Aesth Plast Surg
https://doi.org/10.1007/s00266-021-02350-z

ORIGINAL ARTICLE RHINOPLASTY

3D Printed Surgical Guides Applied in Rhinoplasty to Help Obtain Ideal Nasal Profile

Alexandra R. Gordon[1] · Jillian E. Schreiber[1] · Anmol Patel[1] · Oren M. Tepper[1]

Received: 28 February 2021 / Accepted: 9 May 2021

Abstract
Introduction As computer simulation for rhinoplasty continues to rise, the technology's utility extends beyond increasing patient conversion. Virtual simulation of the surgical result can assist with surgical planning and intraoperative decision-making. 3D printed anatomic models or surgical guides based on 3D images may help align surgeons with their original surgical plan. This study aims to evaluate the utility of 3D printed surgical guides as an intraoperative tool to help establish dorsal height and tip position.
Methods Patients undergoing rhinoplasty had preoperative virtual 3D surgical simulations performed. Simulations were used to create a 3D printed nasal kits containing ceramic models of the preoperative nose and simulated nose, sagittal contour guide, and customized postoperative nasal splint. Nasal guides were sterilized for continual intraoperative assessment of profile contour (i.e., dorsal height and tip position). Postoperative 3D images (1–3 months post-op) were then compared to preoperative simulations. The difference between *z* coordinates and *y* coordinates determined the difference in projection and rotation, respectively.
Results Fifteen patients met inclusion criteria for this study. With the use of 3D printed surgical guides, the final tip position was on average of 0.8±0.7mm from simulated projection and 0.3±0.2mm from simulated rotation. Similarly, projection for the cartilaginous and bony dorsum was within 1.0±0.8 and 0.8±0.7mm of the simulation, respectively.
Conclusion Virtual simulation is useful in defining aesthetic goals preoperatively, but the potential clinical value extends beyond this. 3D printed rhinoplasty guides extend the simulation's utility to decision-making intraoperatively. This technology offers a novel medium for anatomic reference, which may improve adherence to desired aesthetic goals.
Level of Evidence V This journal requires that authors assign a level of evidence to each article. For a full description of these Evidence-Based Medicine Ratings, please refer to Table of Contents or online Instructions to Authors www.springer.com/00266.

Keywords Rhinoplasty · Nasal guide · 3D technology · 3D simulation · Nasal aesthetics

Introduction

Computer simulation using three-dimensional (3D) technology has become increasingly common during rhinoplasty consultations [1, 2]. This technology allows both the surgeon and patient to visualize changes to the nose in three dimensions and also may help improve surgeon and patient communication, aligning the patient and surgeon aesthetic goals and expectations [1–5]. However, the potential of this technology extends far beyond a visual tool used during the consultation process.

Computer simulation is a valuable clinical tool for surgical planning that allows the surgeon to simulate operative maneuvers and visualize the intended aesthetic result. This concept of preoperative 3D simulation is standard in other

✉ Oren M. Tepper
orenteppermd@yahoo.com

[1] Montefiore 3D Printing and Innovation Laboratory, Division of Plastic and Reconstructive Surgery, Montefiore Medical Center, Montefiore Green Medical Arts Pavilion, Albert Einstein College of Medicine, 812 Park Ave, Bronx, New York, NY 10021, US

related fields, including craniomaxillofacial surgery [6–8]. For example, virtual surgical planning (Stryker, 3D Systems) [9, 10] is often used for reconstruction of the craniofacial skeleton in order to simulate a surgical plan in the preoperative setting. Recently, this technology has further advanced to 3D printed anatomic surgical guides that are applied in the operating room. While this technology is increasingly common in surgery on the craniofacial skeleton, very few applications of 3D printed anatomic surgical guides have been used for soft tissue [2, 11–13].

This study aims to extend the principle of virtual three-dimensional simulation for preoperative planning and intraoperative execution in rhinoplasty. 3D printed surgical guides are used to translate the simulated surgical plan to an operative guide to determine dorsal height and nasal tip position.

Methods

Patient Selection and 3D Photographic Images

A retrospective review was performed of primary rhinoplasty patients from February 2019 to February 2020. Inclusion criteria included preoperative 3D photographs with a preoperative virtual simulation of the intended result, the use of 3D printed models intraoperatively, as well as 3D photographs taken at 1–3 months postoperatively. 3D files were taken with the Vectra H1, for simulation and analysis performed with Canfield software. This study was approved by the Institutional Review Board (no. 2020-12420).

