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Supinator to posterior interosseous nerve transfer to restore hand opening in brachial plexus and spinal cord injury: a systematic review and individual patient–data meta-analysis

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OBJECTIVE Cervical spinal cord injury (SCI) and lower trunk brachial plexus injury (BPI) commonly result in hand paralysis. Although restoring hand function is complex and challenging to achieve, regaining volitional hand control drastically enhances functionality for these patients. The authors aimed to systematically review the outcomes of hand-opening function after supinator to posterior interosseous nerve (PIN) transfer.

METHODS A systematic literature review was performed according to the PRISMA guidelines.

RESULTS A total of 16 studies with 88 patients and 119 supinator to PIN transfers were included (87 transfers for SCI and 32 for BPI). In most studies, the time interval from injury to surgery was 6–12 months. Finger extension and thumb extension (Medical Research Council grade ≥ 3/5) recovered in 86.5% (103/119) and 78.1% (93/119) of cases, respectively, over a median follow-up of 19 months. The rates of recovery were similar for the SCI and BPI populations (finger extension, 87.3% in SCI and 84.3% in BPI; thumb extension, 75.8% in SCI and 84.3% in BPI). Type of injury (OR 1.05, 95% CI 0.17–6.4, p = 0.95), time from injury to surgery (OR 1.01, 95% CI 0.8–1.29, p = 0.88), and age (OR 0.97, 95% CI 0.90–1.06, p = 0.60) were not associated with odds of a successful outcome. Duration of follow-up was significantly associated with successful finger extension (OR 1.15, 95% CI 1.01–1.30, p = 0.026). No donor-associated supinator weakness was reported postoperatively given that patients had an intact bicep muscle preoperatively contributing to supination.

CONCLUSIONS Supinator to PIN transfer is a safe and effective procedure that can achieve successful restoration of digital extension in the SCI and BPI population at similar rates. Duration of follow-up was associated with superior outcomes, which was expected.

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KEYWORDS supinator; posterior interosseous nerve; brachial plexus injury; nerve transfer; hand restoration; peripheral nerve; spinal cord injury

Cervical spinal cord injury (SCI) and brachial plexus injury (BPI) often result in hand paralysis.[1] SCI occurring at the C6 level and C7–T1 BPI anatomically are often associated with intact elbow flexion and supination from the bicep muscle.[2,3] However, with these types of injuries, elbow and finger extension stemming from the radial nerve are affected. Hand function has robust effects on quality of life in the setting of SCI and BPI.[1] Historically, reconstruction of hand motion has posed significant challenges to peripheral nerve surgeons.[4,5]

The radial nerve has root contributions from C5 to T1. Interestingly, the nerve to the supinator receives its axons from the C5 and C6 nerve roots whereas the posterior interosseous nerve (PIN) does so from C7 and C8.[6] Both the nerve to the supinator and PIN arise from the radial nerve. The former innervates the supinator muscle whereas the

ABBREVIATIONS BPI = brachial plexus injury; MRC = Medical Research Council; PIN = posterior interosseous nerve; SCI = spinal cord injury.
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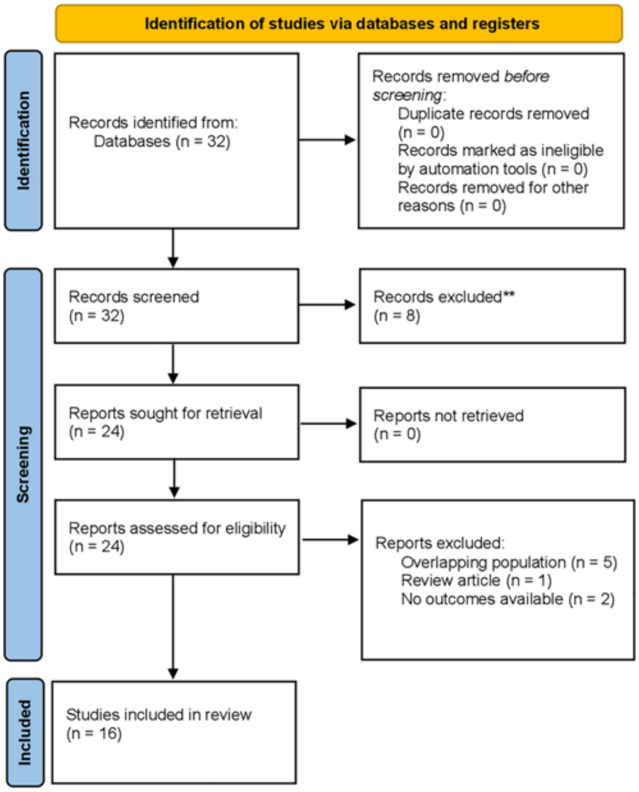

