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Selective Stimulation of Facial Muscles Following Chronic Intraneural Electrode Array Implantation and Facial Nerve Injury in the Feline Model

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Background: Our group has previously shown that activation of specific facial nerve (FN) fiber populations and selective activation of facial musculature can be achieved through acute intraneural multichannel microelectrode array (MEA) implantation in the feline model.

Hypothesis: Selective stimulation of facial muscles will be maintained in the setting of 1) chronic and 2) acute MEA implantation after FN injury and subsequent recovery.

Methods: This study included seven cats. In three cats with normal facial function, 4-channel penetrating MEAs were implanted chronically in the FN and tested biweekly for 6 months. Electrical current pulses were delivered to each channel individually, and elicited electromyographic (EMG) voltage outputs were recorded for each of several facial muscles. For FN injury experiments, two cats received a standardized hemostat-crush injury, and two cats received a transection-reapproximation injury to the FN main trunk. These four underwent acute implantation of MEA and EMG recording in terminal experiments 4 months postinjury.

Results: Stimulation through individual channels selectively activated restricted nerve populations, resulting in activation of individual muscles in cats with chronic MEA implantation and after nerve injury. Increasing stimulation current levels resulted in increasing EMG voltage responses in all patients. Nerve histology showed only minor neural tissue reaction to the implant.

Conclusion: We have established in the animal model the ability of a chronically implanted MEA to selectively stimulate restricted FN fiber populations and elicit activations in specific facial muscles. Likewise, after FN injury, selective stimulation of restricted FN fiber populations and subsequent activation of discrete facial muscles can be achieved after acute MEA implantation. **Key Words:** Facial nerve—Implant—Multichannel electrode array—Stimulation.

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The facial nerve (FN) is a critical motor nerve that animates the face, closes the eyelid, facilitates communication and enunciation, and maintains oral competency, among other functions. Irreversible FN damage can lead to permanent facial paralysis, a debilitating disorder with

substantial functional and psychological sequelae. FN damage can lead to corneal irritation, visual impairment, drooling, intraoral food retention, dryness in the ipsilateral eye and nose, and demoralizing cosmetic deformities. Complete facial paralysis results in atonic facial musculature that can atrophy and irreversibly convert to scar tissue over time (1). Facial paralysis is not uncommon, with an annual incidence of 11 to 40 patients per 100,000 (2,3). Over 127,000 new patients of facial paralysis are diagnosed annually in the United States alone (4). Facial paralysis can be caused by tumors, vascular lesions (e.g., hemangioma), mass effects (e.g., cholesteatoma independent of active infection), stroke, congenital defects, trauma, infectious processes, or can be idiopathic in nature (5). Bell's palsy is a common type of facial paralysis that carries a 65 to 71% chance of full recovery, yet 29 to 35% of patients develop persistent dysfunction, including reduced facial function, spasms, and/or synkinesis (6–8).

Current static surgical strategies for patients with chronic facial paralysis have important but limited

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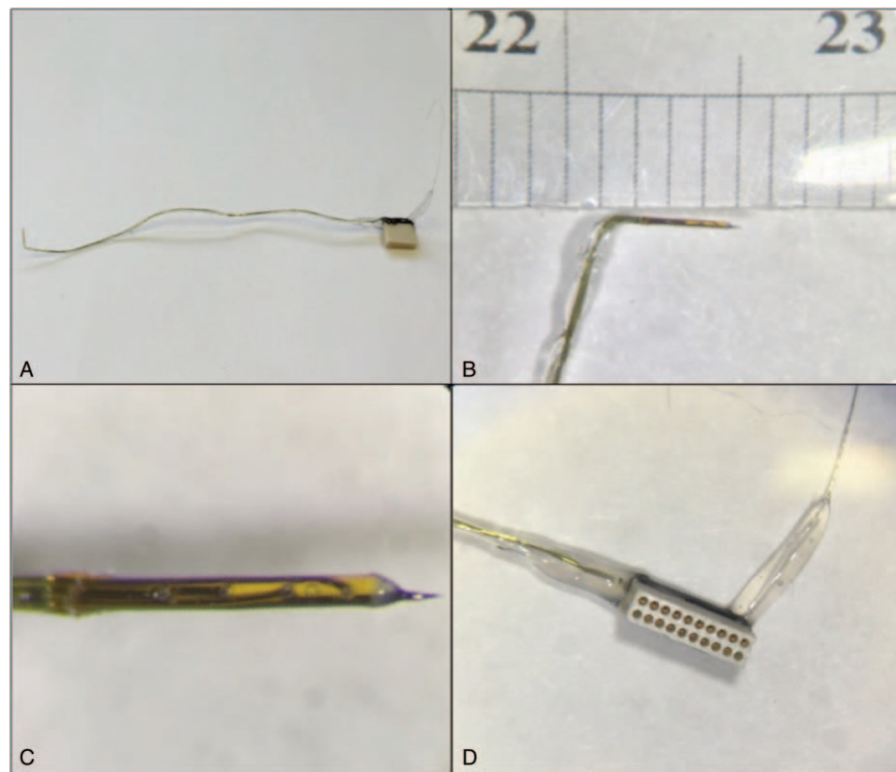


