Quantification of Injection Force Mechanics During Injection Laryngoplasty

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Objectives: In-office or operative injection laryngoplasty requires needle stability for accurate material placement. To date, no reports compare injection forces based on needle gauge, bends, length, or material type or temperature. We hypothesize these factors alter injection forces and could impact clinical use.

Methods: Swine larynges were placed in a compression testing machine. Syringes were affixed to a stabilizing crossbeam. Straight needles (25G 1.5-inch; 27G 1.25-inch; or 9.8-inch malleable shaft 16G per oral with 24G tapered needle tip) were inserted into the swine vocal folds to simulate realistic tissue resistance pressure. Compressive loading was conducted at 40 mm/minute until steady-state force was achieved. Tests were completed with calcium hydroxylapatite (CaHa), carboxymethylcellulose, and hyaluronic acid at various temperatures and CaHa with various bends in the needles (n = 3 per group, comparisons performed by two-way analysis of variance (ANOVA), Tukey’s post-hoc).

Results: Needle size, shape, and temperature altered injection force. Steady-state force was highest with the per-oral needle at a mean of 44.55N compared to 26.44N and 29.77N in the 25G and 27G percutaneous needles, respectively (P < 0.001). Stiffness rate (initial increasing force vs. distance to initiate injection) ranged from 19.75N/mm (per oral) to 22.06N/mm (25G) to 24.56N/mm (27G), (P = 0.875). Adding multiple bends to the per-oral needle increased stiffness rate to 24.99N/mm (P = 0.035), whereas the 25G needle stiffness rate remained unchanged (P = 0.941), with the stiffness rate decreasing in the 27G needle with increasing bends (P = 0.033). Increased temperature decreased injection forces across all materials.

Conclusion: Needle caliber, length, and bends impact steady-state forces and stiffness rates during vocal fold injection.

Key Words: Injection laryngoplasty, vocal fold injection, injection augmentation, mechanics.

Level of Evidence: NA

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INTRODUCTION

Injection laryngoplasty is a common procedure performed in otolaryngology practices in both office and operative settings.1,2 Vocal fold injection of either temporary or long-lasting substances aims to address glottal insufficiency secondary to vocal fold immobility or atrophy that contribute to dysphonia, dysphagia, and aspiration.2-4 The procedure involves injecting a viscous bulking agent into the vocalis muscle to improve glottal closure.2 Voice outcomes from injection augmentation rely heavily on the volume and precise location of injected substances, which can be challenging to control due to the force required to inject a viscous substance through a small needle.2,5

Various materials and techniques are available for injection laryngoplasty in the clinic and operating room.6 Material and approach selection are based on the etiology of glottal insufficiency, patient anatomy, patient and surgeon preference, and the patient’s ability to tolerate in-office procedures.1,2 Commonly used injectables include carboxymethylcellulose (CMC), hyaluronic acid (HA), and calcium hydroxylapatite (CaHa). CaHa is considered a longer lasting material, whereas HA and CMC are used for temporary vocal fold augmentation.1 Each material has unique viscosity (temperature dependent) and resorption characteristics.7,8 To facilitate augmentation, it is common for the provider or an assistant to warm the CaHa syringe raises the temperature to roughly 31.5 °C in 15 minutes. This study examines material temperature through the use of a controlled water bath environment to uniformly heat materials, avoiding variability from holding syringes in a clenched hand.

There are several common approaches to injection laryngoplasty. In the operating room, the surgeon can inject under microscopic visualization or using an endoscope with the needle included with the injectable material. For in-office procedures, the clinician can use a per
oral, transthyrohyoid, cricothyroid, transcartilaginous, or transtracheal approach. Per-oral augmentations utilize a long needle included with the injectable, and neck-based approaches typically utilize a 25G or 27G needle at least 1.5 inches long, that is bent as needed to complete the augmentation.\textsuperscript{9,10} Bends in the injection needle could alter resistance force to move the material through the needle, impacting the stability of the syringe and needle during procedures. There are no existing studies that assess variations in injection force between materials, temperatures, or needle bends. The goal of this study was to investigate different factors that might modify the required injection forces for injection laryngoplasty. We compared injection forces based on needle caliber, bends, length, material type, and material temperature. Injection force differences across varying materials, needles and needle configurations, and temperatures are clinically relevant because both in-office or operative injection laryngoplasty require needle stability for accurate material placement.

