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Mandibular Muscle Attachments in Genial Advancement Surgery for Obstructive Sleep Apnea

Cherine H. Kim, MD, PhD; Nichole Loree, BA; Peter S. Han, MD; Erin T. Ostby, MD; Daniel I. Kwon, MD; Jared C. Inman, MD

Objectives/Hypothesis: Genioglossus advancement is performed in select patients with obstructive sleep apnea. Surgical techniques attempt to capture the genial tubercle of the mandible; however, measurements of the genioglossus, geniohyoid, and digastric muscles are poorly delineated. This investigation is the largest anatomic study exploring the muscles of genial advancement surgery and the first to quantitatively characterize muscular attachments relative to the tubercle, providing new insights from an anatomic perspective on optimizing muscular advancement.

Study Design: Cadaveric study.

Methods: Fifty-three fresh cadaveric mandibles underwent dissection of the genial tubercle and genioglossus, geniohyoid, and digastric muscles. On average, the geniohyoid began 4.88 mm and ended 10.03 mm from the inferior border of the mandible; the genioglossus 11.91 mm and 18.01 mm, similarly. Intermuscular distance, if present, was 2.67 mm; the muscles overlapped in 28% of cadavers. The combined vertical height of the muscles at their mandibular attachment was 13.94 mm, significantly differing from the height of the genial tubercle. The left and right lateral insertion of the digastric muscles was 19.34 mm and 19.31 mm, respectively, from midline.

Conclusions: The variable range of muscle attachments suggests that genioglossal and geniohyoid attachments extend beyond the genial tubercle and may not originate concentrically from the tubercle, but overlap and lie in very close proximity. Mandibular anterior muscle attachments require anatomic accuracy and an effective operative evaluation of advancement before reproducible, clinically effective osteotomies can be recommended.

Key Words: Genial tubercle, genioglossus, geniohyoid, obstructive sleep apnea surgery.
Level of Evidence: NA

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INTRODUCTION

Obstructive sleep apnea (OSA) is a chronic disorder characterized by recurrent collapse of the upper airway during sleep. It affects approximately 3% to 7% of adult men and 2% to 5% of adult women, and the incidence is even higher in those with certain risk factors, including obesity, advancing age, minority race, and specific variations of craniofacial anatomy. Partial or complete collapse of the oral pharyngeal airway leads to hypoxia and hypercapnia, which is corrected by arousal from sleep. This fragmented sleep most commonly results in daytime hypersomnia but may also cause cognitive impairment, cardiovascular disease, and dysfunction of glucose regulation.

Due to practical limitations of long-term lifestyle changes, oral appliances, and continuous positive airway pressure (CPAP) devices, results are variable and often lead to poor compliance by most OSA patients. Anatomically based patient-specific surgery is an appropriate and effective strategy to improve OSA in medically refractory patients. Multiple surgical options aimed at manipulating the tongue, hyoid, and mandible have been described. Specifically, the retrolingual pharynx is a highly prevalent site of obstruction in patients with OSA. Thus, the impact of the genioglossus muscle, which is the primary tongue protruder and a major pharyngeal dilator, on airway occlusion has come under investigation for targeted therapy.

Advancement of the genioglossus muscle with anterior mandible osteotomies has been shown to be effective in treating OSA. The chief consideration in surgical planning is adequate capture of the genioglossus muscle fibers, preservation of mandible integrity, and avoidance of dental injury. Much of the rationale for different surgical methods involves anatomic and imaging data (primarily computed tomography [CT] scanning) designating the position of the genial tubercle as the presumed origin for the muscle attachments. However, the mandibular attachments for the genioglossus and the closely associated geniohyoid muscle (the primary hyoid suspension...
muscle) have not been well described, and the tubercle may actually just be a proxy marker for the actual muscle origins. This study is the first, to our knowledge, measuring the location and size of these muscle fibers in relation to the mandible and to each other. We also describe the poorly studied digastric muscle (another hyoid suspension muscle) to present a more complete anatomic understanding of the muscles that attach to the anterior mandible and may therefore be involved in osteotomy consideration in OSA “genioglossal” advancement. The role of the geniohyoid and digastric muscles in supine airway patency has recently been studied and found to be contributory in regard to their contribution to hyoid suspension. This study helps highlight the importance of the anatomic attachments and function of these muscles when expecting airway diameter opening and clinical improvement in sleep-study parameters resulting from surgery to these targeted anatomic sites.