3D Printed Nasal Kits

Simulated 3D images were uploaded to the MirrorMe3D (New York, NY) platform and an operating nasal kit was ordered. The kits included a customized nasal profile guide, 3D analysis, and full ceramic models of the pre-op image and simulated result (Fig. 1). The guide was sterilized for using intraoperatively (Fig. 2). The cost of the kit ranges between $650 and 800. Because the procedures were a mix of purely cosmetic and insurance, the cost was out-of-pocket or covered by insurance, respectively.

3D Nasal Analysis

The postoperative images were merged with the baseline (simulated) image as an overlay in order to analyze adherence to the simulation. Postoperative images were registered onto the simulated image by manually selecting the forehead and temples (locations unchanged by surgery) followed by software alignment of those surfaces. The resulting overlay was then oriented on a three-axis grid, so the y axis aimed superiorly, x axis laterally, and the z axis ventrally on the face (Fig. 3). The nose was initially assessed for volumetric changes between simulation and postoperative results by creating mesh overlays and color maps. All landmarks were selected manually on the simulated image.

The nasal tip was determined to be the point of maximum projection on the z axis. The landmark coordinates were then measured. The z coordinate for each landmark approximated projection. The y coordinate for the nasal tip point approximated rotation. The cartilaginous dorsum and bony dorsum were approximated by points in the middle 1/3 and upper 1/3 of the nose, respectively (Fig. 3b). The landmarks on the simulated image were projected onto the postoperative image. The absolute difference between the corresponding coordinates on the post-op and simulated images determined the accuracy of the 3D surgical guide.

Statistical Analysis

A two-tailed paired samples t test was used to ascertain differences in perceived age within groups of means and standard error. Statistically significant differences were determined P value of $<.05$.

Microsoft Excel (Microsoft Corp., Redmond, Wash.) and Prism (GraphPad, San Diego, California) were used to calculate averages, percentages, standard deviations, and P values.

Results

Patient Characteristics

A total of 15 patients met the inclusion criteria for this study (Table 1). The average age of the patients at the time of surgery was 30 years old (range, 18–49). Three (20%) of patients were male and 12 (80%) were female. Thirteen rhinoplasties were open (87%) and two (13%) were closed.

Nasal Tip Position—Simulation vs. Actual Result

Postoperative nasal tip projection and rotation were similar to the simulated nose (mean differences of 0.8 $\pm$0.7mm (P=.36) and 0.3$\pm$0.2mm (P=.35), respectively) (Fig. 4a, 4b). Compared to projection, rotation of the nasal tip was significantly closer to the simulation (P=.002). The number of over and under-projected and rotated nasal tips

