EXPERIMENTAL LAB RESEARCH

Comparison of the effectiveness of three different rhinoplasty techniques to correct stenotic nostrils using silicone models: A case study

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Abstract

Objective: To compare the effects of three different rhinoplasty techniques on the postoperative cross-sectional areas (CSAs) of the nares and nasal vestibuli.

Study design: Experimental study.

Sample population: Ninety-nine 3D-printed, remolded silicone models of a single French bulldog’s rostral nose.

Methods: Models were fabricated based on a computed tomographic (CT) scan of the nose of a French bulldog with moderately stenotic nares. Each model underwent either vertical wedge resection (VW), modified horizontal wedge resection (MHW), or ala-vestibuloplasty (AVP) performed by a single surgeon (n = 33 per group). Preoperative and postoperative CT scans of the models were performed, and CSAs of the airway from the nares to the caudal end of the nasal vestibule were calculated.

Results: All three rhinoplasty techniques increased CSAs (adjusted p values <.001) but to different levels caudally within the nasal vestibule. Vertical wedge resection achieved this up to the start of the alar fold, MHW up to halfway between the nares and the alar fold and AVP up to the caudal nasal vestibule. Average percentage increases in CSA were 26%, 15% and 74%, respectively. Ala-vestibuloplasty led to larger CSAs than VW and MHW from the nares to the caudal nasal vestibule (adjusted p values <.05). The proportional difference within each technique was <7%.

Conclusion: Ala-vestibuloplasty resulted in a larger increase in the airway CSA of silicone modeled nares and nasal vestibules of a single French bulldog in comparison with VW and MHW.

Abbreviations: AVP, ala-vestibuloplasty; BOAS, brachycephalic obstructive airway syndrome; CSA, cross-sectional area; CT, computed tomography; MHW, modified horizontal wedge resection; VW, vertical wedge resection; 3D, three-dimensional.

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1 | INTRODUCTION

Stenotic nares are a common feature of brachycephalic obstructive airway syndrome (BOAS), reportedly present in 50%–85% of affected dogs. Addressing this lesion surgically has been shown to improve patient outcomes. A number of surgical techniques to correct stenotic nares have been described, with good subjective outcomes reported. Commonly used rhinoplasty techniques such as vertical wedge resection, modified horizontal wedge resection, and ala-vestibuloplasty are intended to decrease airflow resistance by increasing the cross-sectional areas (CSAs) of the nares and nasal vestibules. The surgical technique that increases the diameter of the nasal aperture the most will be associated with the greatest reduction in resistance to airflow and will therefore be the most effective. Most techniques target the stenotic external nares but it has been suggested that ala-vestibuloplasty also achieves an increase in diameter at the stenosis caused by the obstructive alar fold within the nasal vestibules of many BOAS-affected dogs. As far as the authors are aware there is no evidence to support the superiority of any one technique. This lack of evidence compromises the veterinary surgeon’s ability to make an informed decision regarding which rhinoplasty technique would be the most effective in dogs presenting with stenotic nares and nasal vestibules.

Rhinoplasties are rarely performed as the sole surgical technique in BOAS-affected dogs due to the multifaceted approach to the treatment of BOAS. Assessments of the effect of different rhinoplasty techniques using postoperative assessment, whether using subjective or objective outcome measures, are therefore confounded by the other procedures that are performed simultaneously. Three-dimensional (3D) printing has already been used to produce models that allow surgeons to practice surgical procedures prior to definitive surgery. The production of multiple exact replicas of an individual dog’s nose would allow for accurate comparison of different surgical techniques and enable assessment of the techniques without the confounding presence of other aspects of BOAS surgery having been performed.

This study aimed to compare nares and nasal vestibule CSAs following the application of three rhinoplasty techniques on silicone models. Based on clinical experience it was hypothesized that ala-vestibuloplasty would result in the largest postoperative CSAs at the nares and nasal vestibules when compared with vertical wedge resection and modified horizontal wedge resection.

