

# Reconstruction of the Infraorbital Nerve Using Bilayered Artificial Nerve Conduits after Partial Maxillectomy

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**Background:** Facial sensory nerves play vital roles in daily functions like self-protection, facial expressions, speaking, and eating. Severing the infraorbital nerve (ION) during partial maxillectomy via the Weber-Ferguson incision can lead to sensory disturbances. This study presents immediate ION reconstruction using artificial nerve conduits and its short-term outcomes.

**Methods:** This retrospective study included three patients (mean age: 67.0 years) undergoing immediate ION reconstruction after partial maxillectomy via the Weber-Ferguson incision. Sensory recovery was evaluated using the Semmes-Weinstein and two-point discrimination (2PD) tests. A reference group of five patients who underwent total maxillectomy without ION reconstruction was also assessed.

**Results:** No postoperative complications were observed during the 15.3-month follow-up. Sensory recovery varied among patients, with one achieving normal perception at 24 months, another showing diminished light touch at 13 months, and the third experiencing diminished protective sensation at 7 months postoperatively. In comparison, the reference group showed lower sensory recovery. Two patients showed improvements in 2PD test results at 24 and 13 months, whereas one showed no recovery at 7 months. No patients in the reference group showed improvement.

**Conclusion:** Immediate ION reconstruction using artificial nerve conduits after partial maxillectomy appears feasible, as evidenced by acceptable sensory recovery in the short term. (*Plast Reconstr Surg Glob Open* 2024; 12:e6214; doi: 10.1097/GOX.00000000000006214; Published online 3 October 2024.)

## INTRODUCTION

Facial sensory nerves play essential roles in daily life because they allow contact between the human body and the external environment. In addition to playing an important role in self-protection by helping to avoid facial injury, facial sensory nerves contribute to facial expressions and aid in the perception of corresponding areas, indirectly supporting proper oral intake and articulation. Facial sensory nerves account for one-fifth of Penfield's brain map, highlighting their significance in the human body.

The Weber-Ferguson incision approach, which is frequently used for partial maxillectomy when the maxilla is resected caudal to the infraorbital foramen, requires severance of the infraorbital nerve (ION). ION neuropathy causes a wide range of sensory disturbances from the cheeks to the upper lip and often causes problems with the performance of activities of daily living, such as eating, brushing teeth, and shaving, thus leading to a decreased quality of life. Although there have been few reports of ION reconstruction, many studies on the reconstruction of other trigeminal nerves, such as the lingual nerve and inferior alveolar nerve, have shown that reconstruction of the sensory nerves in the head and neck regions is effective.<sup>1,2</sup>

Artificial nerve conduits (ANCs) are considered as a potential alternative to nerve autografts. In 1982, Lundborg et al<sup>3</sup> first reported peripheral nerve regeneration using silicone tubes, and the use of a conduit for short nerve defects was better than direct suturing under tension. Since then, many improvements have been made

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to ANC design, materials, and fabrication processes, and various types of ANCs are commercially available.<sup>4</sup>

In this study, we report for the first time a case series of immediate ION reconstruction using ANCs after partial maxillectomy and free flap reconstruction, and its short-term outcomes.

## PATIENTS AND METHODS

### Patients

This retrospective study was approved by the internal ethical review committee of the Aichi Cancer Center. Three patients (one male and two female; mean age, 67.0 years) who underwent partial maxillectomy and immediate reconstruction via the Weber-Ferguson incisional approach at Aichi Cancer Center were included in this study (Table 1). The primary diseases were upper gingival cancer (two patients, squamous cell carcinoma and adenoid cystic carcinoma) and carcinoma of unknown origin (one patient, undifferentiated carcinoma). All patients underwent maxilla resection caudal to the ION. The ION was transected at the time of the Weber-Ferguson incision. A bi-layered ANC (Nerbridge; Toyobo, Osaka, Japan) with a diameter of 4.0 mm and length of 8–10 mm was used for nerve reconstruction. Additionally, an anterolateral thigh flap was used for maxillary reconstruction.

