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# Outcome comparison between interposition and "contactless" transposition microvascular decompression approaches for trigeminal neuralgia

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**OBJECTIVE** Microvascular decompression (MVD) is an effective method of treating trigeminal neuralgia (TN). The traditional approach is an interposition technique in which Teflon is placed between the nerve and offending vessel. However, recurrent TN pain has been attributed to the Teflon itself, its migration, inflammatory granuloma formation, or continued direct compression. Thus, transposition techniques in which the nerve is fully decompressed without any contact with the offending vessel or the Teflon have been described. In this study, the authors report their institutional experience with interposition and newer transposition techniques such as sling transposition.

**METHODS** A retrospective chart review was performed on patients who had undergone MVD from July 2015 to March 2024. Demographic, surgical, and clinical variables were collected, including modified Barrow Neurological Institute (BNI) pain intensity scale scores. Clinical outcomes were assessed using univariate and multivariate regression, and propensity score matching (PSM) was employed to minimize inherent heterogeneity in the surgical cohorts.

**RESULTS** Three hundred five patients underwent MVD for TN. Eighty-four patients underwent interposition; 139, transposition with Teflon (full decompression with no contact to the nerve); and 48, transposition using a pericranium sling to the tentorium. A subset of these patients underwent concurrent rhizotomy: 73% interposition cases, 15% Teflon transposition cases, 4% sling transposition cases. Rhizotomy alone was performed in 34 patients. Transposition primarily involved the superior cerebellar artery (90%) and was associated with severe compression and nerve indentation. There were no differences in BNI scores at the last follow-up or in complications among the treatment groups. The only significant predictor of pain freedom on multivariate analysis was MRI demonstrating clear compression (OR 2.49, 95% CI 1.147–5.404, p = 0.021). However, subgroup analyses of patients with at least 1 year of follow-up showed a trend for increased pain freedom (BNI scores I and IIIa) with the sling transposition technique at 1 year, which was statistically significant at the 2-year follow-up (1 year: sling 96.6%, Teflon 86.9%, interposition 81.1%, p = 0.053; 2 years: sling 100%, Teflon 87.5%, interposition 77.5%, p = 0.049). PSM cohort analysis showed that sling transposition patients had higher rates of pain-free outcomes (BNI scores I and IIIa) at the last follow-up than the Teflon transposition patients (93.1% vs 62.1%, respectively, p = 0.003).

**CONCLUSIONS** Interposition and transposition techniques for MVD are both effective. The authors' midterm data suggest longer-term TN pain control with sling transposition. Further studies will need to confirm the durability of long-term pain freedom.

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**KEYWORDS** trigeminal neuralgia; microvascular decompression; transposition techniques; pain; functional neurosurgery

**ABBREVIATIONS** AICA = anterior inferior cerebellar artery; BNI = Barrow Neurological Institute; CN = cranial nerve; MVD = microvascular decompression; PSM = propensity score matching; REZ = root entry zone; SCA = superior cerebellar artery; TN = trigeminal neuralgia.

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Trigeminal neuralgia (TN) is a debilitating facial pain disorder clinically characterized as sudden, excruciating unilateral episodes of pain that can occur multiple times per day. It is often caused by arterial compression of the trigeminal nerve, most often by the superior cerebellar artery (SCA) particularly at the root entry zone (REZ).[1] The REZ is believed to be more vulnerable to demyelination caused by compression from the vessel, resulting in an excessive pain reaction to stimuli through several proposed etiologies including sodium pump channel dysregulation leading to ephaptic neurotransmission.[1,2] Although first-line medical management with sodium channel blockers can be highly effective in minimizing the pain, the use of these drugs is limited by pharmacological side effects that negatively impact quality of life and by the potential of these medications to become less effective over time.[1,3]

Following its introduction by Gardner[4] and Jannetta,[5] microvascular decompression (MVD) of the trigeminal nerve has been the primary surgical treatment option, in which the offending arterial vessel is separated from the compressed trigeminal nerve by an interposed graft. A variety of interpositional materials have been used, including fascia, Gelfoam, and, most commonly, Teflon.[6–8] However, TN can recur in 40%–60% of patients following interpositional MVD,[9,10] and recurrence has been attributed to complications of the graft, including adhesion formation, graft slippage, and reactive Teflon granuloma formation.[8,11–16]

Thus, a range of transpositional techniques have been pursued to increase the durability of MVD. These approaches involve transposing the offending artery toward the tentorium with a variety of methods, including Teflon with glue and slings fashioned from Dacron, Gore-Tex, aneurysm clips, or autologous tissue.[17–21] However, reports on the efficacy of these transposition techniques have been limited to small case series without comparisons among the MVD variations.[18,22]

At our institution, both interpositional and transpositional techniques have been utilized. Within the transpositional methods, we recently transitioned from Teflon transposition toward tentorial slings when feasible. Here, we review the surgical techniques and report our experience in the largest patient series comparing the various interpositional and transpositional MVD techniques for TN.

## Methods

### Data Collection

This was a retrospective review of a prospective observational database including all patients who had undergone MVD for TN at a single institution from July 2015 to March 2024. All procedures were performed by the same surgeon (E.F.C.). The decision to undergo an interpositional or a transpositional approach was made by the surgeon at the time of surgery. Patients with tumors or other nonvascular pathologies that were causing TN were not included in the study. The research was approved by the UCSF Institutional Review Board.

### Study Variables

Demographic and clinical variables were collected for each surgery, including patient age, sex, symptom duration, TN type and location, and presence of clear vascular compression on preoperative MRI. Surgical variables included the compressive artery, compression site, and compression severity as determined by visual inspection. Severity was rated severe when an artery was clearly compressing or indenting the nerve. The primary endpoint was pain outcomes as evaluated using the modified Barrow Neurological Institute (BNI) pain intensity scale:[23,24] score I, no pain, no medication; score II, occasional pain, no medication; score IIIa, no pain, on medication; score IIIb, persistent pain, controlled with medication; score IV, some pain, not controlled with medication; and score V, no pain relief. Unless stated otherwise, pain freedom was defined as BNI score I (no medication) or IIIa (with medication). A planned subgroup analysis was performed for patients with at least 1 year of follow-up. Secondary outcomes included time of pain recurrence, postoperative paresthesias and dysesthesias, and complications. Telephone follow-up was attempted for patients without at least 1 year of clinic follow-up to query for primary and secondary endpoints. Patients who did not have 1-year follow-up data did not undergo subgroup analysis.