FIG. 1. A, Photograph of a Microprobes 4-channel stimulating electrode array. B, Microscopic picture of the shank and distal flexible output table with a metric ruler size reference. C, High-magnification microscopic photograph of the distal end of the penetrating shank; the four electrode sites can be observed. Superficial or proximal electrodes are those furthest from the tip of the array (to the left in this picture), while deep or distal electrodes are those closest to the array tip (to the right). D, Microscopic picture of the male Omnetics connector and ground reference wire.

functional and cosmetic utility. While dynamic surgical interventions for patients with permanent unilateral facial paralysis, such as myoneurovascular gracilis transfer, can provide meaningful movement, these interventions focus on specific facial regions, can require multiple procedures and surgical sites, and carry a 10 to 15% failure rate (9,10). Furthermore, while functional goals may be achieved and quality-of-life improved (11), aesthetic outcomes are uncommonly fully satisfactory and infrequently restore normal facial form and function.

Our group has recently demonstrated in short-term animal studies the ability of a penetrating multichannel microelectrode array (MEA) to selectively stimulate neural fibers within the FN, building on previous work done in the cochlear nerve (12–15). In the present study, we sought to test the safety and efficacy of long-term MEA implantation in the FN over the course of 6 months. Furthermore, we aimed to simulate the human condition of permanent unilateral facial paralysis in cats using standardized and validated injuries to the nerve, which would represent a clinical injury such as a FN sacrifice during parotid cancer surgery, FN damage during vestibular schwannoma surgery, or complete idiopathic facial paralysis. The extent of spontaneous recovery in such patients would be determined over many months, and those with incomplete or unsatisfactory function would become potential candidates for rehabilitative reanimation surgery. Accordingly,

in our animal study, we conducted intraneural stimulation testing after a postinjury recovery period. Based on previous experiments with implantation of similar MEAs in nerve tissue, we hypothesized that the FN implant will be well tolerated by the nerve and stimulation following either transection-reapproximation or crush nerve injury will result in minor threshold increases (16). This work serves to elucidate the functional and histological changes that occur after chronic MEA implantation and stimulation post-FN injury in reanimating facial musculature after facial paralysis.

METHODS

Electrode Array and Stimuli

The custom-designed, multichannel intraneural stimulating MEAs (Microprobes, Gaithersburg, MD, U.S.A.) have four platinum/iridium-plated electrode sites (channels), at 250 μm intervals spanning a distance of 1 mm along a single, 241 μm diameter polyimide tube (Fig. 1). System 3 Tucker-Davis Technologies (TDT; Alachua, FL, U.S.A.) equipment and custom MATLAB (The MathWorks, Natick, MA, U.S.A.) software were used for stimulus presentation. Charge-balanced biphasic electrical stimulus pulses were produced by a 4-channel current source controlled by a 4-channel digital-to-analog converter (TDT RX8). The pulses were initially cathodic, 41 or 82 μs per phase, with illustrated responses obtained with stimulus charge levels of 26 to 41 nC per phase.

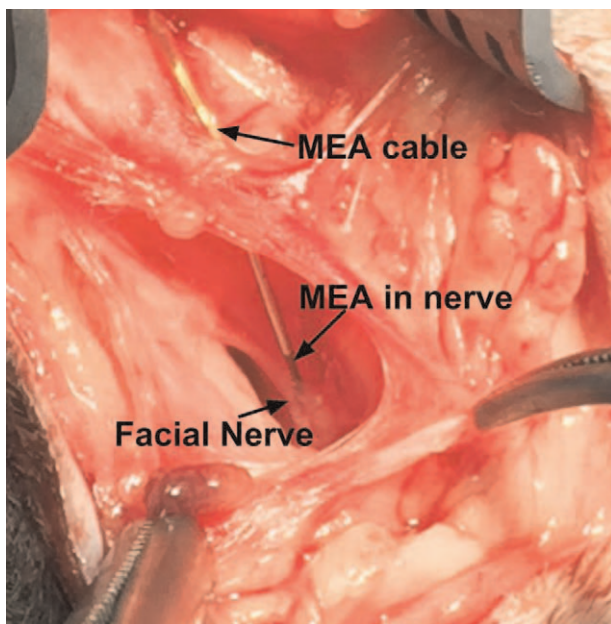


FIG. 2. Image demonstrating a multichannel microelectrode array (MEA) inserted within the feline facial nerve (FN) as it exits the stylomastoid foramen during a chronic implantation surgery. The cable is tunneled underneath adjacent tissue to an Onmetics connector secured to the cranial vertex.