### Surgical Technique

Tumor resection was performed by head and neck surgeons, using the Weber-Ferguson incision (Fig. 1A), and the maxilla was resected caudal to the infraorbital foramen (Fig. 1B). Transection of the ION was performed to retain the bony side of the nerve stump for as long as possible. The cutaneous side of the nerve stump was cut immediately before bifurcation of the fine cutaneous sensory nerve (Fig. 2A). Free-flap reconstruction was performed to fill the partial maxillectomy defect and reconstruct the hard palate defect (Fig. 2B). Nerve reconstruction was performed before skin closure was completed (Fig. 2C). We used a bi-layered ANC with an inner diameter of 4 mm. After adjusting the length, the ANC was placed between the stumps of the transected ION and sutured using 10-0 nylon on both sides to pull the nerve into the ANC (Fig. 3). We usually use three stitches for one side with epineurium suture technique. ION reconstruction required approximately 10–15 minutes. As the conduit was inserted underneath the skin,

### Takeaways

**Question:** Is immediate infraorbital nerve reconstruction using artificial nerve conduits after partial maxillectomy via the Weber-Ferguson incision feasible?

**Findings:** The study, involving three patients, demonstrated acceptable sensory recovery postoperatively, with no complications observed during the 15.3-month follow-up period. Sensory improvements were noted in the Semmes-Weinstein and two-point discrimination tests.

**Meaning:** Immediate infraorbital nerve reconstruction using artificial nerve conduits after partial maxillectomy shows promise for achieving satisfactory sensory recovery, offering a potential solution to the sensory disturbances associated with this procedure.

subcutaneous tissue, and facial muscle, the depth of the conduit was usually at least 1 cm or more.

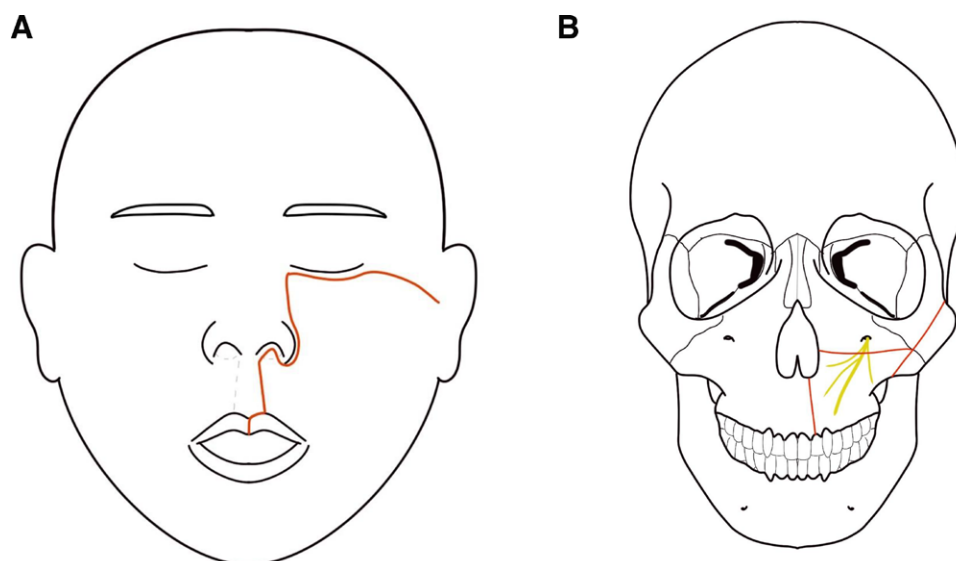
### Evaluation of Sensory Recovery

A sensory evaluation was performed during the clinical outpatient visit. The Semmes-Weinstein (SW) test was performed using the SW monofilament perception tester (SAKAImed, Tokyo, Japan), which is an instrument used to evaluate static tactile pressure. Patients were instructed to close their eyes while in a quiet environment. The point at which the vertical line of the pupil intersected the horizontal line at the base of the nasal ala was used as the measurement point (Fig. 4). Starting with the weakest force of the filament marking (1.65 Fmg), three stimuli were applied at one point. The threshold of the SW monofilament perception tester (SAKAImed) was increased until the patient was able to perceive these stimuli. The weakest stimulus that could be perceived was used as the measurement value. As the average value of the filament marking could not be calculated because it was a logarithmic value, it was converted to a pressure value (gf/mm<sup>2</sup>) according to the work of Bell-Krotoski.<sup>5</sup> A two-point discrimination (2PD) test was performed using a 2PD disc tester (SAKAImed). Both the 2PD disc tester (SAKAImed) and SW monofilament perception tester (SAKAImed) were used in the same manner. As a reference group, five patients who underwent total maxillectomy using the Weber-Ferguson incision, did not undergo ION reconstruction, and were followed up for more than 2 years were retrospectively evaluated using the SW and 2PD tests.

