carpal tunnel while minimizing damage to surrounding tissue. In addition to a shorter operative time and faster wound healing, the endoscopic and illuminated knife techniques avoid dividing the subcutaneous tissue and results in a smaller scar.[20,21,25,26,33–35] The flexor retinaculum lengthening techniques minimize disruption by incompletely severing the transverse carpal ligament, and the short incision technique minimizes tissue trauma by using a smaller incision site.[34,36–38] These techniques result in less postoperative edema due to smaller incision sites and minimal disruption to local tissue. The lack of significant decrease in postoperative pillar pain is supported by existing literature. A 2015 systematic meta-analysis of open versus endoscopic CTR also found no reduction in pillar pain after endoscopic CTR, although faster return to work and better recovery of grip strength was associated with the endoscopic technique.[42] Therefore, although postoperative edema may have clinical significance regarding resolution of carpal tunnel symptoms and postoperative functional benefits, the lack of a significant difference in pillar pain in these techniques observed in our research suggests that postoperative oedema is not solely responsible for pillar pain, therefore suggesting an alternative or multifactorial theory of pillar pain.

A significant component of pillar pain is pain at rest (± paresthesia), which implies that there is a neurogenic component to the pain, as supported by cadaveric evidence of free nerve endings in the soft tissues of the palm.[12] Although not included in the CTR technique subgroup analysis, the surgical techniques that was associated with the lowest incidence of pillar pain were the double incision and double tunnels techniques. Hamed et al[39] reported an OR of 0.09 (95% CI 0.01–0.81) using the double incision technique at 6 months follow-up compared to the combined OR of 0.66 (95% CI 0.15–2.92, $I^2 = 58\%$, $P = .59$) in the analysis of minimally invasive

techniques versus standard open CTR at 6 months follow-up. The double incision technique leaves an intact bridge of the skin at the base of the palm, theoretically reducing damage to the PCBMN.[39] This suggests that there is a neurogenic element of pillar pain that is effectively avoided with these PCBMN-sparing techniques, supporting the popular theory that pillar pain is caused by damage to the PCBMN.[9,43] Additionally, in a sample size of 220 patients, Vanni et al[24] reported an odds ratio of 0.02 (95% CI 0.00–0.36) using the double tunnels technique. No patients in the intervention group had pillar pain at 12 months postoperatively compared to 19 in the control group.[24] It is possible that pillar pain was effectively prevented with the use of the double tunnels technique through a mechanism similar to the double incisions technique, avoiding damage to the PCBMN. As these studies represent techniques that were not included in any other studies included in our review, it was not feasible to perform subgroup analyses. However, such a prevention in pillar pain would also be expected with the other minimally invasive techniques, especially the illuminated knife technique, and this is not consistent with our results. Nevertheless, a neurogenic cause of pillar pain is supported by our time-dependent analyses that illustrates a decrease in pillar pain prevalence after 3 months with most cases resolved after 6 and 12 months. This consistent with the expected natural history of postoperative nerve damage; for instance, rodent studies investigating damage of small peripheral nerves (including C nerve fibers) demonstrate a regeneration period of approximately 3 months with a plateau after 12 months.[44,45] The persistence of pillar pain after 12 months may reflect individual anatomical variants or varying degrees of nerve transection. Further human research is needed to better characterize and describe small nerve fiber injury and repair after CTR, which may provide the basis for postoperative interventions directly targeting neuroregeneration, such as appropriate control of wound contraction with hand therapy, including range of motion and nerve gliding exercises.[46,47]

In conjunction with the inherent methodological flaws contained in the included RCTs, a significant limitation of our review was the paucity of evidence surrounding pillar pain after CTR. It has been found that *P* value-driven methods are underpowered to detect publication bias, especially in reviews containing a small number of studies such as this one.[48] Despite the Egger's test results ($P = .67$), the small number of included RCTs limited our ability to conclusively estimate publication bias, and it is possible that publication bias was under-estimated in our study. The limited number of RCTs also prevented us from investigating surgical techniques other than the four that were included in this review. Due to the lack of a standardized definition of pillar pain, RCTs that combined pillar pain with scar tenderness in their analyses had to be excluded, further limiting the number of available studies.