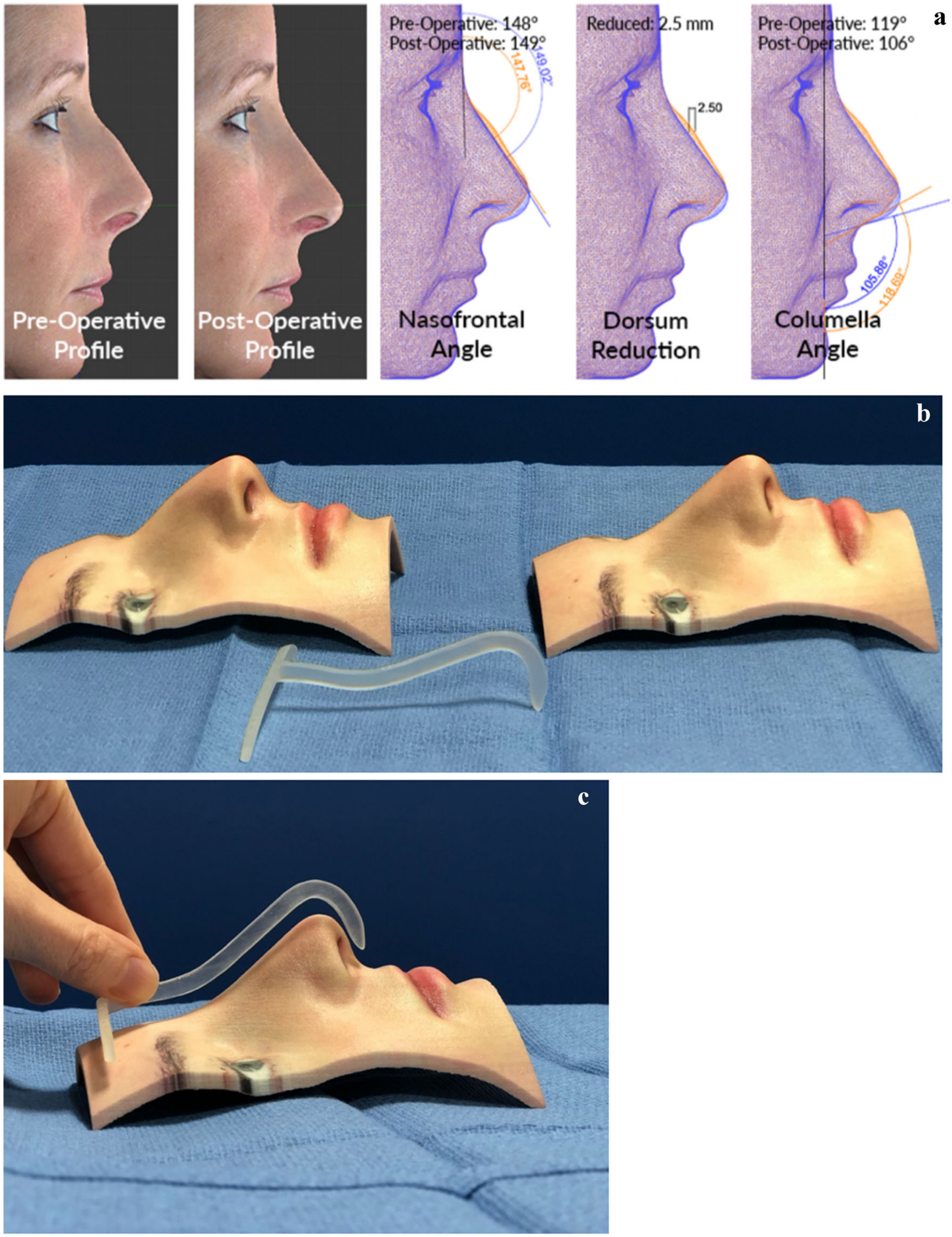


Figure 1: Rhinoplasty Kit. A 3D rhinoplasty kit including (**a**) the surgical plan, (**b, c**) ceramic models of the preoperative nose and simulated result with the sagittal contour guide.

compared to the simulation was similar (*n*=6 over-projected, *n*=9 under-projected, *n*=6 over-rotated, *n*=9 under-rotated) (Fig. 4a, b). Figure 2 shows an example of how the guide was used in a patient who required significant de-rotation.

Nasal Dorsum: Simulation vs. Actual Result

When analyzing the dorsum of the nose, the postoperative results for the cartilaginous dorsum and bony dorsum were also closely matched to the simulation: 1.0 ± 0.8 ($P<.001$)