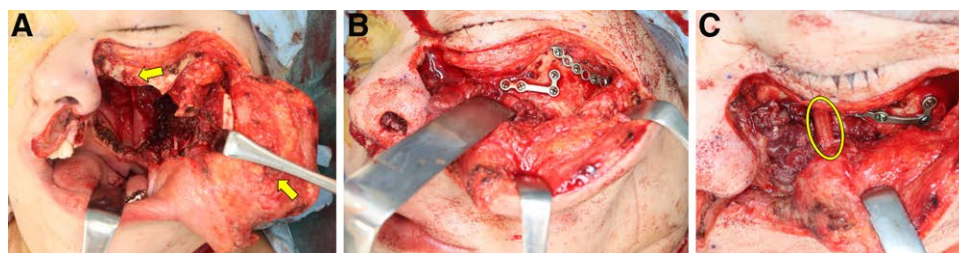
**Table 1. Patient Demographics for Case Series**

Case	Sex	Age (y)	Primary Disease	Reconstruction	ANC Diameter (mm)	ANC Length (mm)
1	F	61	Upper gingival cancer	Anterolateral thigh flap	4	10
2	F	67	Upper gingival cancer	Anterolateral thigh flap	4	10
3	M	73	Cancer of unknown origin	Anterolateral thigh flap	4	8

Three patients who underwent partial maxillectomy and immediate reconstruction via the Weber-Ferguson incisional approach were included in this study.



**Fig. 1.** Schemes of operative description. A, Scheme of the Weber-Ferguson incision approach (red line). B, Scheme of osteotomy (red line).



**Fig. 2.** Intraoperative photographs. A, Intraoperative photograph obtained after resection. B, Intraoperative photograph obtained after the flap was set and the bone was fixed. C, Intraoperative photograph obtained after ION reconstruction.

## RESULTS

### Postoperative Course

The three patients included in this study did not experience postoperative complications and were discharged from the hospital after an average of 24.7 days (Table 2). Postoperative complications associated with nerve reconstruction, such as infection, conduit exposure, or discomfort, were not observed. The mean postoperative observation period was 15.3 months (range, 7.3–23.8 months).