MATERIALS AND METHODS

Fifty-three fresh cadaver heads were dissected to visualize the attachment of the geniohyoid, genioglossus, and digastric muscles to the mandible. The mean age was 77 years (range, 44–97 years), and there were 26 males and 27 females. Digital Vernier 500 Series calipers (Mitutoyo, Kawasaki City, Kanagawa, Japan) with resolution of 0.01 mm and accuracy to 0.02 mm were used to measure the relationship of the mandible to the muscular attachments of these muscles in the vertical plane. Measurements were made from the inferior mandibular border (IMB) to the anterior mandibular border (IMB) to the inferior and superior borders of the geniohyoid and genioglossus to determine the sites of mandibular attachments and heights of each muscle. Figures 1 and 2 depict these measurements, with GHi being the inferior attachment of the geniohyoid to the mandible and GHs the superior attachment. GHs – GHi was calculated to determine the height of the geniohyoid; likewise, GGs – GGi resulted in the height of the genioglossus. The distance between the geniohyoid and genioglossus, the intermuscular distance (IMD), was also similarly determined. In cases where the muscles overlapped, or touched directly, a measurement of 0.00 mm was used. Left and right digastric muscle insertions to the anterior mandible were recorded from their lateral extent from midline, as this would be the clinically relevant measurement in capturing these muscle fibers when considering osteotomy techniques. Genial tubercle measurements were also similarly recorded by directly observing the tubercles rise off the lingual plate of the mandible, in the posterior dimension, denoting the beginning and end of the tubercle. Muscles were measured in the most clinically relevant plane with respect to the known mandibular osteotomy techniques currently and historically practiced for OSA.

GraphPad Prism (GraphPad Software, San Diego, CA) was used for statistical analysis. The t test was used to compare means; P < .05 was considered significant.

RESULTS

The mean genial tubercle height was 7.78 ± 3.15 mm. The mean distances of the geniohyoid muscle fiber attachments in relation to the IMB were 4.88 ± 2.03 mm inferiorly (GHi) and 10.03 mm ± 2.90 mm superiorly (GHs). The mean total height of geniohyoid attachment to the mandible was 5.15 ± 1.75 mm and ranged between 2.35 and 10.50 mm. The mean distances of the genioglossus muscle fiber attachments from the IMB were 11.91 ± 3.55 mm inferiorly (GGi) and 18.01 ± 3.69 mm superiorly (GGs). The mean total height of genioglossus attachment was 6.11 ± 1.81 mm and ranged from 2.46 to 12.69 mm. The IMD mean was 2.67 ± 2.73 mm. The combined height of the genioglossus and geniohyoid was 11.26 ± 2.67 mm and ranged from 6.01 to 19.57 mm. The combined height of the genioglossus, geniohyoid, and IMD was 13.94 ± 3.02 mm and ranged from 8.17 to 23.08 mm. The mean distance from midline to the lateral aspect of the digastric on the left (DG_L) was 19.34 ± 5.04 mm and ranged from 8.79 to 33.48 mm. The mean distance from midline to the lateral aspect of the digastric on the right (DG_R) was 19.31 ± 5.20 mm, with a range of 6.59 to 27.91 mm. The digastric distance from lateral border DG_R to DG_L was 38.56 ± 9.32 mm. These data are summarized in Table I.

Statistical analysis of the various muscle and tubercle measurements exhibited several significant differences. Comparison of GGi and GTi (P < .0001) indicates that the genioglossal fibers attach above the inferior...
border of the genial tubercle. Comparison of the GGs with GTs \((P < .0001)\) suggests that the genioglossus extends above the superior border of the genial tubercle. Comparison of the GHi with GTi \((P < .0001)\) demonstrates that the geniohyoid fibers begin significantly below the inferior border of the genial tubercle. Comparison of the GHs with GTi \((P = .001)\) shows that the genial tubercle begins below the superior border of the geniohyoid. Comparison of the GHs with GGi \((P = .0036)\) indicates that the geniohyoid and genioglossus are most often separated by a statistically appreciable IMD; however, conversely, on direct measurement, 28\% of individual specimens do show overlap with indistinct separate muscle edges at their point of origin. Genial tubercle height differed from both genioglossus \((P = .0011)\) and geniohyoid \((P < .0001)\) height. The combined height of the genioglossus and geniohyoid was significantly larger than that of the genial tubercle \((P < .0001)\); and following, expectantly, the combined height of the genioglossus, IMD, and geniohyoid was larger than that of the genial tubercle \((P < .0001)\).