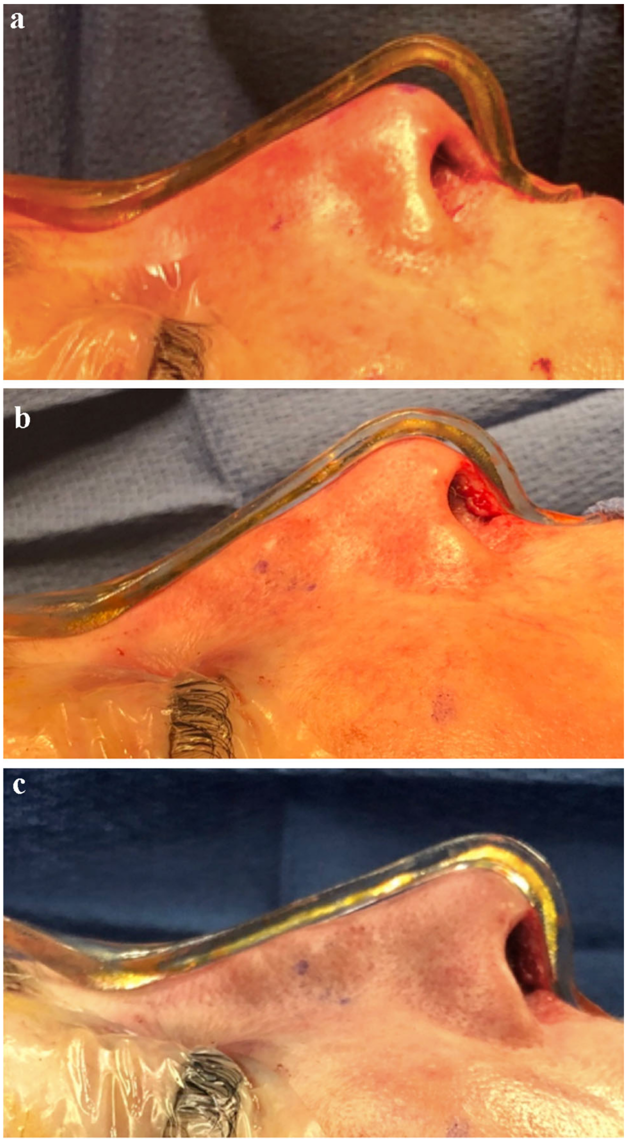


Figure 2: Sagittal Contour Guide on Nose Intraoperatively. (**a**) The nasal guide is used intraoperatively for reference prior to tip de-rotation. (**b**) After initial tip de-rotation, the nose aligns closer to the nasal guide before (**c**) further tip de-rotation for the final result.

and 0.8 ± 0.7mm (*P*=.003), respectively (Fig. 4c, d). When comparing the postoperative nose to the pre-op simulation, the majority of patients had an over-projected dorsum (n=13 over-projected, n=3 under-projected for cartilaginous dorsum; n=14 over-projected, n=1 under-projected for bony dorsum) (Fig. 4c, d).

When comparing the differences in projection between the nasal tip and cartilaginous dorsum, nasal tip and bony dorsum, and cartilaginous dorsum and bony dorsum, no statistically significant changes were found (*P*=.4, *P*=.9, and *P*=.2 respectively).

Discussion

Computer 3D simulation offers a unique tool for manipulating and visualizing the intended rhinoplasty result in the preoperative period. This simulation tool is used by plastic surgeons during consultation in order to help align patient and surgeon aesthetic goals and may also be used intraoperatively as a reference. This study describes the use of a 3D printed surgical guides as a means of translating these virtual plans in the operating room by way of 3D printing. Not only does 3D printing provide a true anatomic reference that is superior to traditional 2D photographs, but also 3D printed surgical guides can be sterilized and placed onto the patient as a reference intraoperatively. Our group applied intraoperative 3D printed surgical guides to assess their efficacy in achieving the desired profile aesthetic defined preoperatively.

3D printing has been extensively used for surgery on the craniofacial skeleton by way of virtual surgical planning (VSP) [9]. VSP allows for a preoperative simulation of operations on the craniofacial skeleton that can then be translated to the operating room with 3D printed reference models and anatomic guides that fit onto the patient. An analogous technology for soft tissue surgery, specifically rhinoplasty, is described in this study.

For this study, we created a custom 3D printed profile contour guide. At the time of initiating this study, this application had not been reported. However, recently, a study by Choi et al. investigated the utility of a similar 3D printed nasal guide [8]. This guide was created using a different software and form compared to the nasal guide used in this study. Additionally, the guide presented in this study provides a simple, yet effective, modality compared to the more nuanced guide presented by Choi et al. Because the goal of our sagittal guide was to help achieve the simulated surgical result, accurate quantification of this endpoint was required.

3D imaging and analysis offer a more detailed and accurate measurement tool relative to previous studies that compared preoperative simulations to postoperative results using 2D measurements [6, 7]. First, the use of 3D images eliminated any variations in lighting, angle, and perspective which naturally occur in 2D images. Second, the 3D software (Vectra) allows for the isolation and quantification of changes in all three planes (*x, y,* and z) by comparing the postoperative and simulated 3D images. Third, this analysis allowed our group to create color maps and mesh overlays (Fig. 3e) to further understand the distribution of the changes in the nose compared to the simulation.