Surgery (Chronic Electrode Implantation)

All the procedures were performed with the approval of the University of California at Irvine Institutional Animal Care and Use Committee according to the National Institutes of Health guidelines. We conducted chronic MEA implantation experiments in three cats. For nerve implantation surgeries, a preauricular incision was made and dissection through the parotid gland proceeded until the FN trunk was identified and skeletonized. The intraneural MEA was then inserted into the main trunk of the FN, and secured to the adjacent connective tissue with nylon suture (Fig. 2). The wire connections to the MEA were brought to a skull-mounted Onmetics (Minneapolis, MN, U.S.A.) connector that was protected by a stainless-steel cylinder. The floor of the cylinder and the base of the connector were sealed with acrylic to ensure that the cylinder interior was isolated from tissue spaces. A screw-on cap was subsequently placed over the cylinder, and the muscle and skin were sutured closed in layers.

Every 2 weeks after implantation, for a period of 6 months, measurements of stimulation thresholds were conducted. Each of the MEA channels was individually stimulated and EMG voltage responses from four selected facial muscles (*orbicularis oris*, *orbicularis oculi*, *nasalis*, and *levator auris longus*) were recorded using a nerve integrity monitoring system (NIM Response 2.0, Medtronic, Inc., Minneapolis, MN, U.S.A.). At the end of the 6-month period, the animal received a lethal dose of barbiturate and was transcardially perfused with a formaldehyde solution. The nerves were then harvested for histological processing and evaluation.

Surgery (Facial Nerve Injury)

For survival surgeries, to produce a standardized FN injury, a preauricular incision was made and the FN trunk was identified and skeletonized. The nerve was then intentionally damaged by either a nerve crush injury (17) consisting of a

30-second one-click crush with a serrated hemostat ($n = 2$) to produce an axonotmesis injury, or complete transection with scissors and reapproximation ($n = 2$), to produce a Sunderland 5th degree (18) neurotmesis injury. For the transection injury model, the nerve endings were aligned but not sutured together. The incision was closed in layers.

Immediate and complete unilateral facial paralysis was observed in all cats that received either a crush or transection-reapproximation injury. Eye ointment was routinely applied to protect the cornea, and animals were carefully monitored per Irvine Institutional Animal Care and Use Committee protocol. In terminal surgeries 4 months postinjury, the FN trunk was again identified, and a MEA was introduced via a micropositioner into the FN proximal to its bifurcation and either directly adjacent or proximal to the injury site, such that all four channels were in neural tissue. Insertion site and angle was dictated by surgical anatomy and micropositioner-mounted electrode access to the nerve. Each of the MEA channels was individually stimulated, and EMG voltage responses from the four selected facial muscles were recorded by the nerve integrity monitoring system. To vary which neural populations were stimulated, the MEA was withdrawn and reinserted into the nerve in variable trajectories and angles along the course of the exposed FN trunk, and each channel was again stimulated. The experimental stimulus parameters of interest included current level, pulse rate, time interval between pulses on pairs of channels, and electrode configuration (i.e., location of active and return electrodes). After a lethal dose of barbiturate and transcardial fixation, the FN was harvested for histological examination.

Statistical analysis was performed to determine the correlation strength between current levels and EMG response (Pearson's correlation coefficient). A paired samples *t* test was conducted to determine whether individual muscles significantly differed in activation based on the channel activated. An independent samples *t* test was used to determine if there was a difference in the mean activation between various muscles within the same stimulation channel, as well as between EMG response following acute versus chronic stimulation experiments. Statistical analysis was performed using PASW Statistics 18.0 software (SPSS, Inc., Chicago, IL, U.S.A.). A *p* value of < 0.05 was considered statistically significant.

RESULTS

Chronic Electrode Implantation in Normal FN

In chronically implanted MEAs, selective activation of two or more distinct muscles was achieved by stimulation of individual channels during each postoperative testing over the course of 6-months. Figure 3A (cat 3) shows representative data of EMG voltages from a single muscle following increasing levels of current injected through an individual channel over a succession of measurements at varying stimulation levels. When using cat 3 as a representative example, EMG response of the *orbicularis oculi* 2 weeks after implantation was significantly greater than that of the *nasalis* when channel 1 was activated ($p < 0.01$); however, activation of channel 2 resulted in similar EMG responses from both muscles, with a trend toward selectivity of *nasalis* activation. Although *levator auris longus* and *orbicularis oris* were also being recorded, they failed to elicit detectable EMG responses.