**DISCUSSION**

The genioglossus muscle is a fan-shaped extrinsic muscle of the tongue that previous studies indicate seemingly originates from the superior mental spine of the genial tubercle and extends posteriorly to insert at the tip of the tongue, the base of tongue, and the body of the hyoid bone. Its main function is to protrude and depress the tongue, but the genioglossus also acts as a major pharyngeal dilator by stiffening during inspiration to counterbalance the negative pressure that would collapse the upper airway.\(^{18,20}\) Genioglossus muscle function has been studied in relation to OSA because airway closure is associated with a decrease in upper-airway muscle tone.\(^2\)

The geniohyoid muscle, as described in previous studies, seemingly originates from the inferior spine of the genial tubercle and inserts in the hyoid. The geniohyoid helps keep the upper airway patent during inspiration by moving the hyoid anteriorly and cephalad.\(^{21,22}\)

The digastric muscle comprises the anterior belly, which originates from the digastric fossa of the mandible, and the posterior belly, which arises from the mastoid process of the temporal bone. Both bellies of the digastric insert on the intermediate tendon of the hyoid and work to depress the mandible and elevate the hyoid.\(^{23}\) Multiple variations in the pattern of the digastric have been reported in the literature.\(^{23–25}\) There is a paucity of understanding regarding the function and structural importance of the geniohyoid and digastric muscles in

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**Table I. Cadaver Measurements.**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean ± SD, mm</th>
<th>Range, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHi</td>
<td>4.88 ± 2.03</td>
<td>1.62–9.59</td>
</tr>
<tr>
<td>GHs</td>
<td>10.03 ± 2.90</td>
<td>5.78–18.23</td>
</tr>
<tr>
<td>GHh</td>
<td>5.15 ± 1.75</td>
<td>2.35–10.50</td>
</tr>
<tr>
<td>IMD</td>
<td>2.67 ± 2.73</td>
<td>0–12.39</td>
</tr>
<tr>
<td>GGi</td>
<td>11.91 ± 3.55</td>
<td>5.54–24.70</td>
</tr>
<tr>
<td>GGs</td>
<td>18.01 ± 3.69</td>
<td>12.50–28.00</td>
</tr>
<tr>
<td>GHh</td>
<td>6.11 ± 1.81</td>
<td>2.46–12.69</td>
</tr>
<tr>
<td>GTi</td>
<td>7.67 ± 3.14</td>
<td>2.26–13.38</td>
</tr>
<tr>
<td>GTs</td>
<td>15.45 ± 2.27</td>
<td>9.69–19.55</td>
</tr>
<tr>
<td>GTh</td>
<td>7.78 ± 3.15</td>
<td>1.49–13.58</td>
</tr>
<tr>
<td>DGL</td>
<td>19.34 ± 5.04</td>
<td>8.79–33.48</td>
</tr>
<tr>
<td>DGR</td>
<td>19.31 ± 5.20</td>
<td>6.59–27.91</td>
</tr>
<tr>
<td>GGH + GHh</td>
<td>11.26 ± 2.67</td>
<td>6.01–19.57</td>
</tr>
<tr>
<td>GGH + GHh + IMD</td>
<td>13.94 ± 3.02</td>
<td>8.17–23.08</td>
</tr>
</tbody>
</table>

\(\text{DG}_L = \text{digastric left}; \text{DG}_R = \text{digastric right}; \text{GG} = \text{genioglossus}; \text{GGh} = \text{genioglossal height}; \text{GHi} = \text{distance from IMB to inferior border of GG}; \text{GHs} = \text{distance from IMB to superior border of GG}; \text{GH} = \text{geniohyoid}; \text{GHh} = \text{geniohyoid height}; \text{GI} = \text{distance from IMB to inferior border of GH}; \text{GTh} = \text{genial tubercle height}; \text{GTi} = \text{distance from IMB to inferior border of GT}; \text{GTs} = \text{distance from IMB to superior border of GT}; \text{IMD} = \text{intermuscular distance between GH and GG}; \text{SD} = \text{standard deviation}.\)
their relation to tongue position, hyoid suspension, and airway dilation.\textsuperscript{19}