FIG. 1. PRISMA search flow diagram. Data added to the PRISMA template (from Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71) under the terms of the Creative Commons Attribution (CC BY 4.0) License (https://creativecommons.org/licenses/by/4.0/).

latter innervates multiple muscles, including the extensor digitorum communis and extensor indicis for finger extension and the extensor pollicis longus and brevis for thumb extension.[6] The two forearm supinators in humans are the biceps brachii and supinator muscle (both innervated by C5–6). This functional redundancy can be taken advantage of by using the supinator nerve as a donor for transfer to the PIN to restore finger extension in the setting of SCI or BPI.[6,7]

Several small case reports and case series have been published reporting the outcomes of this nerve transfer with variable results. The aim of this study was to systematically review and synthesize safety and efficacy outcomes after supinator to PIN transfer. To our knowledge, this represents the first systematic review and meta-analysis on this surgical approach.

Methods

The present systematic review and meta-analysis was performed according to the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines.[8] A systematic search was conducted of the PubMed Medline database by two independent investigators (P.T. and L.L.). Our search terms were “supinator” AND “posterior interosseous nerve” AND “transfer.”

Selection Criteria and Data Abstraction

Our inclusion criteria for selection of a study in our systematic review and meta-analysis were defined as follows: 1) an included study must be an observational study of patients who have undergone supinator to PIN transfer; 2) the study must have reported the primary outcome of interest; and 3) the study must have been published by June 2023. The primary outcome was defined as Medical Research Council (MRC) grade 3 or more for finger extension postoperatively. Secondary outcomes of interest were thumb extension, and postoperative complications included supinator or wrist extension weakness. MRC grade 3 or higher was defined as successful restoration of movement.

Independent reviewers (P.T. and L.L.) extracted data from the eligible studies. Variables of abstraction included the following: author, years of enrollment, location, study design, procedure performed, number of patients, type of injury, time from injury to surgery, sex, duration of follow-up, reported functional scores (MRC grade), age at surgery, and postoperative complications.

Risk of Bias Assessment

Risk of bias was assessed by one investigator (P.T.) with the ROBINS-I tool for nonrandomized studies.[9] The following domains were evaluated: confounding, selection of participants, departure from intended interventions, missing data, measurement of outcomes, and selective reporting. Any discrepancies were resolved via consensus after discussion with the coauthors.

Statistical Analysis

In this systematic review, individual patient data were available from several studies. Continuous variables were described with the median. Categorical or binary variables were described with absolute and relative frequencies as appropriate. Logistic regression analysis reporting ORs with the corresponding 95% CIs was used to assess the effect of time from injury to surgery, type of injury, and age at recovery of finger and thumb extension. A p value < 0.05 was considered significant. Stata 14.1 (StataCorp LLC) was used as the statistical software.

Results

Literature Search

The search strategy identified 24 studies for full-text evaluation after duplicates and irrelevant studies were removed. Eight studies were excluded due to missing the primary outcome, including overlapping population, or due to being a review article. Sixteen studies fulfilled our selection criteria and were included in this systematic review and individual patient–data meta-analysis, as presented in the flow diagram (Fig. 1). All included studies were retrospective observational cohort analyses.[2,3,6,7,10–22] None of the included studies were found to have a high risk of bias (Table 1).

