Rethinking Nasal Tip Support: A Finite Element Analysis

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Objective: We employ a nasal tip finite element model (FEM) to evaluate contributions of two of the three major tip support mechanisms: attachments between the upper and lower lateral cartilages and attachment of the medial crura to the caudal septum.

Study Design: The nasal tip FEM computed stress distribution and strain energy density (SED) during nasal tip compression. We examined the impact of attachments between the upper and lower lateral cartilages and the attachment of the medial crura to the caudal septum on nasal tip support.

Methods: The FEM consisted of three tissue components: bone, cartilage, and skin. Four models were created: A) control model with attachments present at the scroll and caudal septum; B) simulated disruption of scroll; C) simulated disruption of medial crura attachments to caudal septum; and D) simulated disruption of scroll and medial crura attachments to caudal septum. Spatial distribution of stress and SED were calculated.

Results: The keystone, intermediate crura, caudal septum, and nasal spine demonstrated high concentration of stress distribution. Across all models, there was no difference in stress distribution. Disruption of the scroll resulted in 1% decrease in SED. Disruption of the medial crura attachments to the caudal septum resulted in 4.2% reduction in SED. Disruption of both scroll and medial crural attachments resulted in 9.1% reduction in SED.

Conclusion: The nasal tip FEM is an evolving tool to study structural nasal tip dynamics and demonstrates the loss of nasal tip support with disruption of attachments at the scroll and nasal base.

Key Words: Nasal tip support, rhinoplasty, finite element method.

Level of Evidence: N/A

INTRODUCTION

In rhinoplasty, maintaining nasal tip support is important in order to achieve long-lasting aesthetic and functional outcomes. In 1969, Anderson published the “the nasal tripod” as a paradigm to describe how structure relates to tip projection and rotation.¹ Janeke and Wright investigated nasal tip support from a static structural perspective, introducing the concept of “support mechanisms” of the nasal tip.² These included the following: 1) the ligamentous attachments between the upper and lower lateral cartilages; 2) the sesamoid complex expanding the support of the lateral crura to the pyriform aperture; 3) the ligamentous connections between the paired domes of the lower lateral cartilages; and 4) the attachment of the medial crura to the poste-
MATERIALS AND METHODS

Creation of the Digital Nasal Model

This study was performed in accordance with the guidelines of the institutional review board at the University of California, Irvine. A multicomponent FEM of a human nose was derived from a maxillofacial CT scan (1-mm axial resolution). Using thresholding functions in Mimics (Materialize; Plymouth, MI), bone and soft tissue components were created. Cartilaginous components with connections between the caudal border of the upper lateral cartilages and the cephalic border of the lower lateral cartilages (i.e., scroll region) and at the junction of the caudal septum and medial crura (i.e., nasal base) were customized to this patient-specific model’s soft tissue anatomy (Fig. 1) in a manner described previously.10

Simulated Disruption of Scroll and Caudal Septum Attachments

The three-dimensional editing function in Mimics was used to remove the intercartilaginous connections at the scroll region as well as the caudal septum/media crura. Four models were created, as shown in Figure 2: A) a control model with intercartilaginous connections present at the scroll and caudal septum; B) simulated disruption of scroll connections; C) simulated disruption of medial crura attachments to the caudal septum; D) simulated disruption of scroll connections and medial crura attachments to the caudal septum (i.e., complete disarticulation of lower alar cartilage from upper lateral cartilage and septum).

Assignment of Material Properties

The bone, skin, and cartilage components were assembled into finite element models in COMSOL Multiphysics (COMSOL, Los Angeles, CA) and assigned linear elastic properties for skin, cortical bone, and cartilage. Physical properties of skin, including the mass density and Poisson’s ratio, were approximated and applied to the soft tissue envelope.10 Articular cartilage mechanical properties were used in this model due to the limited quality of the data on the mechanical properties of nasal cartilage. Cartilage was considered a viscoelastic material. The intercartilaginous connections were assigned the same properties as all other nasal cartilages.