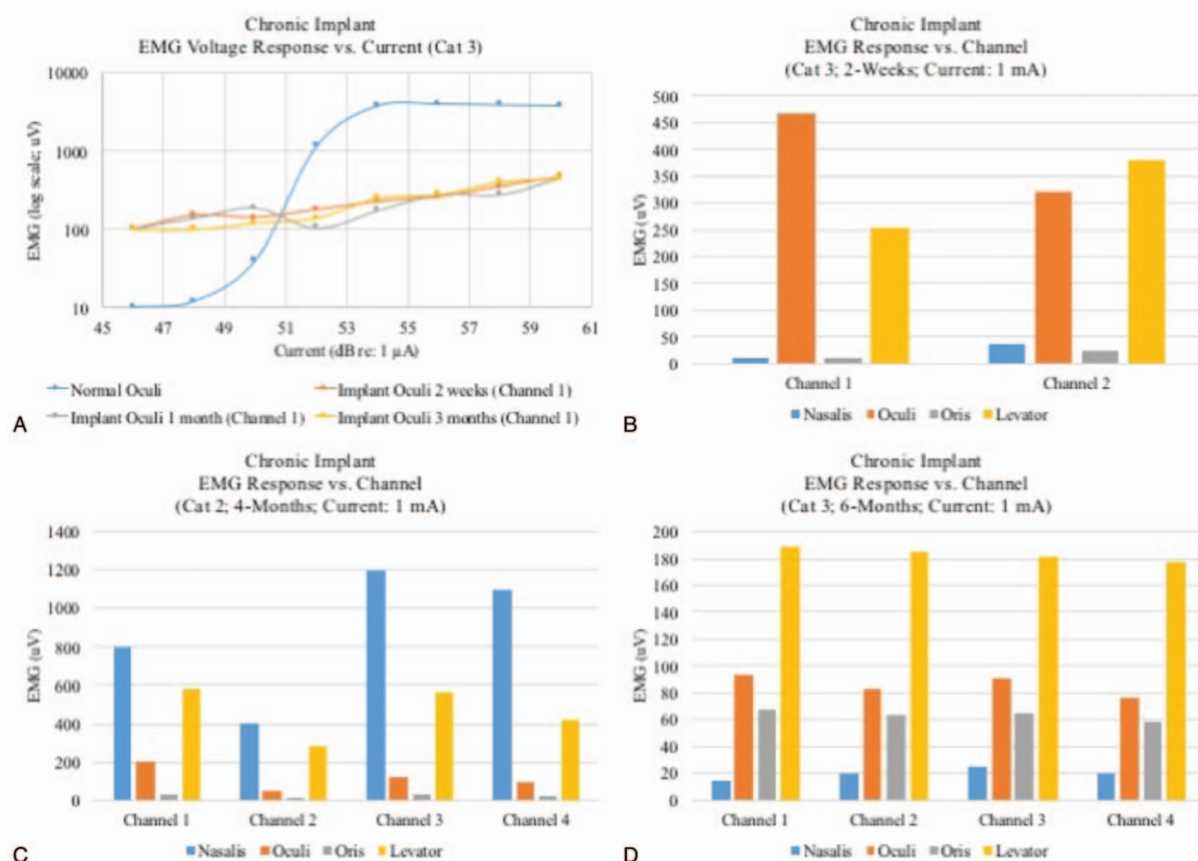


FIG. 3. A, Graphic representation of increasing current levels (from left to right on the x axis) and the corresponding EMG voltage response of the *orbicularis oculi* on the y axis (logarithmic scale). EMG voltage responses respond in a dose-responsive manner to increasing current in panel A, normal oculi represents a data following acute MEA insertion into a normal nerve (Cat 3; phase duration: 82 μs). B and C, Graphic representation of successive stimulation of channels (2 weeks and 4 months postchronic implant) from superficial (channel #1) to deep (channel #4) electrodes, from left to right on the x axis, and the corresponding EMG voltage response of four distinct muscles on the y axis. In (B), only two channels (channels 1 and 2) elicited EMG voltage responses, albeit in a selective manner, while all four channels in (C) elicited strong responses from the *nasalis* (Cats 2 and 3, phase duration: 82 μs). D, Graphic representation of successive stimulation of channels (6 months postchronic implant) from superficial (channel #1) to deep (channel #4) electrodes, from left to right on the x axis, and the corresponding EMG voltage response of four distinct muscles on the y axis. All four channels elicited strong responses from the *levator* (Cat 3, phase duration: 82 μs). EMG indicates electromyographic.

Figure 3B (cat 3) and C (cat 2) shows representative data of EMG voltages from four different muscles based on stimulation channel at two different time points. In cat 3, 2 weeks after implantation, channel 1 of the MEA robustly stimulated the *orbicularis oculi*, while channel 2 activated the *levator auris longus* to a stronger degree (Fig. 3B). Figure 3C (cat 2) demonstrates activation of the *nasalis* across all stimulation channels 4 months after implantation, while Figure 3D (cat 2) shows activation of the *levator auris longus* across all stimulation channels 6 months after implantation. Figure 4 (cat 2) demonstrates changes in EMG voltage responses of three different facial muscles over a 6-month period. Supplemental video content 1–3, <http://links.lww.com/MAO/A555>, shows representative graded movement of the *nasalis* (cat 2) 6-weeks post implantation with increasing current levels.

There were notable threshold changes and marked decreases in the degree of visible facial muscle

contraction when comparing these chronic implantation experiments to our previously published acute experimental data in normal FN (11). EMG responses after chronic MEA implantation in normal, uninjured FN were significantly lower, with maximal EMG responses reaching only 800 μV in chronic implants compared with responses of 4,000 μV at maximum stimulation levels in acute experiments ($p < 0.05$).