Because of the lack of information regarding attachments of these muscles to the mandible, their relationships spatially to each other, and their function as airway supportive structures, we formulated this study to describe these measurements for consideration in genial advancement surgery as a basis to understand how patients with OSA may benefit from structural manipulation when anatomic attachment principles are more quantitatively appreciated.

Yin et al. found the superior genial spines of 40 cadaveric specimens to have a mean height of $5.82 \pm 0.71$ mm and a mean width of $6.98 \pm 1.35$ mm, with distinguishable left and right components in 38 of 40 cadaveric specimens.\textsuperscript{26} Upon visualization, they concluded that the genioglossus origin extended laterally from the superior mental spine in three (7.5\%) of the specimens. They also reported that only five cadavers revealed distinguishable left and right aspects; the rest had fused inferior mental spines, so they did not measure height and width. They did note that the geniohyoid originated from the inferior mental spine in all 40 cadavers. Unfortunately, Yin et al. looked at CT scans and anatomic cadavers; however, their design as described in the Materials and Methods appears to have directly measured only the bone changes and not actually the muscles themselves. The muscles were described as being dissected off the mandible before the muscle measurements were taken—thus, it appears they measured the tubercle, not the actual muscle origin on bone. This highlights the historical literature assumption that the tubercle and the muscle origin share the same quantifiable concentric relationship—which we have found to not directly be the case in the majority of our specimens.

Most studies regarding the genial tubercle do not differentiate between the superior and inferior mental spines. Hueman et al. dissected 17 adult cadavers to characterize the dimensions of the genial tubercle and reported a mean genial tubercle height of $4.7 \pm 1.5$ mm, a mean genial tubercle width of $4.9 \pm 0.9$ mm, and a mean distance from the inferior border of the genial tubercle to the IMB of $13.3 \pm 2.9$ mm.\textsuperscript{27} Comparisons with measurements made on cone-beam CT yielded statistically similar results.\textsuperscript{25} Mintz et al. made measurements on 41 dry skulls and reported similar results: mean genial tubercle height of $4.8$ mm and width of $5.95$ mm.\textsuperscript{26} These measurements of the entire genial tubercle are expectantly smaller than those reported by Yin et al., likely due to bone drying and preparation.\textsuperscript{26} Meanwhile, Hennessee and Miller reported genial tubercle height of $11.64 \pm 1.84$ mm and width of $6.86 \pm 1.03$ mm based on seven preserved cadaveric dissections.\textsuperscript{28} The genial tubercle height in this study is larger than the values reported by Hueman et al. and Mintz et al., further highlighting the inconsistency found within the literature, which we have shown in Table II.\textsuperscript{25,27,28}

<table>
<thead>
<tr>
<th>Authors, Year</th>
<th>Measurement Source</th>
<th>N</th>
<th>Genial Tubercle Height (Mean ± SD), mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yin et al., 2007\textsuperscript{26}</td>
<td>Cadavers</td>
<td>40</td>
<td>6.98 ± 1.35</td>
</tr>
<tr>
<td></td>
<td>Spiral CT</td>
<td>40</td>
<td>7.01 ± 1.13</td>
</tr>
<tr>
<td>Hueman et al., 2007\textsuperscript{27}</td>
<td>Cadavers</td>
<td>17</td>
<td>4.7 ± 1.5</td>
</tr>
<tr>
<td></td>
<td>CBCT</td>
<td>17</td>
<td>5.1 ± 1.6</td>
</tr>
<tr>
<td>Mintz et al., 1995\textsuperscript{28}</td>
<td>Cadavers (dry skulls)</td>
<td>41</td>
<td>4.8</td>
</tr>
<tr>
<td>Hennessee and Miller, 2005\textsuperscript{29}</td>
<td>Cadavers</td>
<td>7</td>
<td>11.64 ± 1.84</td>
</tr>
<tr>
<td>Wang et al., 2012\textsuperscript{32}</td>
<td>CBCT</td>
<td>20</td>
<td>7.3 ± 2.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23</td>
<td>6.5 ± 1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22</td>
<td>7.9 ± 1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
<td>6.7 ± 1.9</td>
</tr>
</tbody>
</table>

CBCT = cone-beam computed tomography; CT = computed tomography; SD = standard deviation.