Simulation of Nasal Tip Depression and Analysis

Each model was assigned a 1-cm² region on the anterior most portion of the nasal tip, whereupon tip depression (palpation) was simulated. In these simulations, the boundary conditions were such that the posterior wall of the bone component was fixed in space, whereas the overlying cartilage and skin envelope were free to move. A 5-mm posterior displacement of the nasal tip was prescribed and the resulting von Mises stress distribution was calculated for all models, as shown in Figure 3. Von Mises stress is a scalar value that combines the principal stresses in all three dimensions. Based on the von Mises yield criterion, a material will fail when the von Mises stress exceeds the yield stress of the material. This is commonly used in finite element analysis to identify key load-bearing regions and areas in which a material will fail within a structure. Additionally, the relative change in strain energy density of the nasal cartilages was calculated to see the amount of energy that is transferred onto the cartilage undergoing tip depression. Percent change in strain energy density compared to the control was calculated with the following formula: (Control – Experimental)/(Control) × 100%.

RESULTS

von Mises Stress Distribution

Simulation of mechanical tip depression (palpation) on the control model (scroll and medial crura-caudal septum attachments intact) is shown in Figure 4. Regions with relatively high concentration of stress distribution are shown in red, indicating key load-bearing regions. The keystone, intermediate crura, caudal septum, and nasal spine were identified as key anatomical load-bearing regions.

TABLE I. Major and Minor Nasal Tip Support Mechanism.

<table>
<thead>
<tr>
<th>Major Tip Support Mechanisms</th>
<th>Minor Tip Support Mechanisms</th>
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<tbody>
<tr>
<td>Connections between the upper lateral cartilages and the lower lateral cartilages (i.e., scroll region)</td>
<td>Interdomal soft tissue</td>
</tr>
<tr>
<td>Connections between medial crura of the lower lateral cartilages to the caudal septum</td>
<td>Cartilaginous dorsal septum</td>
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<tr>
<td>Alar cartilage size and shape</td>
<td>Soft-tissue sesamoid complex</td>
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<td>Alar cartilage attachment to skin and soft tissue</td>
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<td></td>
<td>Nasal spine</td>
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<td></td>
<td>Membranous septum</td>
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Fig. 1. Composite finite element model (FEM) of the nose with bone, cartilage and skin soft tissue envelope. Cartilaginous components inserted connecting the caudal border of the upper lateral cartilages and the cephalic border of the lower lateral cartilages (i.e., scroll region), and connecting the caudal septum and lower lateral cartilage medial crura. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]
bearing regions. Across all other models, there was no difference in the distribution of stress in response to mechanical tip depression (Fig. 5).

Changes in Strain Energy in Response to Mechanical Tip Depression

The strain energy density of the nasal cartilages decreased with the elimination of intercartilaginous connections. Across all other models, there was no difference in the distribution of stress in response to mechanical tip depression (Fig. 5).

Fig. 2. Four models with intact and disrupted major tip support mechanisms: (A) control model with intercartilaginous connections present at the scroll and caudal septum; (B) simulated disruption of scroll connections; (C) simulated disruption of medial crura attachments to the caudal septum; (D) simulated disruption of both scroll connections and medial crura/caudal septum attachments. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

Fig. 3. Simulation of the effects of mechanical tip depression (palpation). A 5-mm posterior displacement of the nasal tip was prescribed, and the resulting von Mises stress distribution and strain energy density was calculated. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

Fig. 4. Simulation of mechanical tip depression on the control model with intact scroll and medial crura/caudal septum attachments. Regions with relatively high concentration of stress distribution in red indicating key load-bearing regions: the keystone, intermediate crura, caudal septum, and nasal spine. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]
connections following mechanical tip depression. Isolated disruption of the scroll region bilaterally showed the least reduction and resulted in a 1% decrease in strain energy density. By comparison, isolated disruption of the medial crura attachments to the caudal septum resulted in a 4.2% reduction in strain energy density. The greatest reduction in strain energy density was identified when both the scroll region and medial crural attachments were disarticulated, resulting in a 9.1% reduction (Fig. 5).

DISCUSSION

The FEM simulations identified a reduction in strain energy density, with disruption of the connections between the upper and lower lateral cartilages (i.e., the scroll region) and the attachment of the medial crura to the caudal septum—two of the traditional major tip support mechanisms described by Tardy and Brown. Strain energy density, the amount of energy required to perform nasal tip palpation, may be considered a surrogate for nasal tip support. Disruption of either connection resulted in alteration of the strain energy density of the nasal tip support. Disruption of either connection resulted in alteration of the strain energy density of the nasal tip. Additionally, there is a synergistic effect with disruption of both attachments together. Such findings have significant clinical implications because the transfixional and intercartilaginous incisions during endonasal rhinoplasty sever tissue in both these regions.