2 | MATERIALS AND METHODS

2.1 Model fabrication

A computed tomographic (CT) scan of a French bulldog’s nose with moderately stenotic nares was obtained retrospectively and used for model fabrication. The CT was performed with a 16-slice multislice CT scanner (Aquilion 16; Toshiba America Medical Systems, Tustin, California). The images were acquired in helical mode, with a slice thickness of 0.5 mm. Tube rotation time was 0.5 s and KVP = 100, mAs = 150. The images were acquired with a bone algorithm (window width = 3500 Hounsfield units [HU], window level = 1500HU). The region of interest was defined as the “nares and nasal vestibule,” starting at the rostral most point of the nasal planum and ending at the first branch of the ventral nasal conchae. The raw multidetector CT bone algorithm datasets were imported into 3D image processing software (Stradview 6.1, University of Cambridge, Cambridge, UK). The images were windowed, and automatic binary segmentation of the cross-sections was achieved via application of a threshold to the CT slices (window center = 500 HU; window width = 4000 HU; threshold = −500 to 2500 HU), highlighting the soft tissues. A square region 5 mm outside the external edge of the soft tissue was selected manually. Using the automated functions within the software, maximal disc-guided interpolation was applied to generate surface interpolation between these cross-sections and triangulate surface mesh models. This created an inverse, virtual, 3D model of the original French bulldog nose, which would serve as a mold.

This mold was then imported into 3D image-editing software (Microsoft 3D builder, Redmond, Washington) and divided into three sections: a rostral section (Mold 1, Figure 1B,C), a middle section (Mold 2, Figure 1D,E), and a caudal section (Mold 3, Figure 1G). A fourth mold (Mold 2b, Figure 1F) was also created, which would fit the silicone model after it was removed from
Mold 1 and 2 and would allow Mold 3 to be applied to it. Connecting “arms” were added to Mold 2 and 3 to attach the airway region of the mold to the external structure (Figure 1D,G). Ten copies of each mold were printed using a desktop stereolithography 3D printer (Form2, Formlabs, Somerville, Massachusetts), Model Resin (V2, Formlabs) with a layer thickness of 0.050 mm. The molds were washed, and the supports removed manually. Two millimeter holes were drilled into the connecting “arms” of Mold 2 and 3 to reduce the formation of air bubbles when filled with silicone. The molds were filled with silicone sequentially and allowed to set, with each mold being placed on top of the previously set section. This was repeated until 99 remolded silicone models had been fabricated (Figure 1A,H,I,J).

2.2 | Surgical techniques

All models had one of three surgical techniques performed; vertical wedge resection (VW), modified horizontal wedge resection (MHW) or ala-vestibuloplasty (AVP) (n = 33 per group). The methods were performed sequentially in repeated groups of three, and all 99 simulated surgeries were performed by a single, right-handed Diplomate of the European College of Veterinary Surgeons (DECVS) familiar with all three techniques. Standard descriptions of each technique were read by the surgeon prior to performing the surgeries and access to these descriptions was available throughout (Video S1). The VW technique involved removing a triangular based pyramid of tissue from the ala nasi, and then suturing the defect closed with simple, interrupted sutures of...
4–0 nylon. The apex of the wedge was positioned slightly dorso-laterally to the dorsal limit of the nares and the surgeon aimed for the angle of the wedge to be ~70 degrees. However, this was not physically measured so that the clinical scenario could be simulated more accurately. A number 11 blade was used, and the entire cutting edge was inserted to standardize the depth of the incisions. The MHW involved removing a pyramid of tissue from the ala nasi with the base having a curved medial incision which followed the outer curvature of the ala nasi from its dorso-medial aspect to its ventro-lateral aspect. A number 11 blade was used and, once again, the entire cutting edge was inserted to ensure adequate and consistent depth. The defect was closed with simple, interrupted sutures of 4–0 nylon. The AVP involved removing the alar fold initially with a number 11 blade, once again inserted to its hub. The dorsal part of the alar fold was grasped with a pair of curved mosquito forceps (Freelance Surgical, Bristol, UK) and a horizontal incision was made at the level of ventral edge of the ala nasi, medially to laterally, severing the ventral attachment of the alar fold to the floor of the nasal vestibule. The dorsal part of the alar fold was rotated medially with the forceps, followed by a dorsoventral incision with the blade angled at 45 degrees medially, severing the lateral and caudal attachments of the alar fold. The ala nasi was then grasped with a curved mosquito forceps (Freelance Surgical) at the ventromedial edge and amputated by cutting across it from the dorso-medial most point of the external nares to its ventro-lateral aspect (~45 degrees). This technique involved no suturing.