On histological examination, facial nerve fibers demonstrated show a desmoplastic foreign body reaction (i.e., granuloma formation) adjacent to the MEA and suture, as well as pale axonal fibers, vacuolization, and irregular atrophic changes indicative of a foreign-body reaction manifested in the axonal neural tissue (Fig. 5).

Responses to Electrical Stimulation Following Facial Nerve Injury

Four months after FN injury, all four cats had good recovery of facial function, with only subtle to minor

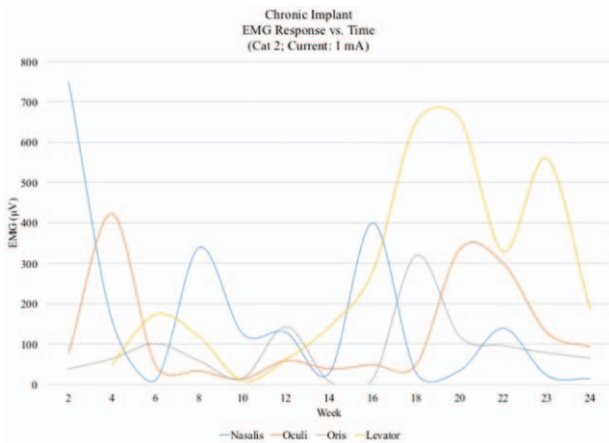


FIG. 4. Graphical depiction of EMG voltage response changes over time in four distinct muscles at current: 0 dB re: 1 μ A (Cat 2; current level: 1 mA; phase duration: 82 μ s). EMG indicates electromyographic.

mimetic deficits, roughly corresponding to House–Brackmann grade II or III function. In acute, terminal experiments 4 months after experimental FN injury, EMG activity in individual muscles was elicited by selective FN stimulation through individual channels. Selective activation of two or more distinct muscles was accomplished by selection of appropriate stimulation

channels in both transection-reapproximation (Fig. 6A) and hemostat crush (Fig. 6C) injuries. Subsequent insertion of the MEA into the FN at varying locations and angles resulted in similarly diverse patterns of stimulation responses. Figure 6B (cat 4, position 2) demonstrates the escalation of stimulation current levels resulted in mounting EMG voltage responses recorded in two different muscles ($p < 0.01$). Furthermore, we found that the *nasalis* had a statistically increased EMG response compared with the *orbicularis oculi* when only channel 4 is activated ($p < 0.05$). Increases in EMG voltage in response to escalating stimulation current were also demonstrated after crush injury (Fig. 6D).

When comparing EMG response of an individual muscle, such as the *levator auris longus* between individual channels in cat 2 (Fig. 6C), significantly elevated EMG output was identified when channel 1 was stimulated compared with channel 4 ($p < 0.05$). Similarly, the *nasalis* in cat 2 had a significantly increased response when channel 1 was activated compared with channels 2, 3, or 4 ($p < 0.05$) (Fig. 6C). Supplemental video content 4–5, <http://links.lww.com/MAO/A555>, shows activation of both *nasalis* and *orbicularis oculi* when channel 1 is stimulated, while only *orbicularis oculi* is activated when channel 4 is stimulated.

Similar to data obtained from chronically implanted electrodes, stimulation after FN injury resulted in