This inconsistency may be due to the heterogeneity in characterizations of the tubercle as well as anatomic variety between cohorts. In most of these studies, according to the researchers performing them, the mandible has one tubercle with both geniohyoid and genioglossus originating from this bony spine; however, strict origins in several studies are not well defined, and we noted mixing of anatomic terms in several datasets—specifically in relation to “spines” and “tubercles.” From our anatomic dissection, it was apparent that the mandible most often has one tubercle, a “superior” tubercle, and variable muscle origins in relation to this tubercle. Multiple tubercles were also seen, but in the minority of cases. Most often, however, the tubercle was seen directly proximate to the GGi and GHs, in between the main muscle body’s separate origins. Additionally, there were most often left and right spines or apices—approximating the midline and appearing to comprise the tubercle. The single genial tubercle, as described in other studies, was seen in a majority of our specimens, and these single tubercles often had larger vertical dimensions. The finding of two separate tubercles we observed in our fresh cadavers may not be easily apparent in CT imaging or in dry skulls, possibly explaining this difference from the existing literature. Most previous studies do not differentiate bony measurements from muscular attachments and use the tubercle (a bone finding) synonymously with the muscle origin. These studies fail to provide a quantifiable description of the genioglossus and geniohyoid muscle attachment on the mandible—instead, they use the tubercle as a surrogate. Moreover, the tubercle is often clinically defined by CT imaging as the most lingual (posterior) projection of the lingual mandible cortex where “the muscles attach.” However, in our dissections, the mental spines (the right and left posterior lingual projections of the tubercle) do not necessarily line up with the genioglossus or geniohyoid muscles. They were often found to lie between the muscular insertions of the geniohyoid and genioglossus.

We found that the distance from the IMB to the inferior geniohyoid attachment to the mandible (GHi) ranged from 1.62 to 9.59 mm, with a mean of 4.88 ± 2.03 mm. This value places the muscle inferior to the inferior border of the genial tubercle (GTi) reported in the studies

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previously described,\textsuperscript{27,28} as well as our measured value of $7.67 \pm 3.14$ mm from the IMD, which was significantly different ($P \leq .0001$), indicating that the geniohyoid origin likely extends beyond the inferior aspect of the genial tubercle. Moreover, the mean total height of geniohyoid attachment to the mandible was $5.15 \pm 1.75$ mm (range, 2.35–10.50 mm) and the mean total height of genioglossus attachment was $6.11 \pm 1.81$ mm (range, 2.46–12.69 mm).

Accounting for the genial tubercle heights previously reported, this indicates that the muscle fibers of the genioglossus and geniohyoid seemingly extend beyond the superior and/or inferior dimensions of the genial tubercle as seen on CT. Moreover, these tubercles or spines, as seen on CT, may not correlate with the muscle attachments to the mandible. The significance of this implication is that genioglossus muscle fibers may be in closer proximity to the tooth roots or that the geniohyoid may attach closer to the IMB than previously thought. Additionally, in our dissections, the muscle attachments were often found extending onto the apex of the tubercles; however, they do not always originate or center on the apex, and the muscles fan out well beyond the tubercle with significant ranges ($P < .0001$). Park et al. used cone-beam CT to analyze 33 patients undergoing surgery for OSA and proposed a potential osteotomy design for genioglossal advancement based on locations of the mental foramen, canine, central and lateral incisor tooth roots, and genial tubercle in relation to the IMB.\textsuperscript{30} This study evaluated the trade-off between maximizing genioglossal muscle capture and the risk for dental and neurovascular injury when performing osteotomies for genioglossus advancement, thus highlighting the importance of adequate understanding of tubercle, muscle, and tooth-root anatomy when designing ideal osteotomy placement for genioglossal advancement.