The surgery was performed through a dorsal proximal forearm approach in most of the studies.[2,22] The dorsal approach involves identification of the PIN between the

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TABLE 1. Risk of bias assessment with the ROBINS-I tool for observational studies

Authors & Year	Confounding	Selection	Classification of Interventions	Deviations From Intended Interventions	Missing Data	Measurement of Data	Selection of Reported Result
Sacco et al., 2022[10]	Moderate	Moderate	Low	Low	Moderate	Low	Low
Xu et al., 2022[19]	Moderate	Moderate	Low	Low	Low	Low	Low
Melamed et al., 2022[15]	Moderate	Moderate	Low	Low	Moderate	Low	Low
Waris et al., 2022[18]	Moderate	Moderate	Low	Low	Moderate	Low	Low
van Zyl et al., 2021[17]	Moderate	Moderate	Low	Low	Low	Low	Low
Souza et al., 2020[16]	Moderate	Moderate	Low	Low	Low	Low	Low
Soldado et al., 2020[3]	Moderate	Moderate	Low	Low	Low	Low	Low
Hill & Fox, 2019[26]	Moderate	Moderate	Low	Low	Low	Low	Low
Emamhadi & Andalib, 2018[12]	Moderate	Moderate	Low	Low	Low	Low	Low
Bertelli & Ghizoni, 2016[11]	Moderate	Moderate	Low	Low	Low	Low	Low
Li et al., 2016[14]	Moderate	Moderate	Low	Low	Moderate	Low	Low
Bertelli & Ghizoni, 2015[2]	Moderate	Moderate	Low	Low	Moderate	Low	Low
Zhang et al., 2014[20]	Moderate	Moderate	Low	Low	Low	Low	Low
Bertelli et al., 2010[21]	Moderate	Moderate	Low	Low	Low	Low	Low
Dong et al., 2010[22]	Moderate	Moderate	Low	Low	Low	Low	Low
Bertelli & Ghizoni, 2010[7]	Moderate	Moderate	Low	Low	Low	Low	Low

extensor carpi radialis brevis and the extensor digitorum communis after sectioning of the supinator muscle. One or both of the two branches to the supinator muscle were then divided distally, while the PIN was divided proximally. Supinator branches were anastomosed with the PIN tension free. The anterior elbow approach was less frequently utilized.[17]

Characteristics of the Included Studies and Patients

Overall, 16 studies and 88 patients were included who had undergone a total of 119 supinator to PIN transfers (Fig. 2). Baseline patient study characteristics are available in Table 2. Eighty-seven transfers were performed after SCI and 32 were performed for BPI.

Outcomes

Finger extension and thumb extension (MRC grade ≥ 3/5) recovered in 86.5% (103/119) and 78.1% (93/119) of cases, respectively, over a median follow-up of 19 months (from studies with available data). Additionally, we per-

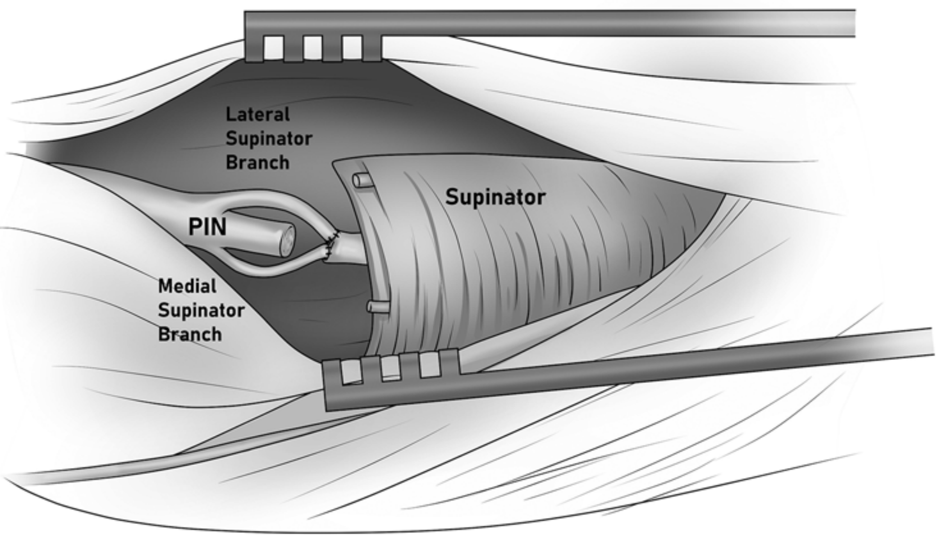

FIG. 2. Illustration demonstrating the supinator branches transferred to the PIN branch. The anterior elbow approach involves identification of the radial nerve under the supinator muscle proximal to the arcade of Frohse. The PIN and one or both of the two branches to the supinator muscle are then divided distally, while the PIN is divided proximally. Supinator branches are anastomosed with the PIN tension free. One or both branches to the supinator can be transferred. © Colin Franz, published with permission.