To isolate the nose into the lower, middle, and upper thirds, our group selected landmarks on the nasal tip,

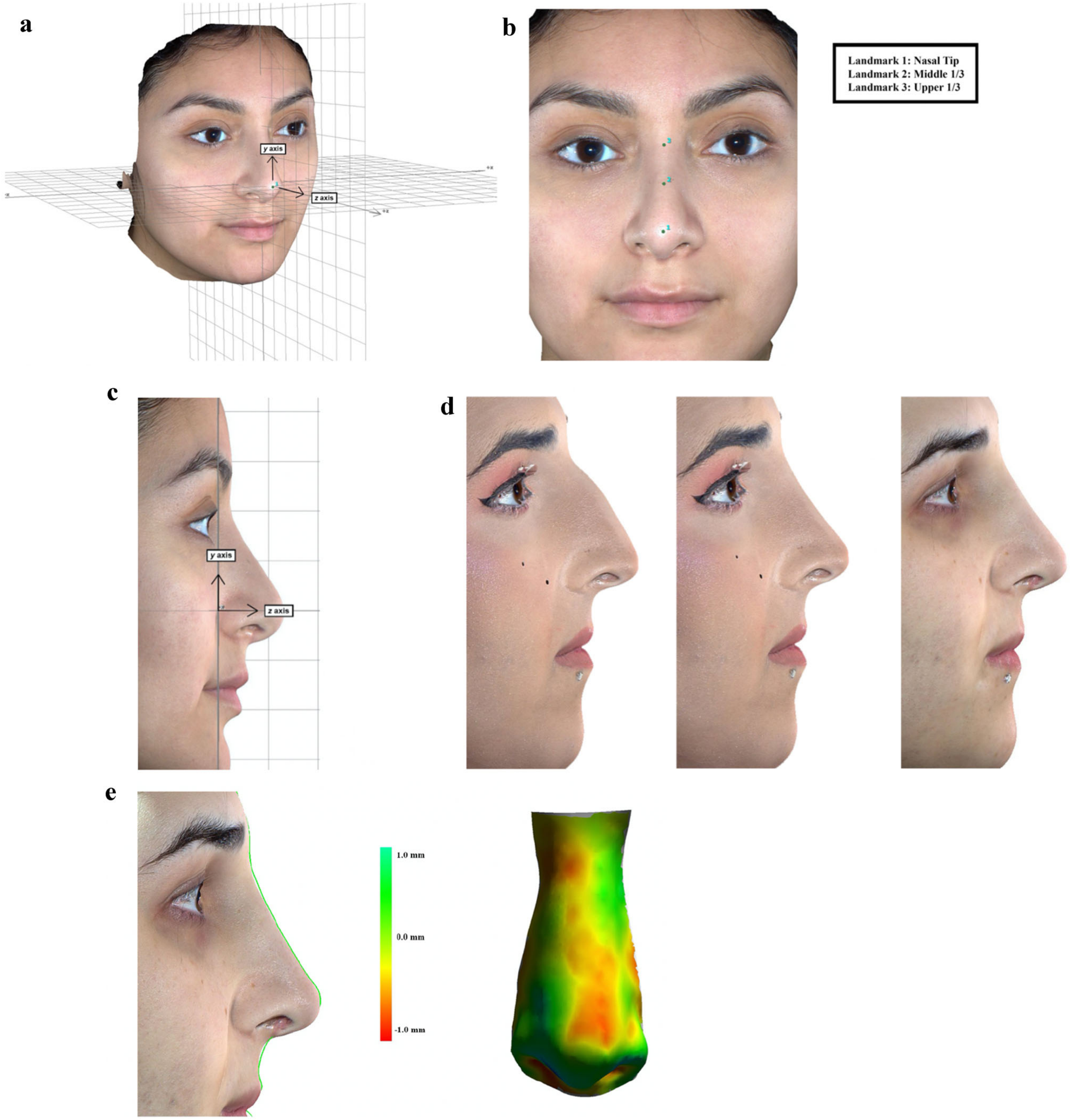


Figure 3: 3D Facial Alignment and Analysis. (**a, b**) The landmarks were placed at the nasal tip, cartilaginous dorsum (middle 1/3), and bony dorsum (upper 1/3). The face was manually aligned with the *x* axis pointing laterally, the *y* axis pointing superiorly, and the *z* axis pointing ventrally. (**c**) The *y* coordinate measured rotation and the *z* coordinate measured projection, respectively. (**d**) 3D photographs displayed are pre-op, 8 weeks post-op, and simulated result. (**e**) The sagittal contour of the simulation (green wire frame) is shown on the post-op image (solid) and the color map of the distance between the simulation and post-op result with a 1mm reduction shown in red, 0mm difference shown in yellow-green, and 1.0 mm increase shown in green.

cartilaginous dorsum, and bony dorsum (Fig. 3b). The nasal tip was determined by the point of maximum projection on the *z* axis (Fig. 3). The points on the cartilaginous and bony dorsum were standardized by selecting (on the simulated image) a point of maximum *z* projection in the middle and upper 1/3 of the nose, respectively. These landmarks were projected to the corresponding point on the post-op image. Our group estimated the location of the bony and cartilaginous dorsa because precise CT imaging would be excessive both clinically and financially.