### Surgical Techniques

For all surgical techniques, a standard retrosigmoid craniectomy was performed. In brief, the patient was placed in a semilateral position on the operating table, and auditory brainstem responses were routinely monitored. A 4- to 5-cm curvilinear incision was made approximately two fingerbreadths behind the ear, centered over the retromastoid space. A pericranium graft was harvested for potential sling transposition and for dural grafting. A retrosigmoid craniectomy was then performed using a coarse diamond drill bit, and the transverse and sigmoid sinuses were partially exposed. Care was taken to wax the mastoid air cells that were encountered. The dura mater was opened, and CSF was drained. Arachnoid adhesions along the tentorial-petrous angle and around the trigeminal nerve were taken down, taking care to maintain arachnoid over the cranial nerve (CN) VII–VIII complex. Branches of the petrosal vein were not routinely transected, and they were only coagulated if necessary to improve the working corridor to the trigeminal nerve. Additional arachnoid adhesions were dissected around each compressive artery to allow for either an interpositional or a transpositional approach for decompression. If no severe compression was identified, a sensory rhizotomy was performed via internal neurolysis without transection or cautery of the nerve.

### Interposition Approach

If the offending artery could not be mobilized safely, the artery was gently dissected from the trigeminal nerve, and a small padding of Teflon felt was placed between the artery and the nerve and then secured with fibrin glue. In these cases, the Teflon was in contact with the REZ and separated this area from the offending artery (Fig. 1A–C).

### Teflon Transposition Approach

The transposition approach was generally favored

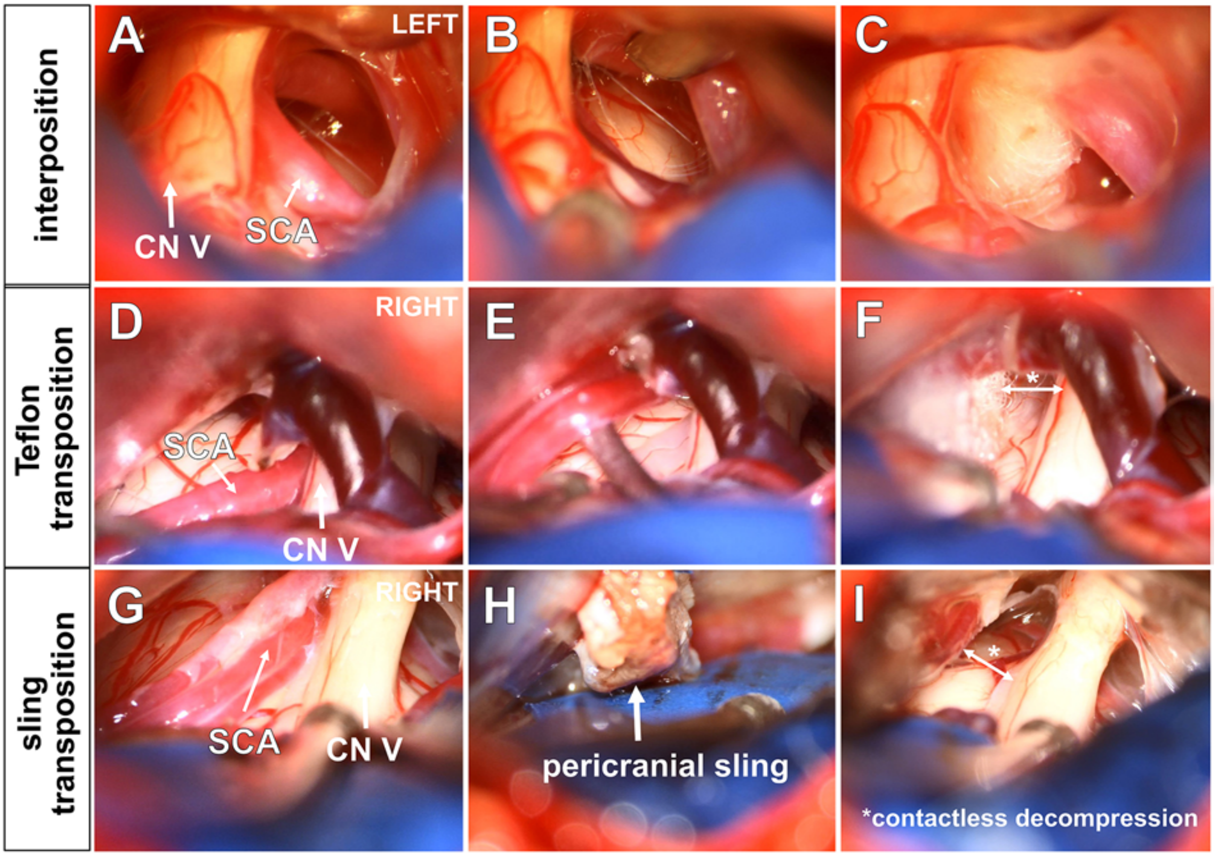


**FIG. 1.** Comparative intraoperative photographs of MVD techniques. **A–C:** Traditional Teflon interposition of AICA and CN V. **D–F:** Teflon transposition buttressing the compressive SCA against the tentorium. **G and H:** Pericranial sling transposition of compressive SCA onto the tentorium. **I:** Both transposition techniques result in "contactless" decompression of CN V REZ. *Asterisks* signify contactless decompression. Figure is available in color online only.

when a longer SCA loop was indenting the trigeminal nerve or even hanging down beyond the nerve. The SCA was gently dissected free from the trigeminal nerve, and the arachnoid was sharply opened distally over the artery. The SCA was then carefully transposed away from the trigeminal nerve, toward the tentorium, and a small piece of Teflon was used to buttress the offending artery against the tentorium. Care was taken to not have any contact between the artery and the nerve (Fig. 1D–F). In many cases in which the petrosal vein was preserved, the SCA was transposed above the petrosal vein where the vein acts as a strut, and the Teflon was used to secure it there. The SCA and Teflon were then secured with a drop of fibrin glue. The nerve was then inspected to ensure no contact whatsoever with the SCA or Teflon.

### Tentorial Pericranium Sling Approach

Beginning in July 2020, the transposition technique transitioned from Teflon transposition to a tentorial sling when feasible, primarily to avoid the potential for foreign body reaction or granuloma reaction to the Teflon. With this approach, the arachnoid both around the trigeminal nerve and along the distal SCA within the ambient cistern was dissected, making sure to prevent injury to perforating arteries and CN IV. Once the artery was dissected away from the trigeminal nerve, a small strip of pericranium was fashioned as a sling to transpose the artery away from the nerve. After creating space around the offending vessel, the pericranial strip was passed around the vessel using microinstruments. This sling was secured to the underside of the tentorium with an 8-0 Prolene suture using microinstruments (Fig. 1G–I). Care was taken to avoid tension, kinking, or vascular injury, and the artery was carefully inspected for patency. A small amount of fibrin glue was then applied to the graft.