**MATERIALS AND METHODS**

**Materials**

Three materials were tested: CaHA (Prolaryn Plus, Merz, Raleigh, NC), CMC (Prolaryn Voice Gel, Merz, Raleigh, NC), and HA (Restylane, Galderma Laboratories, Lausanne, Switzerland). For the purposes of the repetitive testing and the large number of samples required, recently expired injectables were used in the testing, with expiration dates within 18 months of use. Unexpired samples were used to complete room temperature testing to ensure mechanical values were within range of expired material properties.

**Needle Selection and Bends**

To recreate clinical injection scenarios, testing was completed with three common needles: 1) a rigid 16G 9.8-inch cannula with a 24G 0.394-inch 17-degree needle (long needle) that is supplied in Prolaryn (Merz) packaging; 2) a rigid 25G 1.5-inch injection needle with a Huber point, also supplied in Prolaryn (Merz) packaging; and 3) a 1.25-inch 27G needle. Each needle was initially tested in a straight configuration. In addition, the long cannula was also tested with a single bend toward the syringe to reflect injection in the operating room under binocular microscopy. The long rigid cannula was also tested in a multi-bend configuration common in per-oral injection. The short 25G and 27G needles were each also tested with a single bend near the syringe and then with another short bend toward the tip to account for the most common clinical techniques. Figure 1A and 1B illustrate bends and common angle measurements. Three samples were tested for each needle and bend combination using CaHa.

**Temperature**

To assess temperature-related viscosity changes to injection forces, each material was tested at room temperature (22°C). Samples were also tested at 30°C and 37°C after sealed syringes were warmed to the desired temperature in a beaker of distilled water heated on a hot plate for at least 15 minutes. Three samples of each material were tested at each of the selected temperature points.

**Sample Preparation and Placement**

To best simulate needle feedback and the clinical environment, swine larynges were prepared similarly to previous injection studies.\textsuperscript{2} Briefly, previously excised and frozen larynges were bisected in a sagittal plan while maintaining an intact anterior commissure. For testing, the samples were thawed at 4°C for 4 hours and then maintained at room temperature. The needle was carefully inserted in the vocal fold at the appropriate location and then secured to the testing fixture.

**Mechanical Testing**

The swine larynges were placed in a polylactic acid three-dimensional printed mold held by a clamp with both vertical and angular variability. Syringes were inserted into a crossbeam stabilized with two clamp holders and placed with the syringe plunger directly beneath the upper component of the compression machine (MTS Insight 5, Eden Prairie, MN). The platform base was clamped to the machine with an extended metal platform (Fig. 2). Syringe stability in the testing platform was confirmed, and then the syringe plunger was compressed at 40 mm/minutes (approximately half of the syringe in 30 seconds, which is a similar rate to clinical application). In preliminary setup testing, the experimental endpoint was visually determined as the load stabilized following the initial load required for material injection, which occurred within 6 mm of travel. The plunger travel distance required to reach a steady-state load (the load during consistent injection of the material) was calculated and is equivalent to the distance the plunger must move into the syringe before the force provided by the surgeon is consistent.
and the flow of the material is constant. The initial stiffness (rate to steady state) was calculated as the slope of the linear region of the load displacement curve. This represents the force required in compression on the plunger to overcome the resisting force of the material. In other words, the stiffness is amount of resistance the material creates compared to how far the plunger is displaced to start ejecting the material from the syringe. The maximum load overall and difference between the maximum load and the steady-state load were measured as well, which gives information about the maximum amount of work required by the surgeon to start the injection and then maintain a steady injection.

**Statistical Analysis**

Differences among tests were identified using two-way analysis of variance (ANOVA) (comparing across needle type and orientation) followed by post hoc Tukeys test ($P < 0.05$) to examine the effects of the three needle types, various bends, and the interaction of these variables on the injection mechanics. A standard or Kruskal Wallis one-way ANOVA (to compare across temperatures within a material) test with post hoc Tukey testing was completed, with significant differences noted at $P < 0.05$ (sample size $n = 3$). Effect size was calculated by the division of the variable sum of squares, with the total sum of squares for all tests within the normally distributed ANOVA tests and with the $H$ value for the Kruskal Wallis test. All results are reported as mean ± standard error, and all statistically significant findings are reported as ($P$ value, effect size).