Finally, the conclusions from this review are limited by the heterogeneity among individual surgical techniques and institutions. Incision sizes ranged in both the standard open release (4–7 cm) and short incision groups (2–3 cm), and incision location and surgical techniques were not exactly standardized throughout all studies. The endoscopic tools used included the 3M Agee, Linvatec, and MiniSURE kit, which vary slightly in operative time and technique.[21,34,35] Dias et al[37] followed the Simonetta technique for Z-elongation, while Castro-Menendez et al[36] reversed the Simonetta incisions by extending the radial incision to the distal edge of the flexor retinaculum and the ulnar incision to the proximal edge. Nevertheless, there was negligible statistical heterogeneity among the subgroups of short incision, endoscopic, and flexor retinaculum reconstruction techniques, with I^2 statistics of 0% in all cases and corresponding chi-square *P* values of >.05. Interestingly, the subgroup associated with the highest level of statistical heterogeneity was the illuminated technique group. Unlike the other three subgroups, this group used the same device (the Knifelight® instrument) and operative technique in all cases. An I^2 statistic of 68% was observed associated with a chi-square *P* value of 0.04. Despite carefully examining the full texts of Bhattacharya et al,[25] Elsharif et al,[33] and Helm and Vaziri,[20] the authors could not identify a clear source of heterogeneity, noting that Elsharif et al[33] is a follow-up of the original study by Helm and Vaziri.[20] Lastly, although moderate heterogeneity was indicated by the I^2 statistics of the combined analyses, these were both associated with chi-square test *P* values of >.05. It is likely that this reflects the inherent heterogeneity arising from the differences among surgeons and institutions that pervades surgical research.

Ultimately, our review does not support the utility of minimally invasive techniques in preventing the development of pillar pain. Although our findings suggest that standard open CTR may be associated with an increased duration of pillar pain between 3 and 6 months postoperatively, our results suggest that minimally invasive CTR techniques do not affect either the initial development of pillar pain or the persistence of long-term pillar pain. Our results also illustrate the natural history of pillar pain, with the majority of cases resolving after 6 months. Our findings support a multifactorial etiology of pillar pain, with possible neurogenic elements arising from transection of small free nerve endings, highlighting the utility of control of wound contraction through hand therapy to promote nerve regeneration. The combination of a standardized definition and greater awareness and reporting of pillar pain in surgical trials is essential to furthering an understanding of the underlying cause of pillar pain.

Acknowledgments

The authors thank Emeritus Professor John McGeachie for his contributions to the final version of this manuscript and acknowledge the support provided by The University of Western Australia during the completion of this project.

References

1. Austrailian Institute of Health and Welfare. Elective Surgery Waiting Times 2017–18: Australian Hospital Statistics. Accessed August 2, 2023. https://www.aihw.gov.au/reports/hospitals/elective-surgery-waiting-times-2017-18
2. Genova A, Dix O, Saefan A, Thakur M, Hassan A. Carpal tunnel syndrome: a review of literature. *Cureus*. 2020;12(3):e7333.
3. Karl JW, Gancarczyk SM, Strauch RJ. Complications of carpal tunnel release. *Orthop Clin North Am*. 2016;47(2):425–433.
4. Boya H, Özcan Ö, Öztekìn HH. Long-term complications of open carpal tunnel release. *MuscleNerve*. 2008;38(5):1443–1446.
5. Ludlow KS, Merla JL, Cox JA, Hurst LN. Pillar pain as a postoperative complication of carpal tunnel release. *J Hand Ther*. 1997;10(4):277–282.
6. Learmonth J. The principle of decompression in the treatment of certain diseases of peripheral nerves. *Surg Clin North Am*. 1933;13:905–913.
7. Cannon BW, Love JG. Tardy median palsy; median neuritis; median thenar neuritis amenable to surgery. *Surgery*. 1946;20:210–216.
8. Wilson KM. Double incision open technique for carpal tunnel release: an alternative to endoscopic release. *J Hand Surg Am*. 1994;19(6):907–912.
9. Jeong YH, Choi JH, Choi HS, Kang S, Yang SN, Yoon JS. Risk assessment of injury to palmar cutaneous branch of the median nerve using high-resolution ultrasound. *Ann Rehabil Med. Aug*. 2019;43(4):458–464.
10. Hernández-Cortés P, Hurtado-Olmo P, Roda-Murillo O, Martín-Morales N, O'Valle F. Density mapping of nerve endings in the skin of the palm and flexor retinaculum of the hand. Application to open carpal tunnel release. *J Anat*. 2023;242(3):362–372.
11. de Lima LL, Ariel de Lima D, Freire THB, Almeida FAA, Leite JAD, Cavalcante MLC. Analysis of mechanoreceptors and free nerve endings of the transverse carpal ligament. *HAND*. 2022;18(1):62S–70S.
12. Mashoof AA, Levy HJ, Soifer TB, Miller-Soifer F, Bryk E, Vigorita V. Neural anatomy of the transverse carpal ligament. *Clin Orthop Relat Res*. 2001;386(386):218–221.
13. Siegmeth AW, Hopkinson-Woolley JA. Standard open decompression in carpal tunnel syndrome compared with a modified open technique preserving the superficial skin nerves: a prospective randomized study. *J Hand Surg Am*. 2006;31(9):1483–1489.