Table 1: Demographics

Total patients (n=15)	
Gender	
Male	3
Female	12
Age(Year)	
Mean±SD	29.8±10.9
Range	18−49
Rhinoplastry approach	
Closed rhinoplastry	2
Open rhinoplastry	13
Grafts	
Septal extension graft	9
Spreader graft	7
Columellar strut graft	3
Indications for procedure	
Cosmetic	15

Understanding the effect that the nasal contour guide has on creating the desired result informs the value of its use to achieve this endpoint. The nasal tip point position, in particular, is integral to rhinoplasty. To quantify the accuracy of the 3D surgical guide to approximate nasal tip position, the deviation of the post-op result from the simulation in both rotation and projection was measured. The z coordinate determined projection while the y coordinate determined rotation. To measure the accuracy in nasal tip projection, the difference between the z coordinates for the simulated and actual results was subtracted. The same was done for the y coordinate to determine accuracy in nasal tip rotation. To determine the accuracy of the post-op dorsal height compared to the simulation, only projection (z coordinate) was measured. The difference between the z coordinate values for the simulated and actual result was subtracted. This method was repeated for both the bony dorsum and the cartilaginous dorsum.

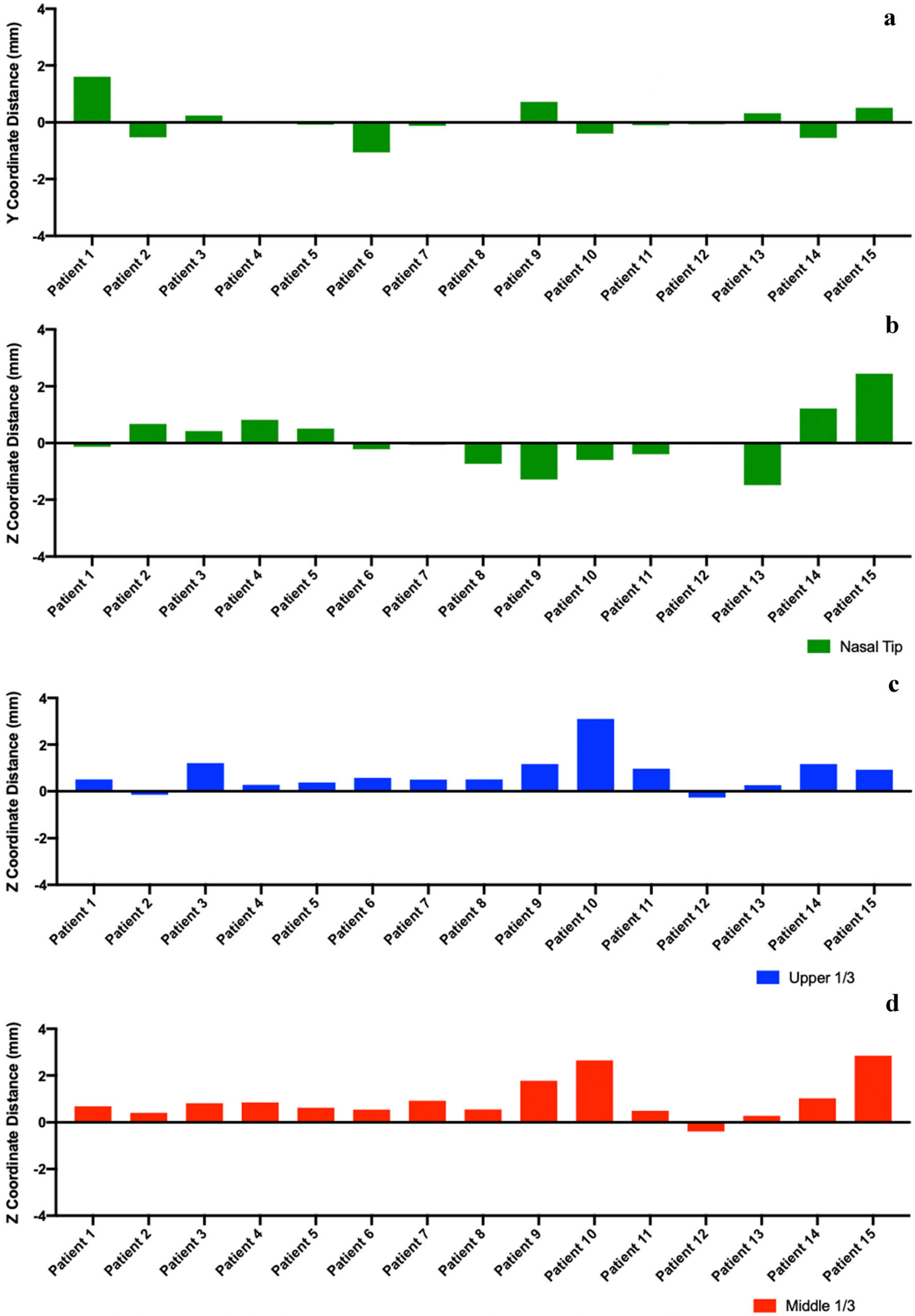
Simplifying measurements to the y and z planes offered more objective and reproducible study endpoints. Because the surgical guide aligns the nasal profile, a measurement in the x plane would not be an assessment of the guide's utility, but rather the plastic surgeon's surgical ability. For a more holistic evaluation of adherence to the surgical plan, the senior author and team reviewed the 3D mesh overlays and color maps of the post-op and simulated results.

