In Vivo Excursion of the Temporalis Muscle-Tendon Unit Using Electrical Stimulation Application in the Design of Smile Restoration Surgery Following Facial Paralysis

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IMPORTANCE The temporalis muscle has the potential to substitute for the function of paralyzed facial muscles in a single-stage procedure when transferred as a muscle-tendon unit (MTU).

OBJECTIVE To measure the available excursion of the temporalis MTU after release from the coronoid.

DESIGN, SETTING, AND PARTICIPANTS Thirteen consecutive patients undergoing the temporalis MTU transfer procedure for facial reanimation participated in this study in an academic research setting.

MAIN OUTCOMES AND MEASURES Using transcutaneous electrical stimulation of the temporalis muscle, excursion of the temporalis muscle after its release as an MTU was recorded. Tension was varied on the released tendon during electrical stimulation of the muscle to determine the optimal muscle length at which the maximum excursion could be achieved. The tendon was inserted at the modiolus at the determined muscle length, and excursion of the oral commissure was recorded. Excursion data were then measured from the video recordings.

RESULTS The mean excursion of the temporalis tendon after its detachment from the mandible and stimulation at an optimized passive tension was 20.6 mm (range, 14-30 mm) (n = 9). Following tendon insertion, the mean oral commissure excursion was 15.5 mm (range, 8-23 mm) (n = 13).

CONCLUSIONS AND RELEVANCE The temporalis MTU has adequate available excursion following mobilization for dynamic reanimation of the paralyzed face. Electrical stimulation of the released temporalis tendon gives useful information that is reproducible and can be an important intraoperative adjunct to setting the MTU at an optimal tension to maximize force generation and excursion.

LEVEL OF EVIDENCE NA.
The primary objective in reanimating the paralyzed face is to restore facial tone, symmetry, and movement that is synergistic and controlled. This is best achieved when the injured facial nerve can be directly repaired, grafted, or substituted to reestablish connection between the facial nucleus and viable facial muscles. When restoration of neural input is not feasible or when the facial muscles are irreversibly injured or congenitally absent, transfer of functional muscle-tendon units (MTUs) offers the potential for restoration of some facial tone, symmetry, and motion after a single-stage procedure. In MTU transfer, the tendon of a functioning muscle is detached, mobilized, and reinserted into another tendon or bone to substitute for the action of a nonfunctioning muscle. The motor nerve and blood supply of the transferred MTU remain intact.

The principles for MTU transfer have been generated mainly from the experience in extremity surgery. An example of MTU transfer is the flexor carpi ulnaris tendon transfer procedure performed in patients with radial nerve palsy. The temporalis muscle is commonly transferred as an MTU to restore symmetry and movement in facial paralysis. Several factors are essential for the success of tendon transfer procedures. Based on an understanding of muscle physiology and biomechanics of muscle contraction, many of the principles of MTU transfer established in extremity surgery can be applied to the temporalis tendon transfer procedure. One critical principle for the success of an MTU transfer is the selection of a donor muscle of adequate strength and excursion. In addition, an understanding of the relationships among muscle length, tension, and force generation is essential to optimize the dynamic range, excursion, and force generation of a transferred MTU (Figure 1). Knowledge of the potential excursion of the temporalis muscle following its tendon release is essential to optimize its effectiveness and application in smile restoration. In this study, we measure the available excursion of the temporalis MTU after release of its tendon from its insertion on the coronoid process. Using electrical stimulation, we measure the intraoperative amplitude of the temporalis MTU after its release and insertion at the modiolus for correction of lower facial paralysis. The muscle-tendon length at which we record the maximum amplitude of excursion of the temporalis MTU is selected as the ideal tension at which the tendon is inserted to maximize postoperative excursion.

Methods

Patients

The study received institutional review board approval. In 13 consecutive patients undergoing the temporalis MTU transfer procedure for dynamic facial reanimation, tendon excursion was measured at maximum contraction after electrical stimulation. The patient provided informed consent to participate in the surgical procedure. The patient demographics and causes of facial paralysis are given in the Table.