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TABLE 2. Baseline patient and study characteristics of the included studies

Authors & Year	Country	Sex/No. of Patients	Age, yrs*	No. of Patients	No. of Operations	Type of Trauma	Interval btwn Injury & Surgery, mos†
Sacco et al., 2022[10]	Italy	M10	31§	10	14	Cervical SCI	>6
Xu et al., 2022[19]	China	M5, F3	31 (18–55)	8	8	C7–T1 BPI	7 (3–13)¶
Melamed et al., 2022[15]	Brazil	F1	28	1	1	Central cord	10
Waris et al., 2022[18]	Finland	M4, F1	22 (15–28)	5	6	Cervical SCI	4–8
van Zyl et al., 2021[17]	Australia	M22, F4	30**	26	44	Cervical SCI	
Souza et al., 2020[16]	Brazil	M11	35.5 (24–59)¶	11	11	C8–T1 BPI	11 (4–13)
Soldado et al., 2020[3]	Brazil	M1	32	1	1	C7–T1 BPI	5
Hill & Fox, 2019[26]	USA	M1	20	1	1	Cervical SCI	8
Emamhadi & Andalib, 2018[12]	Iran	M1	30	1	1	Cervical SCI	12
Bertelli & Ghizoni, 2016[11]	Brazil	M5	30 (27–55)	4	5	Cervical SCI	5.5 (4–6) yrs
Li et al., 2016[14]	USA	M2, F1	21 (17–24)	3	3	C8–T1 BPI	5 (5–7)
Bertelli & Ghizoni, 2015[2]	Brazil	M6, F1	26 (20–30)¶	7	13	Cervical SCI	7 (6–18)
Zhang et al., 2014[20]	China	M2	18, 45	2	2	C7–T1 BPI	1.5–3
Bertelli et al., 2010[21]	Brazil	M1	20	1	2	Cervical SCI	7
Dong et al., 2010[22]	China	M3	18, 28, 45	3	3	C7–T1 BPI	3, 16, 1.5
Bertelli & Ghizoni, 2010[7]	Brazil	M4	19, 24, 25, 55	4	4	C7–T1 BPI	5–7

* Median (IQR) or individual ages are shown unless indicated otherwise.
† Median (IQR), range, or individual durations are shown unless indicated otherwise.
§ Median is shown.
¶ Mean (range).
** Mean is shown.

formed a subgroup analysis of these outcomes based on the type of injury. The rates of successful finger and thumb extension (MRC grade ≥ 3) for SCI were 87.3% and 75.8%, respectively. In the BPI subpopulation, the rates of successful recovery of finger and thumb extension were each 84.3%. Most studies reported follow-up of more than 1 year and an average time from injury to surgery between 6 and 12 months.

No supination weakness was reported by any of the studies. Four patients had temporary wrist extension weakness that self-resolved with time. No other complications were reported.

Individual Patient–Data Meta-Analysis

Fourteen of the included studies with 52 procedures in total provided individual patient data, with which we were able to perform multivariate logistic regression analyses for finger extension. The type of injury (OR 1.05, 95% CI 0.17–6.4, p = 0.95), time from injury to surgery (OR 1.01, 95% CI 0.8–1.29, p = 0.88), and age (OR 0.97, 95% CI 0.90–1.06, p = 0.60) were not associated with odds of successful finger extension restoration. Duration of follow-up was significantly associated with successful finger extension (OR 1.15, 95% CI 1.01–1.30, p = 0.026). Figure 3 illustrates a prediction with the best fit line for finger extension recovery and duration of follow-up. This shows that recovery of function can be observed after the first 10 months postoperatively and steadily increases thereafter.