To aid in creating the desired nasal tip position, the guide proved useful in meeting the position determined in the preoperative simulation. The post-op nasal tip projection and rotation were not significantly different from the simulation. However, the guide was more accurate in achieving tip rotation than projection. This may be due to the position of the guide, as it rests on the subnasale, which is manipulated during surgery.

One interesting thing to consider is whether or not the technology was equally effective in achieving projection for each nasal region. Therefore, we compared the absolute changes in each region and did not find any statistically significant differences among them. Clinically, the feedback from the surgical team is that this guide has particular value at the nasal tip compared to the dorsum. While the data trend this way, these changes were not significantly different.

In the majority of patients (n=13 for bony dorsum and n=14 for cartilaginous dorsum), the dorsum was relatively more projected than the simulation, which could be explained by a small amount of edema. However, there was still only a small discrepancy (on average <1mm) between the simulation and post-op result for the dorsum. For nasal tip projection, the post-op result was not statistically different from the simulation, while the mean values for the cartilaginous and bony dorsa were statistically different from the simulation. One reason for this is the cartilaginous and bony dorsa had a smaller variance among all patients which increased significance. Regardless, the post-op nasal profile was accurate to the simulation within 1mm for all measured locations. This indicates that the guide was effective in actualizing the simulated result. A representable patient result is shown in Fig. 4 which highlights the overlay.

Future studies would address the limitations presented in this study. This study used 3D images obtained at 1–3 months post-op. While the majority of nasal edema resolves by 1 month postoperatively, future studies with longer follow-up are needed to account for further changes to the nose due to resolving edema [14]. To explore the effect that edema has on the results, another future study should use stereophotogrammetry to analyze the anatomic distribution of edema through postoperative volume changes. While this study used only y and z axis measurements, further investigation may include x axis measurements which would ascertain the utility of the guide for correcting nasal deviation. This would require creating a guide that includes the nasal sidewalls, not only limited to the nasal profile. Additionally, the preoperative assessment should identify and mark the exact midpoint of the nose. A method to standardize those measurements should be created to avoid any large user-dependent discrepancies. Due to avoiding unnecessary medical cost and patient discomfort, our group did not use CT to identify the bony and cartilaginous dorsa. Future studies should unite the bony structure with the soft tissue image to accurately delineate the bony dorsum from the cartilaginous dorsum.


a
Y Coordinate Distance (mm)
4
2
0
-2
-4
Patient 1
Patient 2
Patient 3
Patient 4
Patient 5
Patient 6
Patient 7
Patient 8
Patient 9
Patient 10
Patient 11
Patient 12
Patient 13
Patient 14
Patient 15
b
Z Coordinate Distance (mm)
Nasal Tip
c
Z Coordinate Distance (mm)
Upper 1/3
d
Z Coordinate Distance (mm)
Middle 1/3

◀**Figure 4:** Accuracy of nasal tip positioning and dorsal height compared to simulation. These columns show the difference (mm) of postoperative (**a, b**) nasal tip position and (**c, d**) dorsal height from the computer simulation for each patient. **a** Positive values denote over-rotation and negative values denote under-rotation. (**b, c, d**) Positive values denote over-projection and negative values denote under-projection.