### Statistical Analyses

Statistical analyses were performed using SPSS version 29 (IBM Corp.), and graphs were made in Prism 10 (GraphPad Software). Statistical significance was set at $p < 0.05$. Analysis of categorical variables (expressed as frequency and percentage) was performed with the chi-square and Mantel-Haenszel test. For continuous variables (expressed as mean ± standard deviation), an unpaired t-test or N-way ANOVA was used. All multiple comparisons were corrected with Bonferroni. The propensity score matching (PSM) was performed in SPSS using random sampling with replacement and a match tolerance of 0.3. Kaplan-Meier curves illustrating differences in pain freedom were generated in Prism.

## Results

Three hundred five patients underwent MVD for TN during the study period. MVD was performed with interposition, Teflon transposition, and tentorial slings in 84 (27.5%), 139 (45.6%), and 48 (15.7%) patients, respectively (Table 1). Rhizotomy alone was performed in 34 patients when there was no arterial compression. Rhizotomy was performed in conjunction with decompression in 61 interpositions (72.6%), 21 Teflon transpositions (15.1%), and 2 tentorial sling transpositions (4.2%), for cases without severe vascular compression (Table 2). Classic type 1 TN accounted for 94.1% (287/305) of cases, with the SCA (205/271 [75.6%]) and anterior inferior cerebellar artery (AICA; 16/271 [5.9%]) as the most common compressive arteries. Figure 2A depicts the cumulative case count of MVDs by decompression type, with the introduction of tentorial slings in July 2020.

### Baseline Characteristics and Clinical Outcomes

Table 1 depicts the baseline demographics and clinical outcomes of the study sample. There was a significant difference in patient age at surgery among the different modalities, with patients undergoing rhizotomy and interposition significantly younger than those undergoing Teflon and sling transpositions (52.5 ± 14.2 years, 58.0 ± 16.2, 63.3 ± 13.4, 65.5 ± 12.4, respectively; $p < 0.001$ for rhizotomy vs either transposition mode, $p = 0.048$ for interposition vs Teflon, $p = 0.022$ for interposition vs sling). More women underwent rhizotomy than interposition or either transposition mode (rhizotomy 29/34 [85.3%], interposition 63/84 [75.0%], Teflon 87/139 [62.6%], sling 28/48 [58.3%]; $p = 0.01$). There were no differences in symptom duration, number of prior procedures, and TN type (type 1 vs 2) among the treatment modalities.

Fewer patients who had undergone rhizotomy alone demonstrated evidence of vascular compression on preoperative MRI than the MVD groups (rhizotomy 15/34 [44.1%], interposition 58/84 [69.0%], Teflon 123/139 [88.5%], sling 46/48 [87.5%]; $p < 0.001$). There was a significant difference in the distribution of the compressive artery among surgical cohorts ($p < 0.001$). Significantly more patients in the Teflon and sling transposition groups had SCA compression than those in the interposition cohort (Teflon 125/139 [89.9%], sling 44/48 [91.7%], interposition 36/84 [42.9%]), whereas the interposition group had more AICA compressions than the transposition cohorts (interposition 11/84 [13.1%], Teflon 4/139 [2.9%], sling 1/48 [2.1%]). None of the patients in the rhizotomy-alone group had arterial compression; however, 1 patient had compression due to Teflon from a prior MVD, and 8 patients had evidence of venous compression. Arterial compression was significantly more common at the REZ for the Teflon and sling transposition cohorts versus the interposition group (Teflon 99/139 [71.2%], sling 41/48 [85.4%], interposition 37/84 [44.0%]; $p < 0.001$) and was severe in increasingly more patients among the interposition, Teflon transposition, and sling transposition cohorts (interposition 24/84 [28.6%], Teflon 100/139 [71.9%], sling 44/48 [91.7%]; $p < 0.001$). There were no differences in the facial location of TN pain among the treatment groups ($p = 0.165$; Table 1).

There were significant differences in the follow-up period among surgical cohorts: rhizotomy 46.7 ± 68.1 weeks, interposition 105.1 ± 100.6, Teflon 99.0 ± 92.8, sling 57.8 ± 38.7 ($p < 0.001$). Significantly more patients in the interposition group underwent supplementary rhizotomy (interposition 61/84 [72.6%], Teflon 21/139 [15.1%], sling 2/48 [4.2%]; $p < 0.001$), which was performed because of less severe compression in the interposition group or an inability to satisfactorily mobilize the offending vessel. All cohorts had similarly high rates of pain freedom at discharge (rhizotomy 29/34 [85.3%], interposition 78/84 [92.9%], Teflon 129/139 [92.8%], sling 43/48 [89.6%]; $p = 0.542$) and an experience of pain freedom at any point after surgery (rhizotomy 29/34 [85.3%], interposition 78/84 [92.9%], Teflon 131/139 [94.2%], sling 46/48 [95.8%]; $p = 0.319$). Similarly, there were no differences in the time to pain recurrence following surgery (rhizotomy 35.9 ± 21.3 weeks, interposition 21 ± 72.7, Teflon 38 ± 77.7, sling 8 ± 33.6; $p = 0.267$). Neither was there a significant difference in the overall distribution of BNI facial pain scores across treatment groups at the last follow-up ($p = 0.117$; Table 1).

A greater percentage of interposition patients than transposition patients had postoperative paresthesia (interposition 48/84 [57.1%], Teflon 32/139 [23.0%], sling 3/48 [6.3%]; $p < 0.001$), which was expected given the higher rate of concurrent rhizotomy in the former group ($p < 0.001$). Paresthesias were generally well tolerated. No patients had dysesthesias, and complication rates were not significantly different among the treatment modalities. The interposition cohort had 4 patients with CSF leakage and 2 with wound infection, for a group complication rate of 7.1% (6/84). The Teflon transposition cohort had 4 CSF leaks, 1 wound infection, and 2 pseudomeningoceles (7/139 [5.0%]), and the sling cohort had 2 wound infections (2/48 [4.2%]). None of the patients with sling transposition had a vascular complication (e.g., stroke).

### Multivariate Logistic Regression, Subgroup Analyses, and PSM

We next performed multivariate logistic regression using the significant univariate factors to determine whether there were any predictors of pain freedom (BNI scores I and IIIa) at the last follow-up (Table 2) among the three surgical MVD modalities. The only significant predictor of pain freedom was MRI demonstrating clear compression (OR 2.49, 95% CI 1.147–5.404, $p = 0.021$). Patient age, follow-up duration, trigeminal nerve compression site (REZ vs cisternal segment vs both), arterial compression, severe arterial compression, procedure type (interposition vs Teflon transposition vs sling transposition), and concurrent rhizotomy were not significant predictors in the multivariate analysis.