2.3 | Data collection

All 99 models underwent CT preoperatively with the same settings as the original French bulldog, with a slice thickness of 0.5 mm. The raw multidetector CT bone algorithm datasets were imported into a three-dimensional image processing software (Stradview 6.1, University of Cambridge). Thresholds were applied to select the airway (window center = 3000 HU; window width = 1000 HU; threshold = <2641 HU), and the first slice in which the lateral slit terminated was identified (slice 14). Thirteen 0.5 mm slices rostrally and thirteen 1 mm slices caudally from this point had the cross-sectional area of the airway recorded, with right and left nasal airways being calculated separately. Regions of air within the model (i.e., air bubbles) that were selected but not connected to the main airway in each slice were removed manually. Where the airway was confluent with the external airspace (i.e., the edges of the lateral slit) a vertical end point was drawn manually from the lateral most point of the ala nasi to the floor of the nasal vestibule. Postoperatively each of the 99 models underwent repeat CT scanning, and the cross-sectional areas of the postoperative airways were calculated in the same manner as preoperatively. Once again, regions of air within the models that were not connected to the main airway within a single slice were manually removed. In the postoperative models, the removed areas included and air bubbles and the regions of excised tissue where the edges were not completely apposed.

2.4 | Statistical analysis

Preliminary power analysis was conducted using G*Power version 3.1.9.7 for sample-size estimation. The results indicated that the sample size required to achieve 80% power for detecting a medium to large effect (f = 0.35, the effect size was justified from a pilot study), at a significance criterion of alpha = .05, was N = 28 for a one-way ANOVA. The following statistical analyses were conducted in statistical package “R” (version 3.5.3). Estimations of reproducibility of the remolded silicone models were performed using R package “rptR,” and the reproducibility coefficients were calculated.

Wilcoxon signed rank exact tests were used to compare the absolute postoperative CSAs of the right nasal airway to that of the left nasal airway for each technique and further for each slice with Bonferroni corrections. The proportional differences between the right and the left nasal airway postoperative CSAs were calculated as 100*(right CSA-left CSA)/[(right CSA + left CSA)/2] (%).

The proportional differences in CSAs for all slices of postoperative models were calculated as: 100*[(postoperative CSA)–(preoperative CSA)]/(preoperative CSA) (%). An average proportional difference in CSAs were then calculated for each technique of each side. These data were then used to assess the intra-surgeon repeatability of each technique and side. Wilcoxon signed rank exact tests with Bonferroni corrections were used to assess the within-technique difference in CSAs between preoperative and postoperative data for the right and the left nasal airways separately.

Kruskal–Wallis tests followed by Dunn’s tests (p value adjusted with the Bonferroni method) were used to compare the postoperative CSAs of the three rhinoplasty techniques. Results were considered statistically significant when p < .05.

3 | RESULTS

The preoperative models had a high reproducibility coefficient of 0.957 (95% confidence interval [CI]: 0.923–
0.973) and 0.923 (95% CI: 0.87–0.952) for the right and left nasal airway CSAs, respectively. The comparisons between postoperative CSAs for the right and left nasal airways are as follows: for the VW technique, the absolute postoperative CSAs of the right nasal airway were larger than the left for all slices \((p < .05)\) except for slice 16 to slice 26. The average proportional difference in CSAs was 6 ± 16%. For the MHW technique, the absolute postoperative CSAs of the right nasal airway were larger than the left \((p < .01)\) for all slices except for slice 10 and slice 11, with an average proportional difference of 14 ± 14%. For the AVP technique, the proportional differences in CSAs of the right nasal airway were larger than the left \((p < .01)\) for all slices except for slice 18 to slice 34. The average proportional difference was 11 ± 11% (Figure 2). For assessing within-technique variation, the average proportional difference in CSA of the postoperative models within the VW, MHW, and AVP techniques was 7 ± 5%, 7 ± 4%, and 6 ± 2% for the right nasal airways respectively, and 7 ± 4%, 6 ± 3%, and 5 ± 1% for the left nasal airways, respectively (Figure 2).