These considerations possibly have an impact on the design of the osteotomy for genioglossus advancement. Historically, literature cohorts of genioglossus-advancement patients have yielded substantially different clinical results in regard to the effectiveness of treating OSA with sleep-study improvement. Moreover, studies showing muscle advancement effects anatomically are absent from the literature. A study on the effectiveness of the rectangular osteotomy technique in achieving genial tubercle and genioglossus muscle capture in 38 patients showed complete capture of the tubercle in all patients but complete capture of the genioglossus muscle in only 31 patients—a “miss rate” of 18.4%.\textsuperscript{31} Similarly, a trephine system showed complete capture of the genial tubercle in eight cadavers but capture of only 85% of genioglossus muscle fibers and 78% of geniohyoid muscle fibers.\textsuperscript{29} Therefore, based on our data and sparse prior studies, it appears one may conclude that capturing the genial tubercle does not necessarily result in complete, or possibly functional and clinically relevant, muscle capture.

This understanding should be considered when interpreting preoperative imaging and during surgical osteotomy planning. CT imaging should easily demonstrate the bony tubercle accurately but will show the muscle poorly unless advanced CT protocols or postprocessing is used. Magnetic resonance imaging better delineates the muscles of the GH, GG, and digastric; however, the bone tubercle is very poorly seen on magnetic resonance imaging. The correct mandible osteotomy in OSA genioglossus advancement surgery requires capture of the muscle that leads to an appreciable change in the upper-airway diameter at a level of sleep-induced patient-specific obstruction, resulting in postoperative improved sleep-study metrics. As pointed out by other researchers, the characterization of the genial tubercle may not be a reliable surrogate for muscle attachment and may lead to inadequate advancement.\textsuperscript{27,28,32} Further study is needed to determine how best to elucidate the relevant muscle attachments preoperatively to effect appreciable changes in the upper-airway caliber after mandible advancement. In clinical practice, a technique we have found useful is to directly observe the base of the tongue moving forward from the posterior pharyngeal wall during the mandible advancement after the osteotomy is made, or similarly viewing through a nasopharyngoscope, observing the base of tongue and pharynx during the advancement. Anterior mandible bone advancement, if the genioglossus is captured adequately, will result in movement at the opposing end of the genioglossus muscle, resulting in airway dilation. However, if osteotomy did not adequately capture the muscle attachments and base-of-tongue movement is not observed, revision osteotomy would be unlikely to be successful unless there is enough bone quality to allow for further plating options. Additionally, tongue-base suspension may be performed as an adjunctive procedure in the event that revision osteotomy cannot be performed.

Our study cohort was limited in that we did not determine the distance of the tooth roots or intramandibular neurovascular structures from the tubercle or the muscles directly; however, when looking at a different cohort\textsuperscript{30} and comparing it with the data presented in this study, a much more clear picture of the close proximity of these important structures as they relate to anterior sleep mandibular osteotomies can be obtained. Further studies will examine the relationship between the superior border of genioglossus attachment, the tubercle, and the inferior apices of the tooth roots with their supportive neurovascular relationships. Further study is also needed to determine the clinical resultant effects in patients with OSA of the genioglossus, geniohyoid, and digastric muscles, in isolation and in combination, on the upper-airway caliber and hyoid position. We have previously performed a preliminary study of these effects in cadavers.\textsuperscript{19} Additionally, we are uncertain about the percentage of these dense muscle attachments to the anterior mandible that needs to be captured to advance the muscle a clinically relevant distance. For example, if half of the genioglossus muscular attachment is captured, it may not result in the clinically relevant movement of the base of tongue away from the posterior pharynx, thus opening the supine airway.

CONCLUSION

Success of genioglossus advancement surgery is predicated on the sufficient anatomic change in the static position—in natural sleep—of the genioglossus,
genioglossus, and diaphragmatic muscles to open the pharyngeal airway. This study is the first to describe the relationships between these muscle attachments to the mandible and may lead to the development of surgical techniques that will capture the muscle fibers more accurately, leading to more reproducible muscle capture for clinical effect. Further study is needed to describe the anatomic and functional relationships of the pharyngeal muscles and mandible as well as their implications in OSA surgery.

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The authors thank research subjects and all those who donate their bodies to further science and medical education.

BIBLIOGRAPHY