We then performed planned subgroup analyses of patients who had undergone decompression (interposition or one of the transposition techniques) with at least 1 year of follow-up (Table 3, Fig. 2B). There were 53, 84, and 29 patients in the interposition, Teflon transposition, and sling transposition cohorts, respectively. As expected from the treatment plan, more patients in the interposition cohort had undergone concurrent rhizotomy than those in the transposition groups (interposition 75.5%, Teflon 13.1%,

**TABLE 1. Baseline characteristics and clinical outcomes of 305 patients with TN, according to treatment group**

| Variable | Rhizotomy | Interposition | Teflon Transposition | Sling Transposition | p Value |
|---|---|---|---|---|---|
| Baseline characteristics | | | | | |
| No. of patients | 34 (11.1) | 84 (27.5) | 139 (45.6) | 48 (15.7) | |
| Female sex | 29 (85.3)* | 63 (75.0)*† | 87 (62.6)†‡ | 28 (58.3)‡ | **0.011** |
| Age in yrs | 52.5 ± 14.2 | 58.0 ± 16.2 | 63.2 ± 13.4 | 65.5 ± 12.4 | **0.001** |
| Symptom duration in mos | 61.7 ± 64.7 | 62.9 ± 73.5 | 74.2 ± 60.7 | 51.0 ± 49.0 | 0.15 |
| No. of prior procedures | 1.24 ± 0.4 | 1.27 ± 0.6 | 1.15 ± 0.5 | 1.06 ± 0.2 | 0.085 |
| TN type I | 30 (88.2) | 79 (94.0) | 132 (95.0) | 46 (95.8) | 0.414 |
| MRI vascular compression | 15 (44.1)* | 58 (69.0)*† | 123 (88.5)‡ | 42 (87.5)†‡ | **<0.001** |
| Compressive artery | | | | | **<0.001** |
| None | 34 (100.0)* | 28 (33.3)† | 0 (0)‡ | 0 (0)‡ | |
| SCA | 0 (0)* | 36 (42.9)† | 125 (89.9)‡ | 44 (91.7)‡ | |
| AICA | 0 (0)* | 11 (13.1)† | 4 (2.9)* | 1 (2.1)* | |
| Basilar artery | 0 (0) | 1 (1.2) | 0 (0) | 0 (0) | |
| VA | 0 (0)*† | 2 (2.4)*† | 0 (0)† | 2 (4.2)* | |
| PICA | 0 (0) | 0 (0) | 1 (0.7) | 0 (0) | |
| Multiple | 0 (0) | 6 (7.1) | 9 (6.5) | 1 (2.1) | |
| Compression site | | | | | **<0.001** |
| None | 25 (73.5)* | 12 (14.3)† | 1 (0.7)‡ | 0 (0) | |
| REZ | 1 (2.9)* | 37 (44.0)† | 99 (71.2)‡ | 41 (85.4)‡ | |
| Cisternal | 7 (20.6)*† | 32 (38.1)† | 34 (24.5)* | 7 (14.6)* | |
| Both | 1 (2.9) | 3 (3.6) | 5 (3.6) | 0 (0) | |
| Arterial compression severity | | | | | **<0.001** |
| None | 33 (97.1)* | 27 (32.1)† | 0 (0)‡ | 0 (0)‡ | |
| Mild | 1 (2.9)* | 33 (39.3)† | 39 (28.1)† | 4 (8.3)* | |
| Severe | 0 (0)* | 24 (28.6)† | 100 (71.9)‡ | 44 (91.7)§ | |
| TN pain location | | | | | 0.165 |
| V1 | 0 (0) | 3 (3.6) | 3 (2.2) | 4 (8.3) | |
| V2 | 7 (20.6) | 17 (20.2) | 40 (28.8) | 10 (20.8) | |
| V3 | 10 (29.4) | 21 (25.0) | 29 (20.9) | 12 (25.0) | |
| V1/2 | 1 (2.9) | 8 (9.5) | 18 (12.9) | 6 (12.5) | |
| V2/3 | 9 (26.5) | 30 (35.7) | 38 (27.3) | 10 (20.8) | |
| V1–3 | 7 (20.6) | 5 (6.0) | 11 (7.9) | 6 (12.5) | |
| Concurrent rhizotomy | — | 61 (72.6)* | 21 (15.1)† | 2 (4.2)† | **<0.001** |
| FU duration in wks | 46.7 ± 68.1 | 105.1 ± 100.6 | 99.0 ± 92.8 | 57.7 ± 38.7 | **<0.001** |
| Clinical outcomes | | | | | |
| Pain free at discharge | 29 (85.3) | 78 (92.9) | 129 (92.8) | 43 (89.6) | 0.542 |
| Ever pain free | 29 (85.3) | 78 (92.9) | 131 (94.2) | 46 (95.8) | 0.319 |
| Pain recurrence postop in wks | 35.9 ± 21.3 | 21 ± 72.7 | 38 ± 77.7 | 8 ± 33.6 | 0.267 |
| BNI score at last FU | | | | | 0.117 |
| I | 14 (41.2) | 49 (58.3) | 86 (61.9) | 36 (75.0) | |
| II | 3 (8.8) | 6 (7.1) | 9 (6.5) | 0 (0) | |
| IIIa | 9 (26.5) | 11 (13.1) | 17 (12.2) | 7 (14.6) | |
| IIIb | 5 (14.7) | 10 (11.9) | 13 (9.4) | 3 (6.3) | |
| IV | 2 (5.9) | 7 (8.3) | 9 (6.5) | 1 (2.1) | |
| V | 0 (0) | 0 (0) | 4 (2.9) | 0 (0) | |
| No FU | 1 (2.9) | 1 (1.2) | 1 (0.7) | 1 (2.1) | |
| Postop paresthesia | 25 (73.5)* | 48 (57.1)* | 32 (23.0)† | 3 (6.3)† | **<0.001** |
| Postop dysesthesia | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | |

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**TABLE 1. Baseline characteristics and clinical outcomes of 305 patients with TN, according to treatment group**

| Variable | Rhizotomy | Interposition | Teflon Transposition | Sling Transposition | p Value |
|---|---|---|---|---|---|
| Clinical outcomes (*continued*) | | | | | |
| Complication | | | | | 0.315 |
| None | 32 (94.1) | 78 (92.9) | 132 (95.0) | 46 (95.8) | |
| CSF leakage | 1 (2.9) | 4 (4.8) | 4 (2.9) | 0 (0) | |
| Wound infection/dehiscence | 1 (2.9) | 2 (2.4) | 1 (0.7) | 2 (4.2) | |
| Pseudomeningocele | 0 (0.0) | 0 (0.0) | 2 (1.4) | 0 (0) | |