14. Vanhees M, Verstreken F, van Riet R. What does the transverse carpal ligament contribute to carpal stability? *J Wrist Surg*. 2015;4(1):31–34.
15. Boriani F, Granchi D, Roatti G, Merlini L, Sabattini T, Baldini N. Alpha-lipoic acid after median nerve decompression at the carpal tunnel: a randomized controlled trial. *J Hand Surg Am*. 2017;42(4):236–242.
16. Stahl S, Stahl S, Calif E. Latent pisotriquetral arthrosis unmasked following carpal tunnel release. *Orthopedics*. 2010;33(9):673.
17. Turgut MC, Saglam G, Toy S. Efficacy of extracorporeal shock wave therapy for pillar pain after open carpal tunnel release: a double-blind, randomized, sham-controlled study. *Korean J Pain*. 2021;34(3):315–321.
18. Chow JC. Endoscopic release of the carpal ligament: a new technique for carpal tunnel syndrome. *Arthroscopy*. 1989;5(1):19–24.
19. Wongsiri S. Keyhole surgery of CTS using novel tool MiniSure. *BMC Proc*. 2015;9(3):A79.
20. Helm RH, Vaziri S. Evaluation of carpal tunnel release using the Knifelight instrument. *J Hand Surg Br*. 2003;28(3):251–254.
21. Mackenzie DJ, Hainer R, Wheatley MJ. Early recovery after endoscopic vs. short-incision open carpal tunnel release. Article. *Ann Plast Surg*. 2000;44(6):601–604.
22. Simonetta C. [Peripheral nerve compression syndromes of the upper extremity]. *Acta Orthop Belg*. 1977;43(2):170–176.
23. Biyani A, Downes EM. An open twin incision technique of carpal tunnel decompression with reduced incidence of scar tenderness. *J Hand Surg Br. Jun*. 1993;18(3):331–334.
24. Vanni D, Sirabella FS, Galzio R, Salini V, Magliani V. The double tunnels technique: an alternative minimally invasive approach for carpal tunnel syndrome. *J Neurosurg*. 2015;123(5):1230–1237.
25. Bhattacharya R, Birdsall PD, Finn P, Stothard J. A randomized controlled trial of knifelight and open carpal tunnel release. *J Hand Surg Br*. 2004;29(2):113–115.
26. Wong KC, Hung LK, Ho PC, Wong JMW. Carpal tunnel release. A prospective, randomised study of endoscopic versus limited-open methods. *J Bone Joint Surg Br*. 2003;85(6):863–888.
27. Li Y, Luo W, Wu G, Cui S, Zhang Z, Gu X. Open versus endoscopic carpal tunnel release: a systematic review and meta-analysis of randomized controlled trials. *BMC Musculoskelet Disord*. 2020;21(1):272.
28. Moher D, Cook DJ, Eastwood S, Olkin I, Rennie D, Stroup DF. Improving the quality of reports of meta-analyses of randomised controlled trials: the QUOROM statement. Quality of reporting of meta-analyses. *Lancet*. 1999;354(9193):1896–1900.
29. Guyatt GH, Oxman AD, Schünemann HJ, Tugwell P, Knottnerus A. GRADE guidelines: A new series of articles in the *Journal of Clinical Epidemiology*. *J Clin Epidemiol*. 2011;64(4):380–382.
30. Higgins JPT, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343:d5928.
31. Cochrane Training. Review Manager (RevMan). Accessed June 5, 2023. https://training.cochrane.org/online-learning/core-software/revman/revman-5-download
32. JASP. JASP (Version 0.16.4)[Computer software]. Accessed June 5, 2023. https://jasp-stats.org/