Disruption of the attachments of the medial crura to the caudal septum (i.e., nasal base or pedestal) resulted in relatively greater alteration in the strain energy density of the nasal tip compared to disruption of the connections at the scroll region. Therefore, one may infer that the attachment of the medial crura to the caudal septum may be a more important tip support mechanism. This observation echoes Toriumi’s clinical dictum that “stabilizing the base of the nose” is essential prior to performing more nasal tip maneuvers during rhinoplasty.12 Base-stabilizing maneuvers are designed to counter gravitational and scar contracture forces, which over time act to diminish tip projection. They function via reestablishing or augmenting the mechanical relationship between the medial crura and the caudal septum (suturing medial crura to septum, tongue in groove techniques, septal extension grafting) or by adding a vertical post to enhance load-bearing capabilities of the medial crura (columellar strut graft).

Dobratz et al.13 examined the efficacy of these maneuvers in reestablishing the nasal base and maintaining tip support. They performed an open rhinoplasty, cadaveric study with an adjustable tensometer to measure the change in nasal tip support after performing different nasal base-stabilizing maneuvers. Sutures alone provide the least resistance to displacement, followed by the columellar strut graft. The septal extension graft and tongue in groove technique offered the highest resistance to tip displacement and even provided more resistance than the preoperative state. Similarly, Beaty et al.14 also reported the columella/nasal base as the region most resistant to compression compared to the lateral crura and nasal dorsum, using a tensogrometer that measures the resistance of the nasal tip to deformation. These studies further support that the nasal base and its attachments are key contributors to nasal tip support.

A notable shortcoming of this model includes assigning the scroll and nasal base connections with the same physical properties as the nasal cartilages. There are conflicting descriptions of the composition of these attachments. For instance, Han et al.15 describes the scroll connections as a “ligament,” whereas Janeke and Wright2 describe the connection as a “fibrous attachment,” and Gunter16 describes the scroll connections as “connective tissue.” Moreover, the connections at
the nasal base are even more controversial. Janeke and Wright\(^2\) suggested that a “thin and loose connection” exists between the medial crus of the lower lateral cartilage and the caudal septum, whereas McCollough and Mangat\(^3\) reported that a “membranous attachment” exists in this structure. Kridel et al.\(^17\) reported the existence of a ligamentous attachment, whereas Daniel and Letourneau\(^18\) and Han et al.\(^15\) reported that no direct attachment exists between the medial crura and the caudal septum. It is worth mentioning, however, that Han et al. examined an Asian population with a platyrhinine nasal tip that is wider and less projected than the more leptorrhine nasal tip described in our model. This may be attributed to the platyrhinine’s deficient attachment at the nasal base, with more prominent footplate segments of the medial crurs compared to the columnellar segments.\(^19,20\) Nonetheless, due to the lack of knowledge of the physical properties of the connections, we assigned the same properties as the cartilages. This may also explain the lack of discernible change of internal stress distribution in the experimental models.

This FEM simulated how stress changes in the nasal tip following various commonly performed rhinoplasty maneuvers. Previously, Manuel et al.\(^10\) examined the effects of excessive caudal septum resection on the remaining cartilage framework stress distribution using this FEM. Other FEM studies in progress in our laboratory are examining how cephalic trims producealar retraction and how the “inverted V” deformity is produced after separation of the upper lateral cartilages from the nasal septum. In this study, we extended our previous models’ complexity by adding the connections at the nasal base and the scroll region. This updated FEM was used to investigate traditional tip support theory by simulating the disruptions of the scroll and nasal base attachments. The ultimate goal of such studies is to simulate patient-specific nasal surgery and possibly provide insight into potential long-term outcomes following surgery. Rather than manipulating just the skin contour, as in current digital imaging software packages, developing an anatomically accurate computational model for each may provide a means to obtain an accurate representation of both short- and long-term results following surgery.

The present study reinforces the importance of Tardy’s nasal tip support mechanisms and illustrates the relatively greater importance of medial crura-septal connections over the contributions of the scroll.

CONCLUSION

Based on our simulations, disruption of the attachments at the scroll and the attachment of the medial crura to the caudal septum leads to loss of nasal tip support. The attachment of the medial crura to the caudal septum plays a more prominent role in nasal tip support. The nasal tip FEM is a promising approach to study structural nasal tip dynamics.

Acknowledgments

We would like to acknowledge Anthony Chin Loy, MD, and Julia Kimbell, PhD, for their valuable contributions to this project. Without them, this would not have been possible.

BIBLIOGRAPHY