FU = follow-up; PICA = posterior inferior cerebellar artery; VA = vertebral artery.
Values are expressed as number (%) or mean ± standard deviation, unless indicated otherwise. Boldface type indicates statistical significance. Within each row, data marked with the same symbol are not significantly different; data marked with different symbols are significantly different ($p < 0.05$).

sling 3.4%; $p < 0.001$). More than 90% of all three cohorts had a period of pain freedom (interposition 90.6%, Teflon 97.6%, sling 96.6%; p = 0.135). The time to postoperative pain recurrence was not significantly different among the treatment modalities (interposition 74.1 ± 51.8 weeks, Teflon 99.1 ± 86.4, sling 42.9 ± 37.3; p = 0.222), and the treatment failure rate (BNI score IV or V) was equally low across all modalities (interposition 7.5%, Teflon 8.3%, sling 3.4%; p = 0.583). Follow-up durations were significantly different among the cohorts (interposition 160.1 ± 86.0 weeks, Teflon 154.7 ± 78.3, sling 83.2 ± 24.1; $p < 0.001$). When looking specifically at 1- and 2-year outcomes, the sling transposition cohort tended to have a higher rate of pain freedom at 1 year and had a statistically significant higher rate of pain freedom compared to the interposition cohort at 2 years (1 year: sling 96.6%, Teflon 86.9%, interposition 81.1%, p = 0.053; 2 years: sling 100.0%, Teflon 87.5%, interposition 77.5%, p = 0.049). At the last follow-up, pain-free off-medication outcomes (BNI score I) were more frequent in the sling transposition group (interposition 54.7%, Teflon 58.3%, sling 79.3%; p = 0.047).

**TABLE 2. Multivariate logistic regression analysis of pain freedom (BNI scores I and IIIa) at the last follow-up**

| Variable | B | SE | OR | 95% CI Lower | 95% CI Upper | p Value |
|---|---|---|---|---|---|---|
| Age | 0.003 | 0.012 | 1.003 | 0.98 | 1.026 | 0.804 |
| FU duration | −0.001 | 0.002 | 0.999 | 0.995 | 1.002 | 0.419 |
| MRI clear compression | | | | | | |
| No | 0 | | 1 | | | |
| Yes | 0.912 | 0.395 | 2.49 | 1.147 | 5.404 | **0.021** |
| Compression site | | | | | | |
| REZ | | | 1 | | | |
| Cisternal | 0.256 | 0.411 | 1.292 | 0.577 | 2.893 | 0.533 |
| Both | −0.084 | 0.87 | 0.92 | 0.167 | 5.061 | 0.924 |
| Arterial compression | | | | | | |
| No | | | 1 | | | |
| Yes | 0.341 | 0.703 | 1.407 | 0.354 | 5.584 | 0.628 |
| Severe arterial compression | | | | | | |
| No | | | 1 | | | |
| Yes | 0.613 | 0.469 | 1.846 | 0.737 | 4.628 | 0.191 |
| Procedure type | | | | | | |
| Interposition | | | 1 | | | |
| Teflon transposition | −0.205 | 0.438 | 0.815 | 0.345 | 1.922 | 0.64 |
| Sling transposition | 1 | 0.681 | 2.719 | 0.715 | 10.335 | 0.142 |
| Concurrent rhizotomy | | | | | | |
| No | | | 1 | | | |
| Yes | 0.594 | 0.513 | 1.812 | 0.663 | 4.948 | 0.246 |

Boldface type indicates statistical significance.