In comparison with the preoperative models, VW increased the nasal airway CSAs from slices 1–13, MHW from slices 1–7, and AVP from slices 1–34 (adjusted \(p\) value <.001 for all of these slices) (Figures 2 and 3). The average postoperative increases in absolute CSA were 12.2 mm\(^2\) (range = 8.7–16.8 mm\(^2\)), 11.5 mm\(^2\) (range = 3.3–16.8 mm\(^2\)) and 20.1 mm\(^2\) (range = 4.8–28.0 mm\(^2\)) across each of these regions respectively. Average percentage increases in CSA across all slices were 26% (maximum change = 97% [slice 3]) for the VW, 15% (maximum change = 87%, slice 3) for the MHW and 74% (maximum change = 132%, slices 3 and 16) for the AVP. For the MHW technique, the nasal airway CSAs of slices 10–14 reduced in comparison with preoperative values with an average reduction in CSA of 7% (3.1 mm\(^2\); range = 1% [slice 14]–13% [slice 11]) (Figures 2 and 3). This finding was further supported by a single cadaveric study (Figure 4).

When comparing the postoperative CSAs between techniques, AVP had larger postoperative nasal airway CSAs than VW and MHW for all slices (adjusted \(p\) values <.05) except slices 36–40, where none of the techniques caused a postoperative change in CSA. The average

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**FIGURE 2** Line graphs comparing nasal airway cross-sectional areas preoperatively and after each rhinoplasty technique. (A) Right nasal airway. (B) Left nasal airway. The shading surrounding each trend line illustrates the 95% confidence interval. AVP, alavestibuloplasty; MHW, modified horizontal wedge; VW, vertical wedge.
FIGURE 3  Preoperative and postoperative silicone models for each technique, together with screenshots of CT slices 1–40. Note the contact points between the dorsal and ventral aspects of the midlateral slits present from slices 10 to 14 after modified horizontal wedge resection, which is not present in the preoperative model or the other techniques.
percentage increase in the CSA for AVP was 53% greater than VW and 66% greater than MHW across the region of slice 1 to slice 34 (Figure 2). Vertical wedge resection had larger CSAs than MHW by an average of 17% from slices 2–13 of the left nasal airway (adjusted p values <.01), and 17% from slices 8–13 of the right nasal airway (adjusted p values <.0001). There was no difference in CSAs between the VW and MHW techniques from slice 14 to slice 40 for both right and left nasal airways, from slice 1 to slice 7 for the right nasal airway, and slice 1 for the left nasal airway (adjusted p values ≥.05).

4 | DISCUSSION

We used 3D-printed, remolded models as a consistent baseline from which to compare rhinoplasty techniques. Using the AVP resulted in the largest postoperative nasal airway CSA of the assessed techniques when applied to silicone models of a single French bulldog's nose. While the outcome was consistent across all three techniques, the right nasal airway was consistently larger than the left when performed by a single right-handed surgeon.

The high reproducibility of the 3D-printed, remolded silicone models is consistent with previously published evidence regarding the utility of 3D-printing for producing surgical models.14,21,22 Previous studies have looked mainly at directly 3D-printed models; however 3D-printed injection molds made in a manner somewhat similar to our study have also been reported.23 This approach brings the benefit of being able to make models from materials, such as silicone, which exhibit subjectively biomechanical characteristics similar to those of canine soft tissues but cannot be used in widely available stereolithographic 3D-printers.24 The similarities between silicone and human soft tissues have been documented and the superiority of silicone to conventional 3D-printed models has been suggested.23 Such materials are essential when cutting and suturing of the models is required, as in our study. Further benefits of this approach experienced by the authors included the cost effectiveness of model production. Ninety-nine models were produced from 10 sets of molds, reducing the amount of 3D-printing required, and therefore the cost incurred. However manual filling of 3D-printed molds did incur a large time cost and this must be considered by those wishing to fabricate such models.

Intrasurgeon variability within each technique was considered low with only a 5–7% proportional difference across the techniques. An experienced surgeon is likely to produce consistent outcomes using all three techniques when published instructions are followed. The symmetry of all techniques was reasonable but larger CSAs were achieved consistently for the right nares and nasal vestibule when performed by a single right-handed surgeon. Surgeons should be aware that they may be prone to producing a smaller airway on the nondominant side, although further studies with multiple surgeons are required to confirm this. The lower percentage difference in CSA across models for AVP compared to VW and MHW may have been due to the cutting of more consistent anatomical landmarks as opposed to judgment of a wedge angle.