Individual patient data regarding the outcome of thumb extension were available for 51 procedures. The odds of successful thumb extension were not associated with type of injury (OR 0.61, 95% CI 0.12–3.05, p = 0.55), time from injury to surgery (OR 0.99, 95% CI 0.80–1.22, p = 0.95), and age (OR 0.98, 95% CI 0.91–1.06, p = 0.72). Duration of follow-up showed a trend toward significance (OR 1.09, 95% CI 0.99–1.21, p = 0.075).

Discussion

To our knowledge, this is the first systematic review of the literature synthesizing safety and efficacy outcomes of supinator to PIN transfer. Finger extension and thumb extension (MRC grade ≥ 3/5) recovered in 86.5% (103/119) and 78.1% (93/119) of cases, respectively, over a median 19-month follow-up duration. With the individual patient–data meta-analysis, we have shown that time from injury to surgery and type of injury (BPI vs SCI) were not associated with odds of successful recovery of digital extension. Duration of follow-up was significantly associated with successful finger extension (OR 1.15, 95% CI 1.01–1.30, p = 0.026) and demonstrated a trend toward successful thumb extension (OR 1.09, 95% CI 0.99–1.21, p = 0.075).

Cervical SCI and BPI can lead to hand paralysis with commonly intact proximal cervical nerve roots.[1] The branch to the supinator nerve is supplied by C5 and C6 and can be utilized as a donor for nerve transfer to the PIN. The two main forearm supinator muscles are the biceps brachii and supinator muscle, which renders the latter redundant in the setting of SCI caudal to the C5 level and BPI involving the C7–T1 myotomes. From a surgical standpoint, the branches to the supinator and PIN are very close to each other, which facilitates tension-free anastomosis, with a relatively short axon regeneration distance

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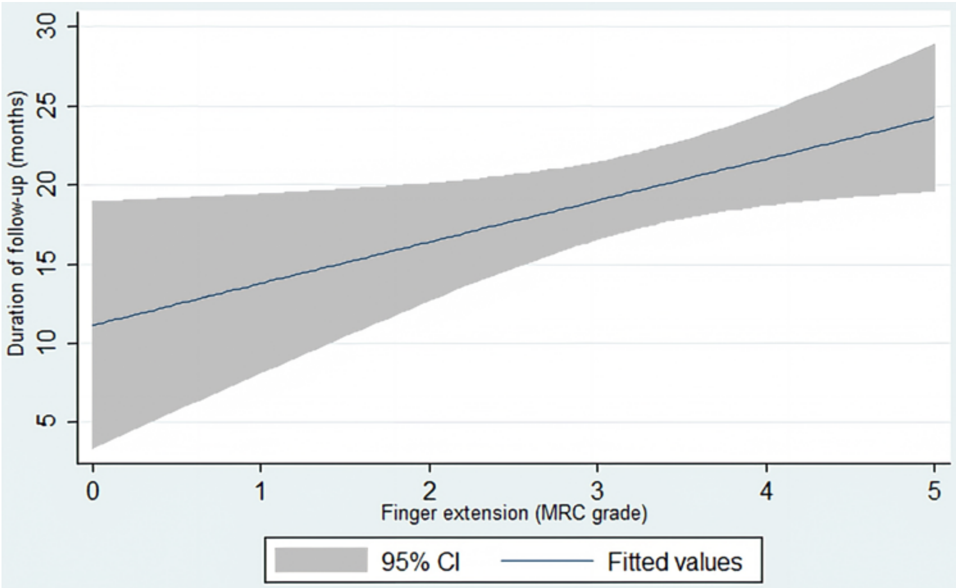

FIG. 3. Prediction with the best fit line for finger extension recovery and duration of follow-up, demonstrating the potential for increased recovery with time. The x- and y-axes illustrate duration of follow-up and recovery of finger extension, respectively. The *best fit line* shows that recovery of function begins after the first 10 months postoperatively and steadily improves thereafter.

from the anastomosis site to the target recipient muscles.[23] In addition, multiple cadaveric studies have shown that these two branches are similar in terms of nerve diameter, which suggests a fair donor/recipient nerve match.[23,24]