**RESULTS**

Results are separated into needle bend effects, needle size effects, and the impact of material temperature on injection forces. Results are summarized in Table I (needle bends and sizes) and Table II (temperature effects and expired vs. unexpired). The different orientations (straight vs. bent needles) had specific effects on injection mechanics. In a straight orientation, the 25G 1.5-inch needle had a higher maximum load, 27.29 ± 0.59N, than the bent orientations of the same needle ($P < 0.001, 0.687$) (Fig. 3A); and the straight orientation had a higher steady-state load, 26.44 ± 0.91N, than two bends ($P < 0.001$) and one bend ($P = 0.002, 0.588$) (Fig. 3B). When evaluating the long needle, it exhibited a lower required maximum load, 41.61 ± 0.25N, when it was bent twice compared to the straight or single bend orientations ($P < 0.001, 0.687$) (Fig. 3A). The long cannula with two bends also had a lower steady-state load, 41.41 ± 0.23N, than the single bend ($P < 0.001$) and straight ($P = 0.002, 0.588$) orientations (Fig. 3B). Lastly, the long needle with two bends had greater stiffness, 24.99 ± 1.27 N/mm than the straight needle ($P = 0.035, 0.168$) (Fig. 3C). For the 27G 1.25-inch needle, the two-bend orientation had a lower stiffness, 19.25 ± 0.69N/mm, than the one bend ($P = 0.028$) and straight ($P = 0.033, 0.168$) orientations (Fig. 3C).

Different needle types also influenced injection mechanics independent of needle orientations. Specifically, each needle type had a different maximum load,

<table>
<thead>
<tr>
<th>Needle Type</th>
<th>Orientation</th>
<th>Maximum Load (N)</th>
<th>Steady State Load (N)</th>
<th>Stiffness (N/mm)</th>
<th>Distance to Steady State (mm)</th>
<th>Max Minus Steady Load (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27G 1.25in</td>
<td>Straight</td>
<td>29.94 ± 0.06</td>
<td>29.77 ± 0.09</td>
<td>24.56 ± 1.51</td>
<td>2.19 ± 0.36</td>
<td>0.17 ± 0.04</td>
</tr>
<tr>
<td>27G 1.25in</td>
<td>1 Bend</td>
<td>30.38 ± 0.09</td>
<td>30.11 ± 0.12</td>
<td>24.71 ± 1.01</td>
<td>2.18 ± 0.36</td>
<td>0.27 ± 0.03</td>
</tr>
<tr>
<td>27G 1.25in</td>
<td>2 Bends</td>
<td>30.55 ± 0.76</td>
<td>30.08 ± 0.47</td>
<td>19.25 ± 0.69</td>
<td>2.82 ± 0.51</td>
<td>0.48 ± 0.29</td>
</tr>
<tr>
<td>25G 1.5in</td>
<td>Straight</td>
<td>27.29 ± 0.59</td>
<td>26.44 ± 0.91</td>
<td>22.06 ± 1.85</td>
<td>2.22 ± 0.22</td>
<td>0.85 ± 0.35</td>
</tr>
<tr>
<td>25G 1.5in</td>
<td>1 Bend</td>
<td>24.10 ± 0.68</td>
<td>23.19 ± 0.46</td>
<td>22.84 ± 0.82</td>
<td>1.53 ± 0.1</td>
<td>0.91 ± 0.37</td>
</tr>
<tr>
<td>25G 1.5in</td>
<td>2 Bends</td>
<td>23.06 ± 0.16</td>
<td>22.83 ± 0.23</td>
<td>22.70 ± 1.19</td>
<td>1.48 ± 0.1</td>
<td>0.23 ± 0.07</td>
</tr>
<tr>
<td>Long</td>
<td>Straight</td>
<td>45.34 ± 0.89</td>
<td>44.55 ± 1.15</td>
<td>19.75 ± 2.14</td>
<td>2.36 ± 0.23</td>
<td>0.78 ± 0.26</td>
</tr>
<tr>
<td>Long</td>
<td>1 Bend</td>
<td>46.65 ± 0.15</td>
<td>46.16 ± 0.14</td>
<td>24.58 ± 1.05</td>
<td>1.96 ± 0.08</td>
<td>0.49 ± 0.03</td>
</tr>
<tr>
<td>Long</td>
<td>2 Bends</td>
<td>41.61 ± 0.25</td>
<td>41.41 ± 0.23</td>
<td>24.99 ± 1.27</td>
<td>1.85 ± 0.02</td>
<td>0.21 ± 0.03</td>
</tr>
</tbody>
</table>