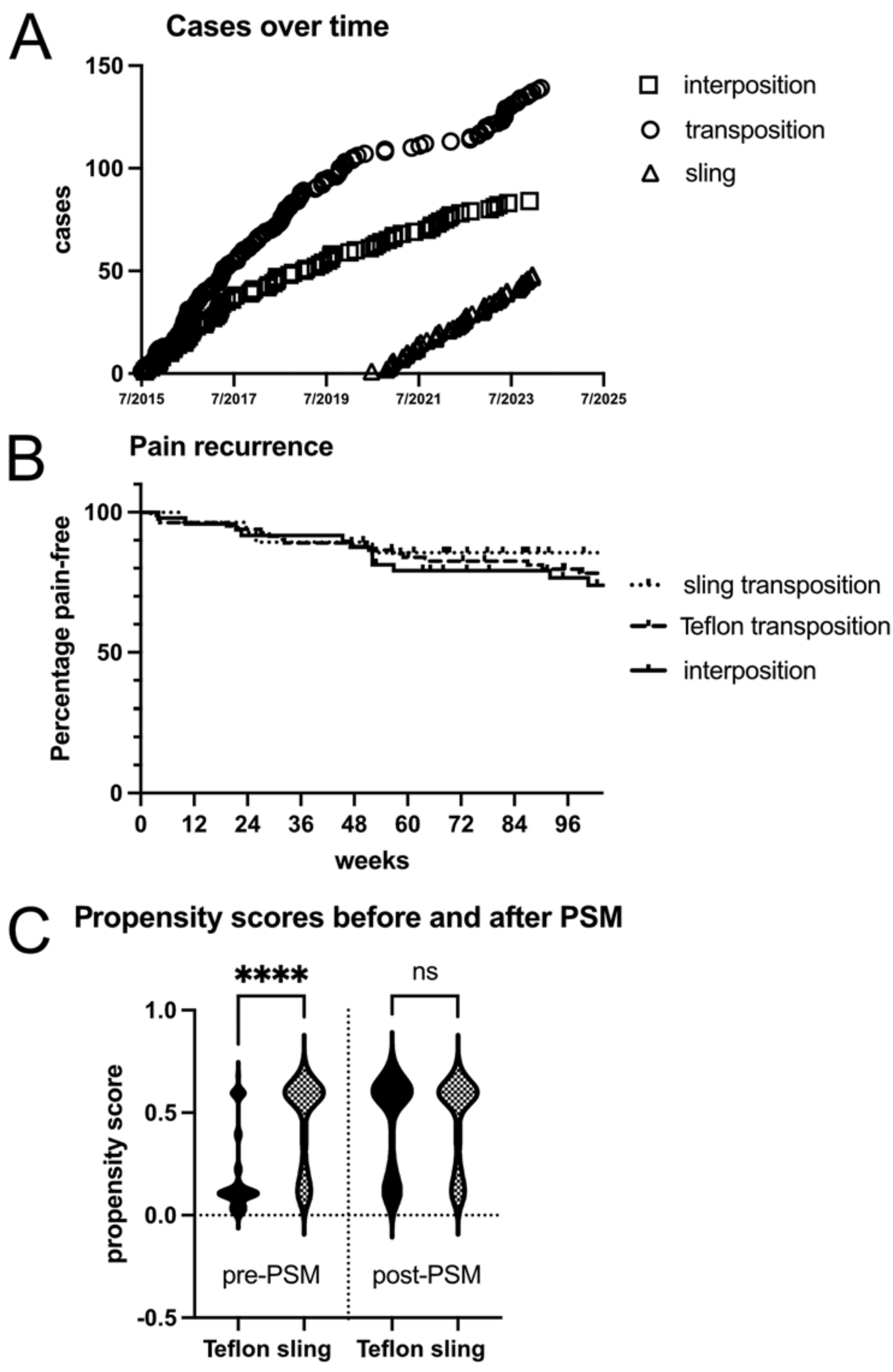


**FIG. 2.** Graph of the evolution of cases over time (**A**), a Kaplan-Meier curve demonstrating differences in pain freedom among interposition and transposition techniques in patients with at least 1 year of follow-up (**B**), and propensity scores before and after PSM for Teflon and sling transposition cohorts (**C**). ns = not significant. ****Statistical significance ($p < 0.0001$).

Because our planned subgroup analyses suggested greater pain freedom with sling transposition than Teflon transposition (Table 3), we next performed a PSM cohort analysis to control for confounders intrinsic to these transposition cohorts. PSM was applied using 2-year follow-up duration, MRI with clear compression, severe compression, SCA compression, and concurrent rhizotomy as covariates. Prior to PSM, the propensity scores between Teflon and sling transposition cohorts were significantly different (Fig. 2C; $0.19 \pm 0.20$ vs $0.46 \pm 0.21$, respectively, $p < 0.0001$

**TABLE 3. Subgroup analyses of decompression cohorts with at least 1 year of follow-up**

| Variable | Interposition | Teflon Transposition | Sling Transposition | p Value |
|---|---|---|---|---|
| No. of patients | 53 | 84 | 29 | |
| Concurrent rhizotomy | 40 (75.5)* | 11 (13.1)† | 1 (3.4)† | **<0.001** |
| Ever pain free | 48 (90.6) | 82 (97.6) | 28 (96.6) | 0.135 |
| Postop pain recurrence in wks | 74.1 ± 51.8 | 99.1 ± 86.4 | 42.9 ± 37.3 | 0.222 |
| Treatment failure (BNI score IV or V) at last FU | 4 (7.5) | 7 (8.3) | 1 (3.4) | 0.583 |
| FU in wks | 160.1 ± 86.0 | 154.7 ± 78.3 | 83.2 ± 24.1 | **<0.001** |
| BNI score I at last FU | 29 (54.7)* | 49 (58.3)* | 23 (79.3)† | **0.047** |
| 1-yr outcome | | | | |
| No. of patients | 53 | 84 | 29 | |
| Pain free, BNI scores I & IIIa | 43 (81.1) | 73 (86.9) | 28 (96.6) | 0.053 |
| 2-yr outcome | | | | |
| No. of patients | 40 | 64 | 7 | |
| Pain free, BNI scores I & IIIa | 31 (77.5) | 56 (87.5) | 7 (100.0) | **0.049** |

Values are expressed as number (%), unless indicated otherwise. Boldface type indicates statistical significance. Within each row, data marked with the same symbol are not significantly different; data marked with different symbols are significantly different ($p < 0.05$).

with Bonferroni correction), which was normalized after PSM (0.46 ± 0.21 vs 0.46 ± 0.21, respectively, $p > 0.9999$ with Bonferroni correction). The difference in propensity scores prior to matching was driven by a longer follow-up duration (Table 4; 157.3 ± 77.4 weeks vs sling 83.2 ± 24.1 weeks, $p < 0.001$) and slightly lower rates of severe compression in the Teflon transposition cohort (75.6% vs sling 89.7%, $p = 0.09$). Following PSM, all covariates, including follow-up duration (93.3 ± 59.3 vs 83.2 ± 24.1 weeks, respectively, $p = 0.398$), were similar between Teflon and sling cohorts. With PSM cohort analysis, sling transposition patients had higher rates of pain-free outcomes (BNI scores I and IIIa) at the last follow-up than the Teflon transposition patients (93.1% vs 62.1%, respectively, $p = 0.003$).

**TABLE 4. Clinical outcomes of propensity-matched cohorts with more than 1 year of follow-up**

| | Before PSM | | | After PSM | | |
|---|---|---|---|---|---|---|
| Variable | Teflon Transposition | Sling Transposition | p Value | Teflon Transposition | Sling Transposition | p Value |
| No. of patients | 82 | 29 | | 29 | 29 | |
| FU duration | | | **<0.001** | | | 0.753 |
| ≥2 yrs | 61 (74.4) | 6 (20.7) | | 7 (24.1) | 6 (20.7) | |
| <2 yrs | 21 (25.6) | 23 (79.3) | | 22 (75.9) | 23 (79.3) | |
| Period in wks | 157.3 ± 77.4 | 83.2 ± 24.1 | **<0.001** | 93.3 ± 59.3 | 83.2 ± 24.1 | 0.398 |
| MRI clear compression | | | 0.788 | | | 0.444 |
| Yes | 72 (87.8) | 26 (89.7) | | 24 (82.8) | 26 (89.7) | |
| No | 10 (12.2) | 3 (10.3) | | 5 (17.2) | 3 (10.3) | |
| Severe compression | | | 0.09 | | | 0.29 |
| Yes | 62 (75.6) | 26 (89.7) | | 28 (96.6) | 26 (89.7) | |
| No | 20 (24.4) | 3 (10.3) | | 1 (3.4) | 3 (10.3) | |
| SCA compression | | | 0.247 | | | 0.55 |
| Yes | 74 (90.2) | 28 (96.6) | | 27 (93.1) | 28 (96.6) | |
| No | 8 (9.8) | 1 (3.4) | | 2 (6.9) | 1 (3.4) | |
| Rhizotomy | | | 0.184 | | | 0.236 |
| Yes | 9 (11.0) | 1 (3.4) | | 0 (0) | 1 (3.4) | |
| No | 73 (89.0) | 28 (96.6) | | 29 (100.0) | 28 (96.6) | |
| Pain freedom (BNI scores I & IIIa) at last FU | | | **0.008** | | | **0.003** |
| Yes | 58 (70.7) | 27 (93.1) | | 18 (62.1) | 27 (93.1) | |
| No | 24 (29.3) | 2 (6.9) | | 11 (37.9) | 2 (6.9) | |

Values are expressed as number (%) or mean ± standard deviation, unless indicated otherwise. Boldface type indicates statistical significance.