All three techniques increased the CSA of the nares (from rostral slice 1 to slice 7), which is consistent with the increase in nasal aperture seen from externally when these techniques are performed in clinical patients.3,9–11 The AVP resulted in the largest increase at the level of the external nares (a 132% increase at slice 3), suggesting it was more effective at opening the external nasal aperture than the other techniques. The magnitude of this difference was 35% and 45% greater than that achieved by the VW and MHW techniques, respectively. This is likely because the AVP amputates the alar wing, whereas the other techniques remove a midsection and involve suturing of the remaining tissue. The exact clinical relevance of this magnitude of difference between techniques in the rostral-most part of the nasal airway is difficult to quantify. It should, however, be noted that any difference with regards to airway diameter will be increased sixteenfold.
when applied to airway resistance. The AVP also resulted in the largest increase in CSA within the nasal vestibule compared to the other two techniques. This technique addressed stenosis caused by the alar fold, whereas VW and MHW did not. This is the main proposed advantage of the AVP technique, and our results support this proposition.

A decrease in nasal airway CSA from slices 10–14 in the MHW group was unexpectedly identified. This can be explained by collapse of the midlateral slit, likely caused by pulling of the dorsal aspect of the lateral slit ventrally when this technique was performed. The single cadaveric study served to confirm that this finding was not specific to the silicone models. It also confirmed that the air-filled regions within the ala nasi (separate to the nasal airway), which appeared in the postoperative VW and MHW models were also present when these techniques were applied to a cadaver. These are regions from which tissue has been removed but the defect has not been closed entirely by the suturing. This is because the cuts performed for these techniques extend far deeper than the external nasal planum where sutures can be placed. In the clinical patient it is hypothesized that these regions would heal through granulation tissue formation and no further increase in nasal airway cross-sectional area would occur as they are not connected to the nasal cavity. However further studies in canine patients are required to confirm this.

Limitations of the study include that it was not possible to objectively assess the similarity between silicone models and the canine tissues due to the uncharacterized biomechanical properties of the canine nasal planum. Despite subjective assessment suggesting the silicone models responded similarly to surgical intervention, future studies are needed to investigate the biomechanics of various canine soft tissues and identify or develop materials that mimic them more accurately. The fabrication steps involved in creating the models were also multifold, including the requirement to create the model from three separate molds and the addition of “arms” to attach the central airway to the outer frame. This could have introduced unappreciated errors. As the use of surgical models gains traction in the veterinary industry, attempts should be made to standardize the process of canine surgical model fabrication where possible. The surgical models used were of a single French bulldog’s nose. The benefit of this study design was a consistent baseline from which to compare the techniques, it affects the extrapolation of the results to clinical cases where nasal conformation will inevitably vary, especially between breeds. Further studies are needed to investigate the variety of nasal conformations within French bulldogs and other brachycephalic breeds, and the effects that these variations may have on the changes in CSA achieved by various rhinoplasty techniques. A further limitation was that no account could be taken of natural tissue healing and the effect that it could have on nasal airway cross-sectional area postoperatively for these rhinoplasty techniques. The long-term outcomes of these techniques, or potential adverse effects of excessive opening of the nares, have not been assessed in this study. Further clinical studies are required to confirm that the findings of this study are replicated in clinical cases and to assess the short-, medium-, and long-term outcomes of the AVP. Finally, due to a single surgeon performing each technique, conclusions cannot be drawn regarding the effects of different surgeons, and surgeons of different levels of experience, on the consistency and efficacy of the techniques. Further studies could be considered to assess the effect of surgeon experience on rhinoplasty techniques.

In conclusion, the AVP resulted in a larger increase in CSA of the silicone modeled nares and nasal vestibules of a single French bulldog compared to VW and MHW. Based on this evidence, the AVP can be considered for French bulldogs with moderately stenotic nares and evidence of nasal vestibular stenosis.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest related to this report.

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REFERENCES


SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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