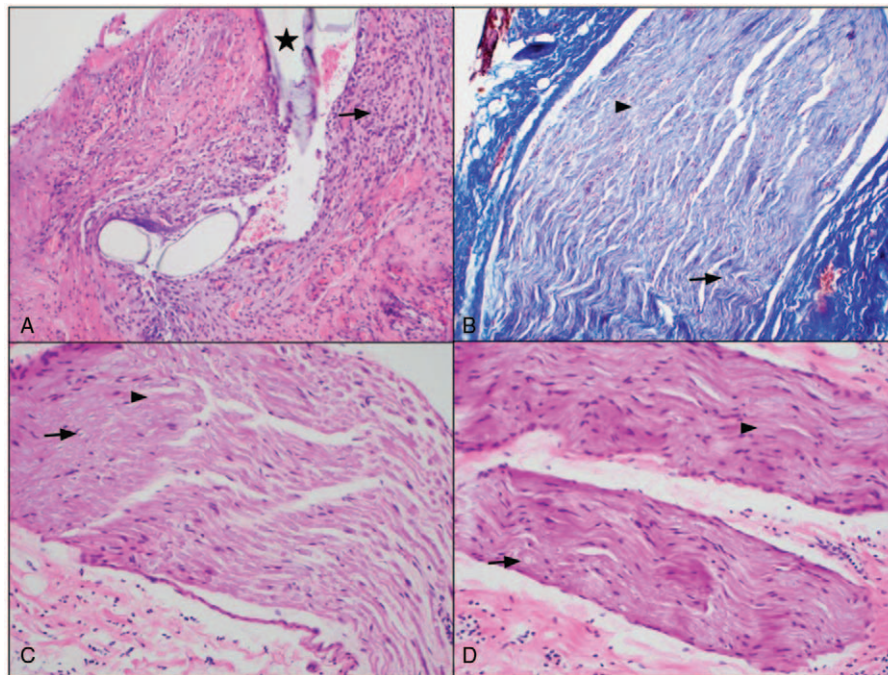


FIG. 5. Light microscopic histological images of implanted nerves at 10 and $\times 20$. A, Section of the facial nerve adjacent to a chronically implanted microelectrode array (hematoxylin and eosin (H and E) stain, $\times 10$ magnification) showing a piece of nonabsorbable suture (star), and a foreign body reaction (granuloma) adjacent to the suture (arrow). B, Section of the facial nerve adjacent to a chronically implanted microelectrode array (trichrome stain, $\times 10$ magnification) showing pale axonal fibers (arrowhead), vacuolization (arrow); note the pale appearance of the neural fibers at the top of the image compared with the bottom darker fibers. C, Section of the facial nerve adjacent to a chronically implanted microelectrode array (H and E stain, $\times 20$ magnification) showing pale axonal fibers (arrowhead) and vacuolization (arrow). D, Section of the facial nerve adjacent to a chronically implanted microelectrode array (H and E stain, $\times 20$ magnification) showing pale axonal fibers (arrowhead) and vacuolization (arrow).