Surgical Technique

All procedures were performed using general anesthesia. A short-acting nondepolarizing neuromuscular agent was administered. Electrical stimulation measurements were performed after the anesthesiologist verified the return of a full twitch response. The temporalis tendon transfer release procedure was performed as previously described by Boahene et al. Briefly, the coronoid process is exposed through the buccal space. The temporalis tendon is elevated off the inner aspect of the mandibular ramus, and a coronoidectomy is performed. A small segment of the coronoid is kept with the attached temporalis tendon. A Kocher retractor is placed on the tendon before inferior release and complete division of the tendon. The mobilized tendon is transposed through a gliding bed of buccal fat to reach the desired attachment site around the modiolus. The temporalis muscle is electrically stimulated with transcutaneous electrodes (DigiStim II Plus).
The objective of this study was to determine the available excursion of the temporalis muscle following release of its tendinous insertion on the coronoid as an MTU. Knowledge of the excursion variables is essential to optimize the design of the temporalis MTU transfer procedure for dynamic reanimation of the paralyzed face. The mean excursion of the temporalis muscle after release of the tendon was 20.6 mm. This available excursion compares favorably with the 15- to 20-mm excursion of the zygomaticus major muscle and supports the use of the temporalis MTU in smile restoration surgery following facial paralysis.

After selecting an appropriate donor muscle with the desired excursion range, the ultimate desired outcome is a transferred MTU generating maximum strength and excursion that is synergistic and comparable to the contralateral side. Achieving that goal depends on several factors, central to which is a key understanding of the biomechanics of the transferred donor MTU. The biomechanical determinant of active muscle force after transfer is the classic Blix curve, which depicts the relationships among active force, passive force, and muscle length. A muscle's resting length represents the position from which the muscle can generate its greatest force and is reflected by its fiber length, which depends on the sarcomere length. Setting the donor muscle near its normal resting length is probably the most important factor in achieving maximum force generation and excursion from a transfer MTU. Traditional principles used to choose the length at which the transferred muscle should be attached are vague. It is common dogma that muscles lose a grade of strength after surgery. Hence, many surgeons are taught to set the donor muscle tightly (overcorrecting) during muscle transfer because muscles are thought to stretch and weaken after surgery. Short of measuring sarcomere length, judging the muscle's resting length during surgery is mostly guesswork. In 1996, Lieber et al demonstrated that sarcomere length could be measured in vivo during a tendon transfer procedure using laser diffraction measurements. Using microendoscopes as small as 350 μm in diameter, Llewellyn et al

Table. Patient Demographics and Causes of Facial Paralysis

<table>
<thead>
<tr>
<th>Patient Sex/Age, y</th>
<th>Cause of Paralysis</th>
<th>Excursion, mm</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Optimized</td>
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<tr>
<td></td>
<td></td>
<td>Length</td>
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<tr>
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<tr>
<td>M/65</td>
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<td>23</td>
</tr>
<tr>
<td>M/70</td>
<td>Temporal bone neoplasm</td>
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</tr>
<tr>
<td>F/44</td>
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<td>NM</td>
</tr>
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<td>F/50</td>
<td>Advanced oral neoplasm</td>
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</tr>
<tr>
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<td>Parotid neoplasm</td>
<td>20</td>
</tr>
<tr>
<td>M/66</td>
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<tr>
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<tr>
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<td>20</td>
</tr>
<tr>
<td>M/73</td>
<td>Temporal bone neoplasm</td>
<td>23</td>
</tr>
</tbody>
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Abbreviation: NM, not measured.
imaged individual sarcomeres in passive and activated muscles, demonstrating the feasibility of minimally invasive methods for in vivo measurement of sarcomere length. Intraoperative measurement of sarcomere length would allow the surgeon to set the tension of the donor muscle to the ideal sarcomere length and enable a maximum sarcomere length-tension-relationship for actin-myosin interaction. Overstretching a donor muscle sets its fibers at a length longer than the natural resting sarcomere length, which is well into the passive part of its Blix curve and at a biomechanically inefficient starting tension. This was confirmed in vivo by Fridén and Lieber in 1998, when overstretching the donor muscle into the passive tension portion of the Blix curve decreased its potential contractile force to 28% of its maximum force. In the absence of clinically available methods of measuring sarcomere length, intraoperative electrical stimulation of an MTU offers an alternative method of judging the biomechanical muscle length-tension-excitation-relationship of a donor MTU. Electrical stimulation allows the direct determination of muscle amplitude, which is the available active excursion of a given muscle. Freehafer et al. applied electrical stimulation to numerous muscles during extremity surgical reconstruction to determine muscle-tendon properties. While few investigations have shown the electrical response of the human temporalis muscle and its effect on jaw movement, no studies to date have measured the in vivo excursion properties of the temporalis muscle once the tendon is detached.