Data presented as Mean ± standard error of the mean.
with the long needle requiring a higher load than the 27G 1.25 inch, which in turn was higher than the 25G 1.5 inch (\( P < 0.001, 0.993 \)) (Fig 3A). Specifically, in the straight configuration, the long needle maximum load, 45.34 ± 0.89N, was higher than the two other needles (\( P < 0.001, 0.993 \)), and the maximum load observed with the 27G 1.25 inch, 29.94 ± 0.06N, was different compared to the maximum load of the 25G 2-inch needle, 27.29 ± 0.59N (\( P = 0.004, 0.993 \)). The steady-state loads of all needles followed the same trends as the maximum

### TABLE II.
Summary of the Loads and Travel Distance Measurements for the Various Materials Evaluated and Testing Temperatures

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature (^{\circ}C)</th>
<th>Maximum Load (N)</th>
<th>Steady State Load (N)</th>
<th>Stiffness (N/mm)</th>
<th>Distance to Steady State (mm)</th>
<th>Max Minus Steady Load (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaHA</td>
<td>22</td>
<td>20.35 ± 0.73</td>
<td>19.56 ± 0.75</td>
<td>20.09 ± 1.46</td>
<td>1.15 ± 0.02</td>
<td>0.79 ± 0.08</td>
</tr>
<tr>
<td>CaHA</td>
<td>30</td>
<td>20.37 ± 0.63</td>
<td>19.56 ± 1.14</td>
<td>25.12 ± 3.4</td>
<td>0.85 ± 0.03</td>
<td>1.11 ± 0.52</td>
</tr>
<tr>
<td>CaHA</td>
<td>37</td>
<td>18.98 ± 0.3</td>
<td>18.19 ± 0.69</td>
<td>22.94 ± 4.54</td>
<td>0.92 ± 0.03</td>
<td>0.79 ± 0.45</td>
</tr>
<tr>
<td>CMC</td>
<td>22</td>
<td>23.65 ± 0.5</td>
<td>22.99 ± 0.36</td>
<td>15.55 ± 0.46</td>
<td>1.58 ± 0.08</td>
<td>0.67 ± 0.26</td>
</tr>
<tr>
<td>CMC</td>
<td>30</td>
<td>21.76 ± 0.28</td>
<td>21.22 ± 0.27</td>
<td>20.35 ± 4.51</td>
<td>1.36 ± 0.25</td>
<td>0.47 ± 0.07</td>
</tr>
<tr>
<td>CMC</td>
<td>37</td>
<td>21.76 ± 1.1</td>
<td>20.61 ± 0.98</td>
<td>20.51 ± 3.9</td>
<td>1.18 ± 0.15</td>
<td>1.15 ± 0.77</td>
</tr>
<tr>
<td>HA</td>
<td>22</td>
<td>14.86 ± 0.05</td>
<td>14.32 ± 0.09</td>
<td>10.91 ± 0.82</td>
<td>1.36 ± 0.08</td>
<td>0.55 ± 0.04</td>
</tr>
<tr>
<td>HA</td>
<td>30</td>
<td>15.69 ± 0.15</td>
<td>14.79 ± 0.16</td>
<td>16.86 ± 0.85</td>
<td>0.98 ± 0.06</td>
<td>0.90 ± 0.04</td>
</tr>
<tr>
<td>HA</td>
<td>37</td>
<td>14.77 ± 0.16</td>
<td>14.27 ± 0.14</td>
<td>15.17 ± 0.2</td>
<td>1.51 ± 0.35</td>
<td>0.51 ± 0.01</td>
</tr>
<tr>
<td>CaHA - unexpired</td>
<td>22</td>
<td>20.9 ± 0.18</td>
<td>20.5 ± 0.15</td>
<td>17.7 ± 0.34</td>
<td>1.24 ± 0.04</td>
<td>0.35 ± 0.10</td>
</tr>
<tr>
<td>CMC - unexpired</td>
<td>22</td>
<td>20.6 ± 0.31</td>
<td>20.4 ± 0.31</td>
<td>13.8 ± 0.26</td>
<td>1.55 ± 0.02</td>
<td>0.23 ± 0.02</td>
</tr>
<tr>
<td>HA Restalyne - unexpired</td>
<td>22</td>
<td>17.11 ± 0.29</td>
<td>16.58 ± 0.27</td>
<td>14.07 ± 0.19</td>
<td>1.49 ± 0.10</td>
<td>0.54 ± 0.03</td>
</tr>
</tbody>
</table>

Data presented as mean ± standard error of the mean.