33. Elsharif M, Papanna M, Helm R. Long-term follow up outcome results of Knifelight carpal tunnel release and conventional open release following a departmental randomized controlled trial. A prospective study. *Pol Orthop Traumatol*. 2014;79:67–70.
34. Larsen MB, Sorensen AI, Crone KL, Weis T, Boeckstyns MEH. Carpal tunnel release: a randomized comparison of three surgical methods. *J Hand Surg Eur Vol*. 2013;38(6):646–650.
35. Rojcharoenngam P. Minimal invasive surgery by Wongsiri technique versus standard open carpal tunnel release: a randomized trial. *J Med Assoc Thai*. 2022;105(6):505–509.
36. Castro-Menendez M, Pagazaurtundua-Gomez S, Pena-Paz S, Huici-Izco R, Rodriguez-Casas N, Montero-Vieites A. Z-Elongation of the transverse carpal ligament vs. complete resection for the treatment of carpal tunnel syndrome. 2016;60(6):355–365. https://doi.org/10.1016/j.recot.2016.06.007
37. Dias JJ, Bhowal B, Wildin CJ, Thompson JR. Carpal tunnel decompression. Is lengthening of the flexor retinaculum better than simple division? Article. *J Hand Surg (GBR)*. 2004;29 B(3):271–276. 392016;60(6):355–365.
38. Jugovac I, Burgic N, Micovic V, et al. Carpal tunnel release by limited palmar incision vs traditional open technique: randomized controlled trial. *Croat Med*. 2002;43(1):33–36.
39. Hamed AR, Makki D, Chari R, Packer G. Double- versus single-incision technique for open carpal tunnel release. *Orthopedics*. 2009;32(10).
40. Eversmann WW Jr. Compression and entrapment neuropathies of the upper extremity. *J Hand Surg Am*. 1983;8(5 Pt 2):759–766.
41. Phalen GS. The carpal-tunnel syndrome. Seventeen years' experience in diagnosis and treatment of six hundred fifty-four hands. *J Bone Joint Surg Am. Mar*. 1966;48(2):211–228.
42. Sayegh ET, Strauch RJ. Open versus endoscopic carpal tunnel release: a meta-analysis of randomized controlled trials. *Clin Orthop Relat Res*. 2015;473(3):1120–1132.
43. Kuhlmann N, Tubiana R, Lisfranc R. [Contribution of anatomy to the understanding of carpal tunnel compression syndromes and sequelae of decompression operations]. *Rev Chir Orthop Reparatrice Appar Mot*. 1978;64(1):59–70.
44. Fox IK, Brenner MJ, Johnson PJ, Hunter DA, Mackinnon SE. Axonal regeneration and motor neuron survival after microsurgical nerve reconstruction. *Microsurgery*. 2012;32(7):552–562.
45. Bester H, Allchorne AJ, Woolf CJ. Recovery of C-fiber-induced extravasation following peripheral nerve injury in the rat. *Exp Neurol*. 1998;154(2):628–636.
46. Yannas IV, Tzeranis DS, So PTC. Regeneration of injured skin and peripheral nerves requires control of wound contraction, not scar formation. *Wound Repair Regen*. 2017;25(2):177–191.
47. Tamaru Y, Yanagawa A, Matsugi A. Sensory nerve conduction velocity predicts improvement of hand function with nerve gliding exercise following carpal tunnel release surgery. *J Clin Med*. 2021;10(18).
48. Furuya-Kanamori L, Xu C, Lin L, et al. P value-driven methods were underpowered to detect publication bias: analysis of Cochrane review meta-analyses. *J Clin Epidemiol*. 2020;118:86–92.