We used electrical stimulation of the temporalis muscle to determine the optimal tension at which to insert the temporalis tendon. By varying tension on the mobilized temporalis tendon during stimulation of the temporalis muscle, an approximate Blix curve for the temporalis MTU is generated, and the muscle length at optimal excursion is selected for reinserting the tendon at the modiolus. We use this method of electrical stimulation and tension variation to approximate the optimal length and tension at which to insert the mobilized temporalis MTU at the modiolus. With this approach, the following 3 clinical scenarios arise: (1) when to insert the tendon without an extender, (2) when to extend the tendon with a graft, and (3) when to perform a lengthening myoplasty. The temporalis tendon inserts mostly on the medial aspect of the coronoid and extends inferiorly toward the buccinator line. Following and dissecting the tendon carefully up to the buccinator line can provide enough tendon length to reach the modiolus. In patients in whom the temporalis tendon reaches the modiolus at the determined optimal length, the tendon is inserted without overstretching. When the temporalis tendon is 1 to 2 cm short of the insertion point at the optimal length determined by electrical stimulation, a tendon extension with fascia lata or a donor tendon is used. To securely extend the tendon, we drill holes into the coronoidectomy segment, through which sutures are passed to firmly attach the fascia or donor tendon. When the ideal tension on the temporalis tendon leaves it more than 2 cm away from the desired insertion site at the modiolus, we prefer to slide the entire temporalis MTU inferiorly by releasing the muscle from its attachment on the temporal fossa. This minimizes restriction from adhesions, the need for a long tendon extender, and the effects of altering the elastic properties and passive components of the temporalis MTU.

The release of the temporalis muscle has been described by Labbé and Huault as the lengthening myoplasty. In their technique, the temporalis muscle is exposed through a scalp incision, and the posterior third of the muscle is released and elevated from its periosteal attachment. By sliding the released muscle inferiorly, the muscle fibers are redistributed and fixated inferiorly, allowing the released coronoid with the attached temporalis tendon to reach the lip. When releasing the temporalis muscle, care should be taken to avoid injury to the neurovascular supply deep to the muscle. In addition, the released muscle should be reattached at the appropriate tension close to its passive length with the aid of electrical stimulation. As previously described, this procedure can be performed with endoscopic assistance through minimal access incisions. Har-Shai et al. reported on the use of intraoperative stimulation as an adjunct to selecting the ideal vector of action of the temporalis muscle and anchor points of its tendon, enhancing a more coordinated and symmetrical smile. The effect of tendon extension on the strength of the MTU has been studied. Muscles have been shown to adapt to functional length changes by altering the number of sarcomeres in series. If the tendon is elongated with an extender, the number of sarcomeres in series is reduced, and the muscle produces less force and excursion. The muscle force and excursion can be preserved after tendon extension if the passive tension is altered to maintain the number of sarcomeres in series. Adjusted and optimized tension with electrical stimulation of the temporalis MTU becomes more important when a tendon extension is performed. To avoid the restrictive effect of adhesion between a long tendon extender and surrounding tissue, we prefer to release and slide the entire temporalis MTU inferiorly when an extender longer than 2 cm is required.

While in vivo electrical stimulation of the temporalis muscle provides valuable information on the temporalis MTU, manual traction and tactile feedback are essential. Because of muscle-specific passive elements and intersurgeon variability, tactile feedback introduces subjectivity in estimating the optimal sarcomere length. We are exploring methods of in vivo measurement of sarcomere length combined with electrical stimulation to select the optimal tension and length at which to insert the mobilized MTU.

In conclusion, the temporalis MTU has adequate available excursion following mobilization for dynamic reanimation of the paralyzed face. Electrical stimulation of the released temporalis tendon gives useful information that is reproducible and can be an important intraoperative adjunct to setting the MTU at the optimal tension to maximize force generation and excursion. The current principles used to choose the length at which the transferred temporalis MTU muscle should be attached are vague and risk overstretching. Misunderstanding of the sarcomere length–passive tension relationship can cause severe overstretching of the transferred temporalis MTU and result in poor function.
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Study concept and design: Boahene, Byrne.
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Analysis and interpretation of data: All authors.
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Critical revision of the manuscript for important intellectual content: Boahene, Ishii.
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REFERENCES