It has been shown that time from injury to surgery is an important predictor of successful nerve transfers.[5,25] In general, surgery within 6–12 months of injury has been considered the standard of care.[13,25,26] The pathophysiology of BPI is consistent with peripheral type nerve injury. In contrast, nerve injury in the setting of cervical SCI can be either the central or central/peripheral (mixed) type.[26] The former occurs at all levels distal to the SCI level (due to intact motor neurons in the anterior horn of the spinal cord that are affected proximal to the injury corticospinal tract).[26] However, the peripheral/central type injury can occur at the level of SCI secondary to motor neuron injury in the anterior horns, in addition to corticospinal tract damage.[26,27] In theory, time from injury to surgery would be more important in the setting of BPI but not as much for SCI.[26,28] Wallerian degeneration of the nerve and muscle atrophy occurs faster after an injury at the level of or distal to the motoneurons in the anterior horn. To that end, a study by Bertelli and Ghizoni showed that supinator to PIN transfer was successful (MRC grade 3/5 in 3/5 patients) after a median of 5.5 years after SCI.[11] Various predictors, including those from the clinical picture and electrodiagnostic studies, have to be considered when discussing nerve transfers > 12 months after injury.[29]

The studies in this review performed the nerve transfers at various intervals after injury, as shown in Table 1. The average time from injury to surgery was less than 12 months in all but one study.[11] This is the accepted time frame for standard care for nerve transfers.[13,25,26] For this reason, our analysis did not show an association between time from injury to surgery and surgical outcomes, as expected. Several studies performed early transfers (< 6 months from injury), but this study was likely underpowered to detect a difference—if any—in outcomes between the < 6-month and > 6-month interval groups. A potential interpretation of our analysis is that performing supinator to PIN transfer anytime earlier than the 12-month interval may not affect outcomes. Duration of follow-up varied between the studies included in this systematic review. Our analysis shows that, as expected, longer follow-up is associated with superior outcomes even though all but one study provided an average follow-up of more than 1 year. This suggests that digital extension strength is expected to improve with time, as shown in Fig. 2.

This study had limitations. Our results should be interpreted in the context of the biases associated with the retrospective design and nonrandomized nature of the included studies, limiting the generalizability of our results. Most of the included studies were small retrospective case series reporting outcomes of supinator to PIN transfer. Therefore, selection bias associated with the retrospective design and surgeons' preferences cannot be adjusted for. In addition, follow-up duration and time from injury to surgery varied across the studies. However, some of the included studies provided individual patient data, which enabled us to perform additional multivariate logistic regression analyses to investigate the effect of type of injury, duration of follow-up, and time from injury to surgery on the surgical outcomes. Lastly, some of the studies performed additional hand procedures (i.e., additional transfers such as brachialis to anterior interosseous nerve transfer for hand closing and tendon transfers) at various time intervals compared to the supinator to PIN transfer, and it is in theory possible that this could have affected the reporting of functional restoration outcomes. Larger-scale prospective studies or multi-institutional registries are needed to

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validate the results of this study and to identify potential predictors of outcomes. In addition, future studies should report outcomes assessing functional recovery in a practical way (e.g., Disability of the Arm, Shoulder, and Hand [DASH] questionnaire), in addition to the MRC grade.

Conclusions

Supinator to PIN transfer appears to be a safe and effective procedure that can achieve successful restoration of hand opening in the SCI and BPI populations at similar rates. Finger and thumb extension (MRC grade ≥ 3/5) recovered in 86.5% (103/119) and 78.1% (93/119) of cases, respectively, over a median 19-month follow-up duration. Duration of follow-up was associated with superior outcomes, which is expected. No permanent donor-associated adverse events were reported.

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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.

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Author Contributions

Conception and design: Texakalidis, Karras, Alden, Swong. Acquisition of data: Texakalidis, Liu, Swong. Analysis and interpretation of data: Texakalidis, Liu, Franz, Swong. Drafting the article: Texakalidis, Franz, Swong. Critically revising the article: Texakalidis, Karras, Alden, Franz, Swong. Reviewed submitted version of manuscript: Texakalidis, Liu, Alden, Franz, Swong. Approved the final version of the manuscript on behalf of all authors: Texakalidis. Statistical analysis: Texakalidis. Administrative/technical/material support: Swong. Study supervision: Alden.

Supplemental Information

Previous Presentations

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