Fig. 3. The (A) maximum load, (B) steady-state load, (C) stiffness “rate,” (D) maximum minus steady-state load data, and (E) distance to steady-state load are displayed for the comparison of specific needles among the three orientations. Significant differences are denoted by (*) for significantly different from all other needle orientations within the same needle type, by (#) for main effects of significant differences between needle types irrespective of needle orientation, and by (@) for significant differences between individual configurations indicated. All differences are significant at \( P < 0.05 \). [Color figure can be viewed at www.laryngoscope.com.]
loads ($P < = 0.001, 0.991$). The stiffness was different only between the long, $24.99 \pm 1.27$ N/mm, and $27G$ 1.25-inch needles, $19.25 \pm 0.69$ N/mm, when the needles were bent twice ($P = 0.021, 0.015$) (Fig 3C). The $27G$ 1.25-inch needle had a higher distance to steady-state value with two bends, $2.82 \pm 0.51$ mm, than the $25G$ 1.5-inch needle, $1.48 \pm 0.10$ mm ($P = 0.007, 0.329$) (Fig. 3E).

Mechanical evaluation of the three materials at different temperatures produced consistent trends with a few differences. The HA group at $30\, ^\circ C$ produced a higher maximum load, $15.69 \pm 0.15$ N, than the other temperatures of HA, $22\, ^\circ C$ ($P = 0.009$) and $37\, ^\circ C$ ($P = 0.005, 0.840$) (Fig. 4A). Steady-state loads were similar within each material regardless of temperature (Fig. 4B). The HA stiffness at $22\, ^\circ C$, $10.91 \pm 0.82$ N/mm, was less than the other HA temperature groups of $30\, ^\circ C$ ($P = 0.002$) and $37\, ^\circ C$ ($P = 0.012, 0.867$) (Fig. 4C). Similar to the maximum load, the $30\, ^\circ C$ HA group had significant differences in maximum minus steady-state loads ($P < 0.001, 0.943$) (Fig 4D). The distance to steady-state load decreased with increased temperature, except within the HA group at $37\, ^\circ C$ (Fig 4E). This trend was also observed in the stiffness or “rate to steady state” data (Fig. 4C). Expired and unexpired materials were compared at room temperature ($22\, ^\circ C$) to ensure the range of values of expired materials encompassed the unexpired material values. This is shown in Table II and is true for the maximum load, stiffness, and steady-state loads. Although the maximum minus steady-state load ranges were different, this is not concerning because these values are dependent on the maximum and steady loads, which were within the same ranges.

**DISCUSSION**

Although injection laryngoplasty is commonly performed via multiple different effective approaches, no evidence on injection force differences between materials, needle orientations, or temperature exists.2,9,11 This study quantified the impact of variables in vocal fold augmentation procedures on injection forces and found that temperature, needle selection, and needle bends all impart changes to injection forces during vocal fold augmentation that ultimately contribute to needle stability during injection laryngoplasty. It also confirmed the long-held belief that increasing material temperature lowers material resistive forces at the onset of augmentation, making it easier for the surgeon to inject the material.

The long 9.8-inch cannula with a 24G needle (long needle) included in the CMC and CaHa commercial packaging is the most commonly used needle for injection, used for per-oral and operative approaches.1,2,12 The long needle had higher maximum and steady-state injection forces in all orientations compared to the other needles. As illustrated in Figure 3C, the long needle had a higher stiffness rate with two bends, making it more difficult to overcome material resisting force at the onset of augmentation. This suggests the greatest force required to perform injection laryngoplasty is through a long needle at the onset of augmentation in the per-oral bent configuration, challenging the provider to maintain needle stability and avoid injecting material in the incorrect location or depth. Conversely, the $27G$ 1.25-inch needle had a greater stiffness in the straight orientation than when bent twice. This could be due to the small diameter and
short length of the needle not having as much of an effect on the pressure required for ejection and the bends reducing inner needle volume to reach the sample without as much variation in diameter. The finding of bends creating altering injection forces could lead to advancements in needle design.

The 27G 1.25-inch and 25G 1.5-inch needles tested are commonly used in neck-based approaches.\textsuperscript{2,3,9,11,12} The 25G needle tested comes packaged in the CMC and CaHa boxes. These neck approaches are performed in clinic under local anesthesia with visualization via videolaryngoscopy. Rosen et al., Amin, and Achkur have all described in-office injection laryngoplasty techniques that utilize different needle orientations and calibers, each with successful results.\textsuperscript{2,9–11} Results from this investigation suggest that the 27G 1.25-inch needle requires a higher steady-state force than the 25G 1.5-inch needle in all orientations ($P \leq 0.001$), suggesting that it is more difficult to inject the material through a smaller needle. Additionally, the 27G 1.25-inch needle with two bends had a higher distance to achieve steady state, which clinically is the length of time required to get material moving as compared to the 25G 1.5-inch needle ($P = 0.007$). Overall, the 25G 1.5-inch unbent needle required the least injection force, which is indicative of its larger diameter without changes induced from bending.