### Sensory Recovery

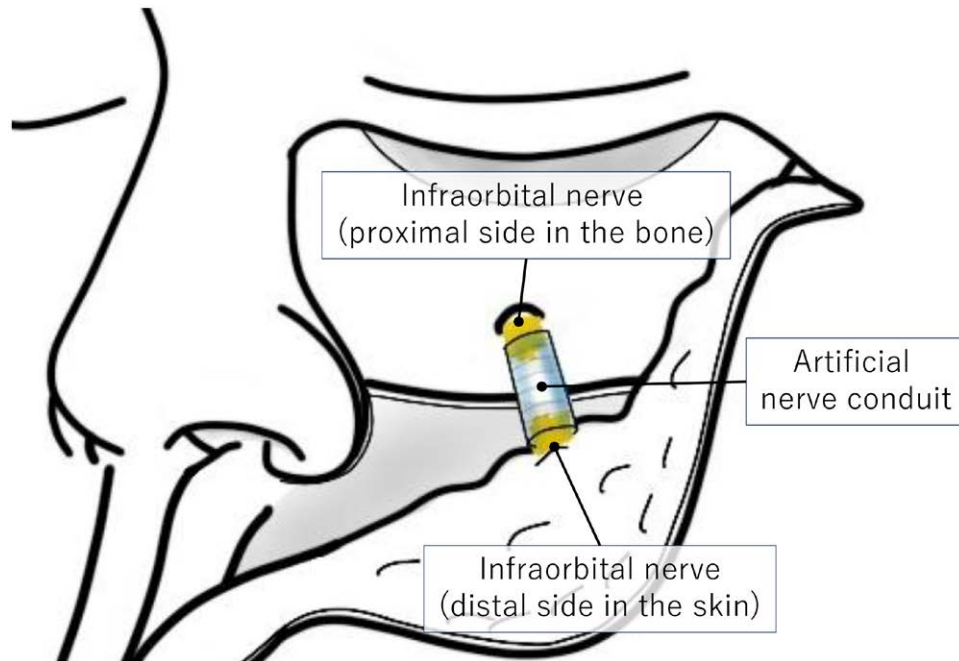
Figure 5 shows the sensory recovery of the three study patients. The SW test results indicated that all three patients achieved sensory recovery. One patient experienced recovery with normal perception (2.52 gf/mm<sup>2</sup>) at 23.8 months postoperatively. One patient experienced recovery with diminished light touch (8.73 gf/mm<sup>2</sup>) at 15.8 months postoperatively. One patient experienced recovery with diminished protective sensation (19.28 gf/mm<sup>2</sup>) at 7.3 months postoperatively. The five patients in the reference group who underwent total maxillectomy

with the Weber-Ferguson incision without ION reconstruction had a mean pressure value of 89.08 gf per mm<sup>2</sup>. Therefore, patients who underwent ION reconstruction experienced better recovery.

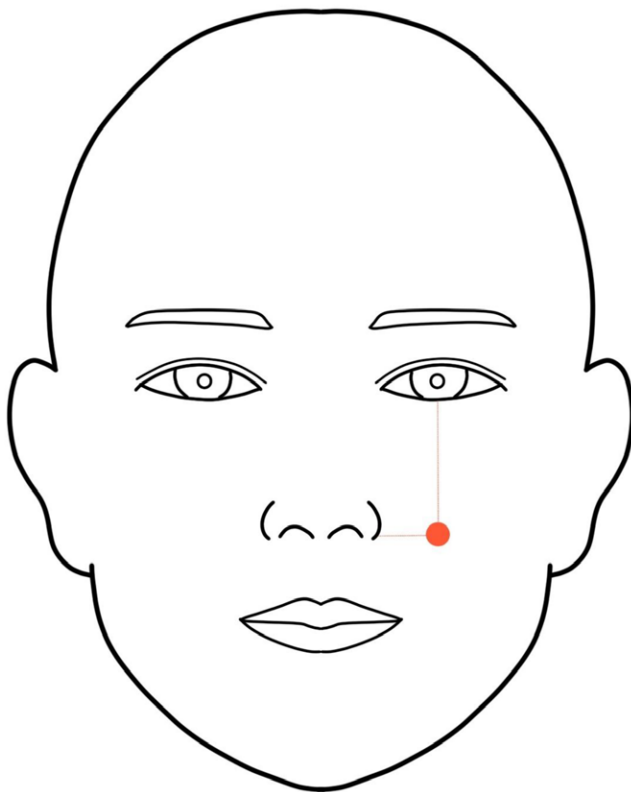
The 2PD test results indicated that one patient experienced recovery to 20 mm at 23.8 months postoperatively, one patient experienced recovery to 13 mm at 15.8 months postoperatively, and one patient experienced recovery to 20 mm at 7.3 months postoperatively. In contrast, according to the 2PD test results, none of the five patients in the reference group who underwent total maxillectomy without ION reconstruction experienced recovery.