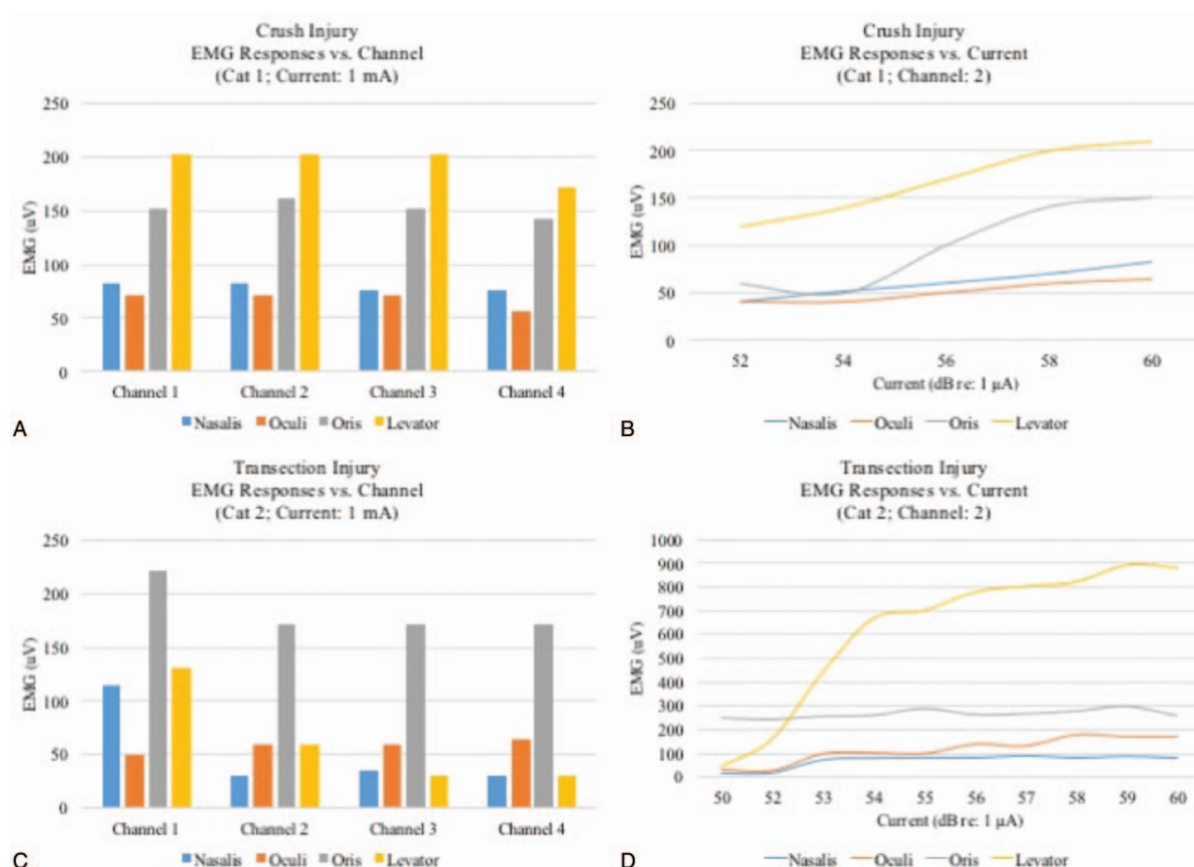


FIG. 6. A, Graphic depiction of channel-specific activation of four different muscles demonstrating no selectivity but strong activation of *levator auris longus* and *orbicularis oculi* (Cat 1; position 2; current level: 1 mA; phase duration: 82 μ s). B, Graphic depiction of escalating stimulation current levels in four individual muscles 4 months after a standardized and validated facial nerve hemostat crush injury resulting in complete unilateral facial paralysis (Cat 1; position 2; channel: 2; phase duration: 82 μ s). C, Graphic depiction of channel-specific activation of four different muscles demonstrating strong activation of the *orbicularis oculi* in all four channels, with selective activation of the *levator auris longus* in channel 1 compared with the other channels (Cat 2; position 2; current level: 1 mA; phase duration: 82 μ s). D, Graphic depiction of escalating stimulation current levels in four individual muscles 4 months after a standardized and validated facial nerve transection-reapproximation injury resulting in complete unilateral facial paralysis (Cat 2; position 2; channel: 2; phase duration: 82 μ s).

significantly diminished EMG output and marked reduction in the degree of visible facial muscle contraction compared with the previously published acute FN experiments (11), with maximal EMG responses reaching 400 μ V in acute stimulation of injured FN compared with a 4,000 μ V maximal response in uninjured FN experiments ($p < 0.01$).

On histological examination, crushed and transected facial nerve fibers show desmoplastic and irregular atrophic changes and perineural thickening indicative of a posttraumatic neuroma under hematoxylin and eosin (H&E) staining, and thickened perineurium with fibrosis within the neural bundles on trichrome staining (Supplementary Figure 1, <http://links.lww.com/MAO/A549>).

DISCUSSION

In this study, we demonstrated the feasibility of long-term implantation of an intraneural MEA in eliciting facial muscle activation, as well as a proof-of-concept

validation of acute stimulation after FN injury. Furthermore, we confirmed previous reports suggesting that efficacy of stimulation changes after chronic implantation (19,20) and following nerve injury due to desmoplasia, and is dependent on the degree of FN recovery after MEA implantation or injury (21). Despite decreases in maximal EMG responses and less robust visible muscle activation, these results suggest that we can continue to selectively elicit activations of discrete muscles and regions of the face in a graded, current-dependent fashion after chronic nerve implantation and after complete nerve injury. The selectivity of muscle activation and current-dependent EMG voltage responses reported here are similar to findings reported in our previous acute studies in the uninjured FN (11). The primary distinction in the results reported presently and our previously reported results lies in the markedly reduced EMG voltage responses and reduction of visible muscle activation after chronic MEA implantation.

In our chronic implantation experiments, muscular activation was present in a current-dependent graded fashion during the majority of the 6-month testing period. While the strength of elicited activations was not as strong following chronic implantation when compared with acute stimulation of an uninjured facial nerve, Supplementary Video Content 1–3, <http://links.lww.com/MAO/A555>, demonstrates graded activation of facial muscles with escalating levels of current delivered to the chronic MEA implant. Importantly, however, beginning at approximately 8 to 12 weeks after chronic implantation, visible contractility, and movement of facial musculature steadily diminished until eventually no movement could be appreciated with intraneural stimulation, despite continued robust EMG voltage responses throughout the 6-month implantation. Intriguingly, visible spontaneous muscle movement of the facial muscles was observed when the cat was awake, and visible activation was elicited after stimulation of the FN by a stimulating probe during the terminal surgery, at which intraneural positioning of the MEA was confirmed in all animals. It is possible that the desmoplastic tissue response at the nerve–electrode interface reduced the current delivery to the nerve, and thus diminished the extent of facial musculature activation. Furthermore, isometric contraction may have contributed to reduced visibility of facial muscle contraction (interestingly, contractions were accompanied by robust EMG voltage outputs). Isometric contraction is a fatigue-induced impairment in excitation–contraction coupling of muscle fibers. Although the exact cause of isometric contraction remains unknown, it can result from decreased intracellular calcium release, decreased sensitivity of myofilaments to calcium, and/or reduced force produced by each active cross-bridge (15). Other described theories into why visible implant-mediated muscle contraction diminished over time include muscle (22,23) and/or neural (21) fatigue, and ionic dysregulation (24,25). Further studies will need to be conducted to provide additional insights into the origins of this unusual observation.

Based on the chronic implantation literature reported in other animal nerves (e.g., sciatic nerve), histologic or physiologic consequences of intraneural array placement are most likely to occur within the first several weeks to months (26–28). Moreover, any inflammatory or desmoplastic response to chronic foreign body implantation and electric stimulation has been demonstrated to increase stimulation thresholds, but maintain the ability to elicit muscle activations (29). We found relatively stable stimulation thresholds, but attenuated levels of maximal muscular activation as measured by EMG response in both chronically implanted FNs and following acute stimulation of injured FNs when compared with acute experiments in normal FN. Figure 4 demonstrates changes in EMG voltage responses of four different facial muscles over a 6-month period. Despite lack of a global increase or decrease in EMG voltage responses across all facial muscles over time, there was considerable variability in EMG voltage responses throughout the

chronic implant testing period. Sources of this variability could include minuscule movement of the implanted array residing in the extratemporal portion of the facial nerve, variability in intramuscular EMG needle placement between testing sessions, and variations in the electrochemical microenvironment at the neural–electrode interface. Although maximal EMG voltage responses peaked at 1,200 μ V during the 6-month implantation period, the responses were typically below 400 μ V.