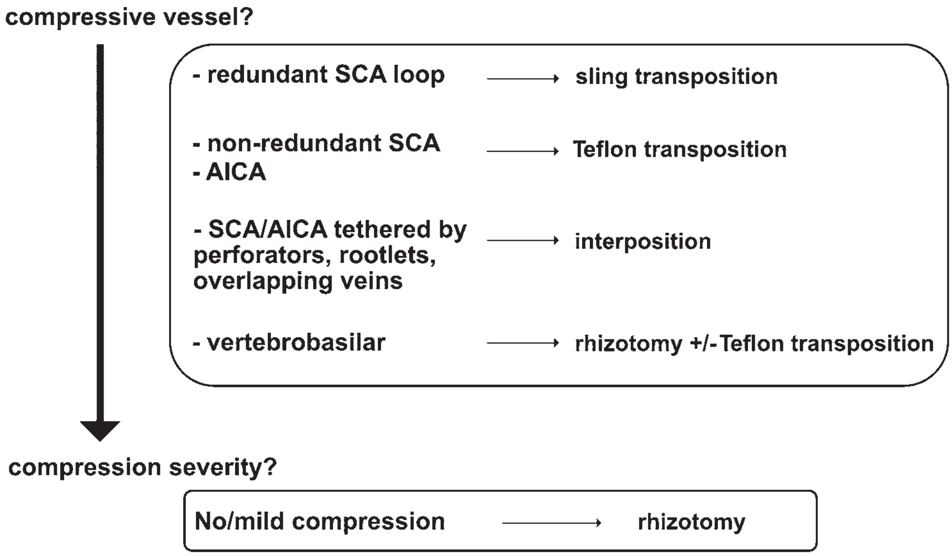


**FIG. 3.** Schematic of MVD algorithm.

## Discussion

The primary surgical treatment for TN is MVD with Teflon interposition between the compressive artery and trigeminal nerve. Although this treatment has high pain-free rates (70%–90% at 1 year), pain recurrence following MVD remains a challenging issue for a significant proportion of patients. In one of the largest and longest studies to date, Barker et al. found that 25% of patients had pain recurrence at 1 year, which increased to 36% at 10 years' follow-up.[9] Multiple series have attributed Teflon granuloma formation or ongoing vascular compression as a primary cause of TN recurrence,[14–16,25,26] although the occurrence of Teflon granuloma formation varies widely in the literature. Some studies have found an approximately 5% incidence, whereas a recent study by Sun et al. demonstrated Teflon granulomas in 10/14 patients with recurrent TN pain.[15,25] Indeed, in the present case series, one patient with a history of interpositional MVD at an outside institution had severe SCA compression by the residual Teflon. Thus, there has been a renewed focus on investigating transpositional techniques to minimize the use of Teflon and other inert materials.[27]

In a recent single-institution study of interposition versus transposition decompression for TN, Uhl and colleagues found similar rates of pain control using either method.[28] The transposition method they described is analogous to the Teflon transposition used in our current series, in which Teflon was used to affix the offending vessel to the tentorium. We also described an alternative transposition method, the tentorial sling, which physically secures the vessel to the tentorium with a pericranial sling (Figs. 3 and 4, Video 1).

**VIDEO 1.** An accompanying video of 3 cases illustrating the MVD techniques described in this study: traditional Teflon interposition, Teflon transposition, and pericranial sling. © Anthony Lee, published with permission. Click here to view.

In our current midterm analysis, we found evidence that sling transposition might provide more robust pain control than Teflon transposition or interpositional decompression. Despite the increased complexity of the sling transposition, we reported fewer study complications overall (approximately 25% in the Uhl et al. study vs 6% in the present study).

Other groups have also shown alternative transposition techniques to be effective for MVD. These methods involve using a Weck clip to secure a sling fashioned by a slit in the tentorium, which wraps around the SCA;[22] using a synthetic adhesive to adhere the vessel onto the tentorium;[29] the "birdlime" technique whereby TachoSil soaked with fibrin glue is used to affix the offending artery to the dura mater of the petrous bone;[30] and fenestrated aneurysm clips for securing long ectactic arteries to the dura.[31] Although these case series were limited in sample size and follow-up, they did highlight the promise of transposition approaches. Potential advantages of the pericranial sling transposition include the security and robustness of the pericranial graft anchor, the use of a pericranial autograft without the use of foreign materials, and the absence of metallic clips, which introduce artifacts on imaging. However, sling transposition is technically more complex to master because of the SCA arachnoid microdissection and tentorial graft suturing. Longer-term studies are necessary to confirm whether contactless transposition techniques result in more durable pain control than traditional Teflon interposition and how various transposition techniques may be influenced by anatomical considerations, prior operations, or complication rates.

Given the concern for inflammatory reactions to Teflon and persistent compression, we transitioned our practice to transposition for full nerve decompression whenever possible. For transposition methods, additional arachnoid dissection is often required to free the offending artery for adequate mobilization. For example, this requires additional dissection of the distal SCA using a supracerebellar working window toward the ambient cistern. In our experience, certain clinical scenarios are more conducive to