## DISCUSSION

To the best of our knowledge, this is the first report to describe ION reconstruction using ANC. Although there have been few reports on ION repair, there have been some reports of microscopic decompression and suturing of ION injuries associated with trauma.<sup>6,7</sup> Callahan et al reported maxillectomy and immediate allograft reconstruction for benign maxillary diseases (ossifying fibroma and ameloblastic fibroma) and demonstrated that immediate allograft reconstruction of the ION is a feasible option



**Fig. 3.** Scheme of the ION reconstruction image.



**Fig. 4.** The measurement points of the SW and 2PD tests. The point where the vertical line of the pupil intersects the horizontal line at the base of the nasal ala was used.

for achieving functional sensory recovery.<sup>8</sup> Medina et al also reported that immediate reconstruction of the ION using allografts for polyostotic fibrous dysplasia lesions

yielded satisfactory neurosensory results.<sup>9</sup> The results of these studies suggest that it is desirable to reconstruct the ION as much as possible because sensory impairment of the ION area is directly related to decreased quality of life. However, reconstruction of the ION after tumor resection using the Weber–Ferguson incision has not been sufficiently documented, possibly because of the challenges associated with suturing the ION during wound closure after resection caused by the confined surgical space, which often makes precise nerve repair difficult. The ANC offers a practical solution because it is flexible, thereby overcoming spatial limitations and enhancing the feasibility of ION reconstruction.

For immediate reconstruction, we prefer to use the Nerbridge ANC (Toyobo), which is a bi-layered biodegradable ANC comprising an outer polyglycolic acid mesh and collagen filler in the lumen that provide a scaffold to promote nerve growth. The advantages of artificial nerves are the absence of donor sacrifice and the ability to bind nerve bundles because of their luminal structure. Given that the ION has multiple branches after emerging from the infraorbital foramen,<sup>10</sup> the severed nerve ends spread radially and are difficult to suture directly or with a normal autologous nerve graft; therefore, an artificial nerve is effective. Moreover, ANCs are effective when used for short gaps ( $\leq 5$  mm) and are comparable to direct sutures.<sup>11</sup> A study on the use of a bioabsorbable conduit for peripheral sensory nerve repair showed that polyglycolic acid ANC repair was superior to standard end-to-end repair for improving sensation associated with nerve gaps less than or equal to 4 mm, thus highlighting the efficacy of ANC repair.<sup>4</sup> Many other studies on the use of ANC in the head and neck regions have reported its safety and efficacy, and some studies have reported its use for the lingual and inferior alveolar nerves. Hirata et al and Fujishiro et al reported immediate



Table 2. Postoperative Course of Three Patients

Case	Postoperative Complication	Length of Hospital Stay (d)	Follow-up Period (mo)	SW at Last Visit (gf/mm <sup>2</sup> )	2PD at Last Visit (mm)
1	—	24	23.8	2.52	20
2	—	25	15.8	8.73	13
3	—	25	7.3	19.28	20

None of the patients experienced postoperative complications. The mean length of hospital stay was 24.7 days and the mean postoperative observation period was 10.9 months.

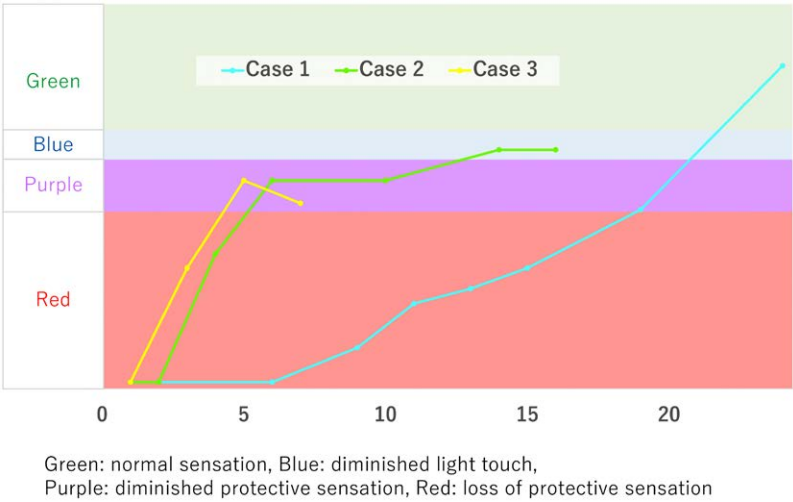


Fig. 5. Trends of the SW test results. One patient experienced recovery to normal perception (green) at 24 months postoperatively. One patient experienced recovery to diminished light touch (blue) at 13 months postoperatively. One patient experienced recovery to diminished protective sensation (purple) at 7 months postoperatively.