The observed deterioration of functional changes is likely a result of fibrous tissue formation around the electrode site, as described by Bowman and Erickson (27). It has been shown in chronically implanted intrafascicular electrodes of peripheral nerves, the immune system elicits a macrophage-mediated response resulting in an increase in endoneural connective tissue (30). However, intraneural electrode studies in both rabbits and feline models have illustrated no significant difference in nerve conduction velocities between chronically or acutely implanted electrodes (31). In our experiments, on histological examination of injured FN 4 months postinjury and following acute MEA implantation, we observed posttraumatic scarring within neural bundles, manifested by perineural fibrosis and neuroma-like irregular and atrophic neural proliferation (Supplementary Figure 1, <http://links.lww.com/MAO/A549>). Although these chronic changes likely contributed to the reduction in voltage response levels when compared with acute stimulation of a normal nerve (11), the MEA was able to selectively stimulate distinct neural fibers and elicit activation in specific muscles and regions of the face following complete FN injury similar to the acute and chronic experimental results.

With regards to our FN injury experiments, the results demonstrate that the direct electrode-to-nerve interface is sufficient to generate movement in a cat following a severe neural injury and partial recovery of facial function. Similarly, Frigerio et al. successfully and routinely elicited a full blink in patients with House–Brackmann grade VI paralysis with transcutaneous stimulation (32). This suggests that even in patients with severe neural injury, there are enough axonal fibers to stimulate muscle activation. Overall, despite the fact that some degree of selectivity in muscle activation was present following FN injury in our experiments, it was not as robust as that previously demonstrated in acute experiments in uninjured nerve. However, despite the decreased EMG response and selectivity, there continued to be a current-dependent graded EMG response, similar to the chronic implantation experiments.

Selectivity of muscular activation following chronic MEA implantation was demonstrated in only a subset of our animals. This variation likely results from natural variation in the somatotopic distribution of the facial nerve fibers innervating specific muscles, the limitations of the MEA design, and the variability in the surgical placement of the MEA. Notably, the neurostimulator will not be effective if implanted into a distal nerve trunk that

lacks a proximal neuronal cell body/ganglion, as the distal neural fibers would permanently degenerate. However, the distal FN can potentially be anastomosed with or without a nerve graft to any regional viable motor nerve before or at the time of implantation. Axonal regeneration from a brainstem motor nucleus (e.g., trigeminal, facial, and hypoglossal) could provide the excitable neural circuitry susceptible to neuroprosthetic stimulation. The clinical utility of a FN implant system can potentially be negatively impacted by the extent of randomly targeted neural regeneration, which results in synkinesis. The ability to satisfactorily address this issue with individual electrode stimulation parameter adjustment and optimization remains to be determined. Nonetheless, the stability of implanted MEAs to elicit EMG voltage potentials in selective facial musculature has been suggested in this study. Further refinements of the electrode composition, current characteristics, and intraoperative testing of intraneural stimulation may help enhance the selectivity of stimulation. Improving the selectivity of specific muscular activation by stimulating restricted nerve fiber populations within the FN requires further modulation of MEA materials, design, and array dimensions before contemplating clinical applicability. The deterioration of the MEAs ability to selectively elicit muscle activation following chronic implantation highlights the necessity of enhancing the biocompatibility of the MEA to avoid the chronic foreign body response that is characteristic of implanted electrode arrays (33). One such example of enhancing the biocompatibility characteristics of the MEA would be by applying a CD200 coating on the array which would mitigate the macrophage-mediated foreign body response (34). Additional work will focus on improving the biocompatibility of the MEA and ensuring that the current delivered to the nerve and surrounding tissue will not result in long-term damage. Furthermore, recapitulating the clinical condition in which the efficacy of chronic MEA implantation following complete FN injury and recovery will be assessed.

This proof-of-concept study demonstrated the feasibility of chronic MEA implantation in initiating muscular activation in normal nerve, as well as stimulation of previously injured FN. This study served to further elucidate the possibility and limitations of FN intraneural implantation in facial nerve reanimation. Future studies could be directed as investigating the function of chronically implanted intraneural electrodes in these nerve injury models.

CONCLUSION

We have established in the animal model the ability of a chronically implanted MEA to selectively stimulate restricted fiber populations within the FN and to elicit activations in specific facial muscles. These results hold true in acute experiments 4 months after complete FN injury and recovery. Despite the need to further refine the selectivity of muscle stimulation, the feasibility of chronically implanted intraneural MEAs to activate specific

muscles with functional muscular activation warrants further investigation of a FN implant system in the setting of facial paralysis.

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