Previous material studies determined injection forces above 100N are an impractical level of required force for a simple injectable system.\textsuperscript{13–15} With smaller forces than 100N recorded for all systems evaluated in this study, the accumulation of pressure and poor feedback from injection resistance confound hand-operated injection even with smaller force values because visualization under the microscope blinds the user to the injection hand and disrupts stability necessary to ensure proper placement of the material to avoid tissue scarring or suboptimal outcomes.\textsuperscript{16} Due to these considerations, there has been recent interest in the development of assistive pneumatic dispensing devices.\textsuperscript{17} To that end, the findings of this study have the potential to improve the feedback controls on such devices and enhance their function to actively sense material injection by providing an understanding of needle orientation and material behavior-based changes in injection forces.

CaHa, HA, and CMC are three of the most commonly used materials for these procedures.\textsuperscript{12} A recent review showed that CaHA and CMC are the most commonly injected substances in the operating room (used in 36% and 35% of the cases, respectively) and in-office (26% and 35%, respectively) settings.\textsuperscript{12} It has also been noted in a recent clinical prospective study that there were pressure-based concerns in the use of CaHA to treat glottal closure insufficiency, which resulted in injected material backing out with the needle or rupturing through tissue in some cases.\textsuperscript{18} Whereas material backing out was not observed in our testing, a better understanding of injection mechanics and the effects of needle orientation and material temperature characteristics might better inform clinical use of these materials. These materials vary in their resorption rate and viscosity, with HA being the least viscous material, easiest to inject, and becoming progressively more viscous and longer acting from CMC to CaHA.\textsuperscript{8,19} Our results identified that HA requires the least amount of force to complete the injection from start to finish. These materials were also compared at room temperature (22 °C) and at two prewarmed temperatures (30 °C and 37 °C).

Increased material temperature, often just by holding the product in a clenched fist, is commonly done to ease injection resistance. This study quantitatively confirms that hypothesis because the distance to reach the steady state decreased with increasing temperatures across all materials, meaning that prewarming made it easier to overcome the resisting forces of the materials. Material viscosity, or its inherent resistance to flow, has a known temperature correlation, which held true in the decreased overall resisting force for injection in the augmentation materials tested with increased temperature. Contrary to overall resistive force, stiffness appeared to increase with increased temperature. This finding could be attributed to frictional changes caused by material temperature variation in the primed needle and syringe as well as the temperature of the syringe itself. These interactions could cause variations in stiffness that equilibrate as the material begins to flow, leading to a lower steady-state load at higher temperatures consistent with the change in viscosity.

A recent study tracked patient pain levels during and following in-office procedures and suggested that stretched tissues may cause increased or longer durations of pain.\textsuperscript{20} The ability to harness the findings of this study to produce streamlined injection procedures may reduce procedural time and stretching or damage to surrounding tissue from efforts to maintain needle stability during injection laryngoplasty. These results may also translate to other procedures that use these materials.

This study had some limitations. Second to the large number of required testing conditions, expired augmentation materials recently were employed. To avoid confounding results, available unexpired samples were tested for each material in a straight needle system at 22 °C. This was completed to show that the unexpired data gives a representative view of the materials used, but future testing should be completed to determine exact values of the unexpired materials using the different needles, orientations, and temperatures. The values for the unexpired materials were within the range of values by the expired materials for maximum load, stiffness, and steady-state load.

Additionally, although the needle for each test was appropriately placed in a swine larynx, any real-life increased force necessary to expel cartilage or tissue clogging the needle was not tested. Furthermore, a commonly encountered situation in injection augmentation is an off-axis vector of force from the finger creating increased forces in the flexible syringe plunger, particularly at the beginning of an injection. Despite these limitations, this study identified differences in injection forces between materials, temperature, and needle size and configuration worth consideration in selection of technique and development of new materials and approaches.
CONCLUSION

Temperature, material selection, and bends within a needle all impact necessary injection forces during vocal fold augmentation. As new materials and approaches for vocal fold augmentation continue to be identified, efforts should be made to minimize necessary injection forces to optimize ease of augmentation.

BIBLIOGRAPHY