reconstruction of these nerves using ANCs (Nerbridge) after tumor resection and showed a trend of sensory recovery.<sup>12,13</sup> Nishiyama et al performed nerve repair using the Nerbridge ANC (Toyobo) for old lingual nerve damage after tooth extraction and achieved sensation recovery.<sup>14</sup>

Although the effectiveness of ANC including Nerbridge has been widely report as discussed above, surgeons must consider cost-effectiveness because this ANC is relatively expensive (around US \$3000). To date, there is no cost-analysis report regarding artificial nerve conduit. There is a report for peripheral nerve injury repair using allograft,<sup>15</sup> in which authors concluded that the use of allograft provided a higher percentage of meaningful recovery than autologous nerve graft, making a modest reduction in associated cost. In another report comparing allograft to nonsurgical management for persistent trigeminal neuropathy,<sup>16</sup> surgical treatment with allograft was more effective and had a lower long-term cost. Although these results cannot be applied directly to ANC, the treatment effect is considered to be well worth the cost of ANC because the product costs are comparable.

When considering alternative methods for ION reconstruction, direct suturing and autologous nerve grafts are viable options. However, because of the challenges associated with precise suturing in confined spaces, direct suturing is less favorable. Reconstruction of a proximal infraorbital nerve injury that was difficult to repair via

nerve crossing using the healthy external nasal branch and peroneal nerve has been reported, but the progress of this technique is unknown.<sup>17</sup> Although autologous nerve grafts are effective, they involve donor sacrifice. Autologous nerve grafts that can be harvested with free flaps (lateral cutaneous femoral nerve or intercostal nerve) usually have insufficient nerve diameter and are not ideal for reconstruction of the ION. In contrast, ANC is readily available and has multiple diameters, allowing the surgeon to select appropriate diameter.

In the current study, all three patients who underwent ION reconstruction experienced effective sensory recovery. In contrast, according to the SW test results, the five patients in the reference group who did not undergo ION reconstruction did not experience functional recovery with 89.08 gf/mm<sup>2</sup>. The results of the 2PD test indicated that all three patients in the reconstruction group showed some degree of recovery, whereas none of the five patients in the reference group experienced recovery after 24 months. Although the extent of resection differed between the study and reference groups, better sensory recovery was observed among those who underwent ION reconstruction, thus demonstrating the efficacy of ANC reconstruction.

One patient in our case series received postoperative radiotherapy (PORT). and experienced some recovery. Whether PORT influences sensory nerve recovery remains

controversial. Santamaria et al claimed that patients who underwent hemi-glossectomy reconstruction with a free flap experienced significantly decreased light touch sensation, pain, and temperature perception after PORT.<sup>18</sup> However, Lee et al<sup>19</sup> reported that nerve recovery after facial nerve reconstruction with sural nerve grafts was not influenced by PORT. Similarly, Tomita et al reported that PORT after breast-conserving surgery did not influence sensory recovery of the breast.<sup>20</sup> For ION reconstruction, we recommend immediate reconstruction even when PORT is planned, because scar formation makes it difficult to perform secondary reconstruction. Although one patient underwent PORT, both the SW and 2PD test results indicated substantial recovery.

This study had some limitations. First, this was a retrospective single-arm study that included only three patients. Because of the nature of the study, and because of ethical considerations, we did not include a nonreconstruction group. Instead, we included a reference group who underwent similar resection and reconstruction; however, the proximal portion of the ION was resected with the maxilla, and ION reconstruction was impossible. A prospective case-control study including a larger number of patients may provide further insight regarding this topic. Additionally, some of our patients were followed up for less than 2 years. As nerve recovery occurs gradually up to 2 years postoperatively, a longer follow-up period is necessary to observe detailed results.

## CONCLUSIONS

The results of postoperative SW and 2PD tests showed acceptable sensory recovery in three patients who underwent immediate ION reconstruction using ANCs after partial maxillectomy via the Weber–Ferguson incision approach. Therefore, our technique seems to be feasible for ION reconstruction.

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## DISCLOSURE

*The authors have no financial interest to declare in relation to the content of this article.*

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