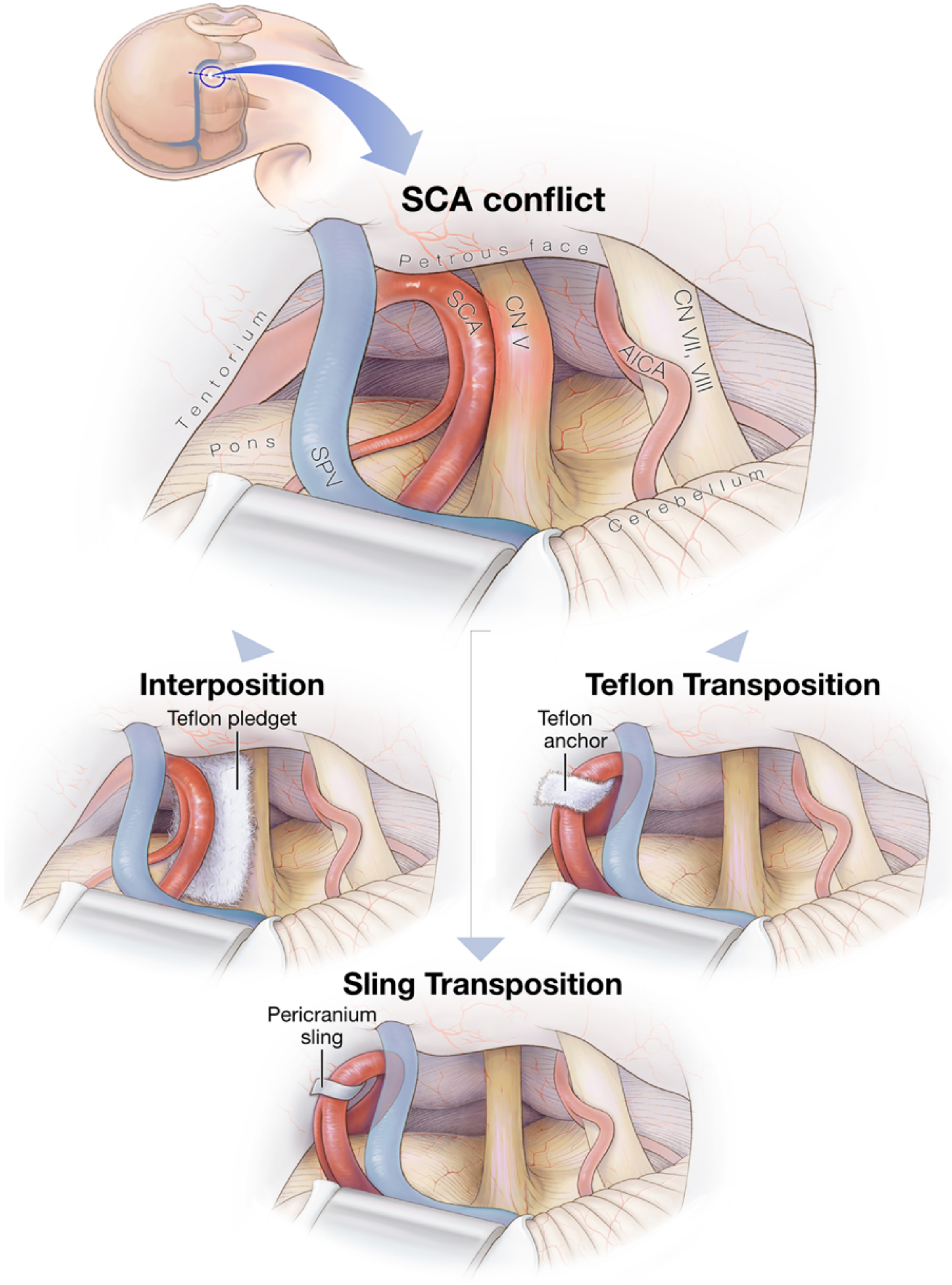


**FIG. 4.** Traditional MVD in which a Teflon pledget is inserted between the offending SCA and the compressed CN V. In the Teflon transposition, the offending vessel is fully transposed to the tentorium and secured by a Teflon anchor. In the sling transposition, the transposed vessel is affixed by a pericranial sling sutured to the tentorium. SPV = superior petrosal vein. © Melissa Logies, UCSF, Neurological Surgery, published with permission. Figure is available in color online only.

vessel transposition, especially in cases in which the SCA compresses the superior aspect of the trigeminal nerve. The SCA can be freed from the trigeminal REZ and dissected from the arachnoid more distally as it travels within the ambient cistern. This allows for mobilization of the SCA posteriorly, which removes the redundant loop that compresses the nerve. Teflon (or a sling) may act to bolster the artery away from the trigeminal nerve. The decision between a sling or Teflon-based transposition is dictated by anatomical constraints including the degree of redundancy of the SCA. For example, a longer loop of the SCA can provide for an easier window to place a sling and more laxity to secure it to the posterior tentorium. When AICA loops are involved, the vessel often needs to be mobilized inferiorly or toward the petrous face to separate it from the trigeminal nerve, which can be technically challenging without injury to the CN VII–VIII complex.

There are several reasons transposition may not be feasible. Tethering perforators or overlapping veins may limit mobilization. Sometimes the offending artery may travel in between rootlets of the trigeminal nerve, tethering the vessel in place. In these cases, attempts are made to create a small window between the REZ and the offending artery to place Teflon as an interposition graft. If separation of the offending artery and the nerve cannot be achieved, then a rhizotomy can be considered. Alternatively, the degree of compression of an artery may be questionable, and in these cases, our preference is to perform a rhizotomy to ensure pain control postoperatively.

### Study Limitations

Despite the prospective data collection, this study was not randomized between groups. However, the success of our midterm analysis and the clear noninferiority of transposition approaches to traditional interpositional methods may preclude randomized controlled trials to directly assess interposition and transpositional methods.

Differences in follow-up duration may reflect the tendency for natural follow-up in patients who have pain recurrence. To minimize this confounder, we attempted phone calls to subjects without a recent clinic follow-up. Furthermore, confirmation bias is inherent to this study, as our practice pattern has evolved from interposition to transposition when anatomically possible. This change in practice pattern also complicates comparisons between cohorts, which are inherently heterogeneous from selection bias. For example, after the introduction of sling transposition to our practice, patients with severe CN V compression by a redundant SCA now routinely undergo sling transposition, whereas patients with a less favorable vessel (e.g., an AICA or a short loop of SCA tethered by perforators) may undergo Teflon transposition or interposition. Our PSM cohort analysis attempted to address these confounders between surgical cohorts by directly controlling for follow-up period, MRI with clear compression, SCA compression, compression severity, and concurrent rhizotomy.

## Conclusions

We showed that transposition techniques are safe and effective in treating TN. Our midterm analysis suggests that transposition techniques, specifically the use of a pericranial sling, may result in improved pain control compared to Teflon interposition in subgroup and PSM cohort analyses. As interest in contactless transposition grows, future studies will need to directly assess the long-term durability of pain control (5–10 years) between traditional interposition and newer transpositional methods.

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## Disclosures

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

## Author Contributions

Conception and design: Chang, Lee, Ward. Acquisition of data: Chang, Lee, Morshed, Kondapavulur, Caldwell, Nichols, Wang, Ward. Analysis and interpretation of data: Chang, Lee, Morshed, Kondapavulur, Caldwell, Nichols, Wang. Drafting the article: Chang, Lee, Morshed, Kondapavulur, Nichols, Smith. Critically revising the article: Chang, Lee, Morshed, Kondapavulur, Caldwell, Smith, Wang, Waung, Winkler. Reviewed submitted version of manuscript: Chang, Lee, Morshed, Kondapavulur, Caldwell, Smith, Wang, Ward, Waung, Winkler. Approved the final version of the manuscript on behalf of all authors: Chang. Statistical analysis: Lee. Administrative/technical/material support: Chang, Smith, Ward. Study supervision: Chang, Morshed, Winkler.

## Supplemental Information

Videos

*Video 1*. https://vimeo.com/1060138769.

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