Conclusion

Virtual simulation of rhinoplasty is useful for visualizing nasal aesthetics preoperatively. Previously, there was no accurate way to confirm this endpoint was achieved, other than referring to photographs. These simulations can now be translated directly to the patient by using 3D printed surgical guides. The intraoperative use of our group's surgical guides resulted in a nasal tip position and dorsal height that correlated closely with the simulated ideal result. Virtual simulation aligns the patient and surgeon's aesthetic goals, while the sagittal guide allows that vision to be accurately achieved. Our 3D printed guide assists with intraoperative workflow, aiding in surgical decision-making. Using this technology, surgeons may more easily adhere to the surgical plan, which may improve patient satisfaction and the overall aesthetic result.

Declarations

Conflict of interest Oren Tepper is a shareholder of MirrorMe3D.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent For this type of study, formal consent is not required.

References

1. Pfaff MJ, Steinbacher DM (2016) Plastic surgery applications using three-dimensional planning and computer-assisted design and manufacturing. Plastic Reconstruct Surg J Am Soc Plastic Surg. 137(3):603e–616e
2. Weissler JM, Stern CS, Schreiber JE, Amirlak B, Tepper OM (2017) The evolution of photography and three-dimensional imaging in plastic surgery. Plastic Reconstruct Surge J Am Soc Plastic Surg 139(3):761–769
3. Guyuron B, Precision rhinoplasty, (1988) Part II: Prediction. Plastic and reconstructive surgery: J Am Soc Plastic Surg 81(4):500–505
4. Sharp HR, Tingay RS, Coman S, Mills V, Roberts DN (2002) Computer imaging and patient satisfaction in rhinoplasty surgery. J Laryngol Otol 116(12):1009–1013
5. GökçeKütük S, Arıkan OK (2019) Evaluation of the effects of open and closed rhinoplasty on the psychosocial stress level and quality of life of rhinoplasty patients. J Plast, Reconstruct Aesthet Surg. 72(8):1347–1354
6. Mehta U, Mazhar K, Frankel AS (2010) Accuracy of preoperative computer imaging in rhinoplasty. Arch Facial Plastic Surg 12(6):394–398
7. Adelson RT, DeFatta RJ, Bassischis BA (2008) Objective assessment of the accuracy of computer-simulated imaging in rhinoplasty. Am J Otolaryngol 29(3):151–155
8. Choi JW, Kim MJ, Kang MK et al (2020) Clinical application of a patient-specific, three-dimensional printing guide based on computer simulation for rhinoplasty. Plastic and reconstruct surg J Am Soc Plast Surg 145(2):365–374
9. Tepper OM, Sorice S, Hershman GN, Saadeh P, Levine JP, Hirsch D (2011) Use of virtual 3-dimensional surgery in post-traumatic craniomaxillofacial reconstruction. J Oral Maxillofacial surg. 69(3):733–741
10. Zamborsky R, Kilian M, Jacko P, Bernadic M, Hudak R (2019) Perspectives of 3D printing technology in orthopaedic surgery. Bratislavské lékarské listy 120(7):498–504
11. Suszynski TM, Serra JM, Weissler JM, Amirlak B (2018) Three-dimensional printing in rhinoplasty. Plast Reconst Surg: J Am Soc Plast Surg 141(6):1383–1385
12. Yen C-I, Zelken JA, Chang C-S et al (2019) Computer-aided design and three-dimensional printing improves symmetry in heminasal reconstruction outcomes. J Plast Reconstr Aesthet Surg 72(7):1198–1206. https://doi.org/10.1016/j.bjps.2019.03.012
13. Sultan B, Byrne PJ (2011) Custom-made, 3D, intraoperative surgical guides for nasal reconstruction. Facial plast surg clinics North Am 19(4):647–653
14. Pavri S, Zhu VZ, Steinbacher DM (2016) Postoperative edema resolution following rhinoplasty: a three-dimensional morphometric assessment. Plastic Reconst Surg J Am Soc Plastic Surg 138(6):973e–979e