THE JOURNAL OF PROSTHETIC DENTISTRY

DENTAL TECHNIQUE

Digital database for nasal prosthesis design with a 3D morphable face model approach

Rachael Y. Jablonski, BDS, MFDS RCS(Ed),[a] Taran Malhotra, MSc, MIMPT,[b] Trevor J. Coward, PhD, MPhil, FIMPT, FETC,[c] Daniel Shaw, MIMPT,[d] Chris Bojke, BA(hons), MSc, PhD,[e] Sue H. Pavitt, BSc, PhD,[f] Brian R. Nattress, BChD, PhD,[g] and Andrew J. Keeling, BSc, BDS, MFGDP, PhD[h]

ABSTRACT

Designing nasal prostheses can be challenging because of the unpaired nature of the facial feature, especially in patients lacking preoperative information. Various nose model databases have been developed as a helpful starting point for the computer-aided design of nasal prostheses, but these do not appear to be readily accessible. Therefore, an open-access digital database of nose models has been generated based on a 3-dimensional (3D) morphable face model approach. This article describes the generation of the database, highlights steps for designing a nasal prosthesis, and points readers to the database for future clinical application and research. (J Prosthet Dent 2024;131:1271-5)

Various computer-aided design (CAD) techniques have been used to aid facial prosthesis design, including free-form sculpting,[1,2] templates of presurgical anatomy,[3] scans of volunteers,[4] and mirroring contralateral features.[5-10] CAD can benefit clinicians by simplifying processes, reducing dependence on artistic skills, enhancing reproducibility, and improving process efficiency.[4,8,10] Patients may benefit from reviewing different design options, inputting during real-time adjustments, reduced clinical sculpting time, and the potential to store successful designs.[4,8,10,11] CAD approaches require an understanding of maxillofacial prosthetic and anatomic principles,[4,8,12] as well as access to suitable software programs, training, and techniques.[10,11,13]

Nasal prostheses can be challenging to design because of the unpaired nature of the facial feature, which can preclude the use of mirroring techniques.[12,14] Furthermore, information about the previous anatomy may be unavailable or may have been distorted, limiting the benefit of preoperative scans.[12,14] In these scenarios, a preexisting systematically organized digital library of varying nose shapes or proportions could provide a rapid and straightforward way of trialing multiple options as a starting point for prosthesis design.[12,14]

Various libraries of facial features have been created based on the scans of volunteers or anatomic casts.[11,12,14] In the authors' experience, these databases are not readily accessible[9] because of missing links or because data have been incorporated in software programs,

Supported by the National Institute for Health and Care Research (NIHR; England), NIHR Doctoral Fellowship (NIHR300235), and by Leeds Hospitals Charity (England). Funding for Research and Innovation (ULXXO/A200515). The views expressed in this publication are those of the authors and not necessarily those of the NIHR, NHS or the UK Department of Health and Social Care. Data statement: Data associated with this article are available from the University of Leeds Data Repository (https://doi.org/10.5518/1228).

[a]Specialty Trainee in Restorative Dentistry and NIHR Doctoral Fellow, Department of Restorative Dentistry, School of Dentistry, University of Leeds, Leeds, England.
[b]Lead Specialist Maxillofacial Prosthetist, Maxillofacial Prosthetics Laboratory, Liverpool University Hospitals NHS Foundation Trust, Aintree University Hospital, Liverpool, England.
[c]Professor and Honorary Consultant in Maxillofacial and Craniofacial Rehabilitation, Academic Centre of Reconstructive Science, Faculty of Dentistry, Oral and Craniofacial Sciences, King's College London, London, England.
[d]Maxillofacial Laboratory Manager, Maxillofacial Department, Chesterfield Royal Hospital Calow, Chesterfield, England.
[e]Professor of Health Economics, Academic Unit of Health Economics, School of Medicine, University of Leeds, Leeds, England.
[f]Professor of Translational and Applied Health Research, Dental Translational and Clinical Research Unit, School of Dentistry, University of Leeds, Leeds, England.
[g]Clinical Professor and Honorary Consultant in Restorative Dentistry, Department of Restorative Dentistry, School of Dentistry, University of Leeds, Leeds, England.
[h]Professor of Prosthodontics and Digital Dentistry, Department of Restorative Dentistry, School of Dentistry, University of Leeds, Leeds, England.

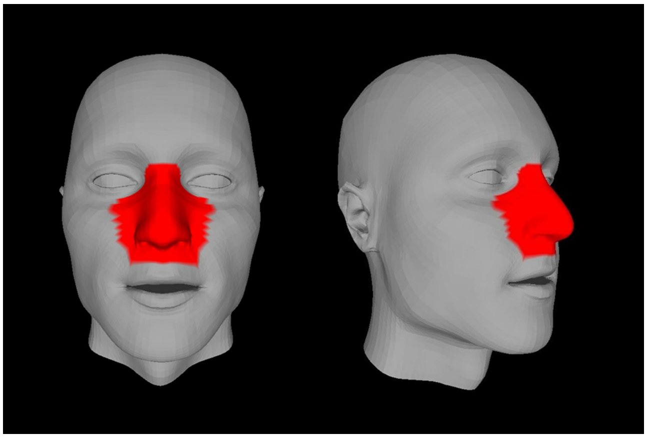

Figure 1. Three-dimensional morphable face model with *red* indicating region cropped from each randomly generated face. Reviewing cropped region may aid positioning of nose model.

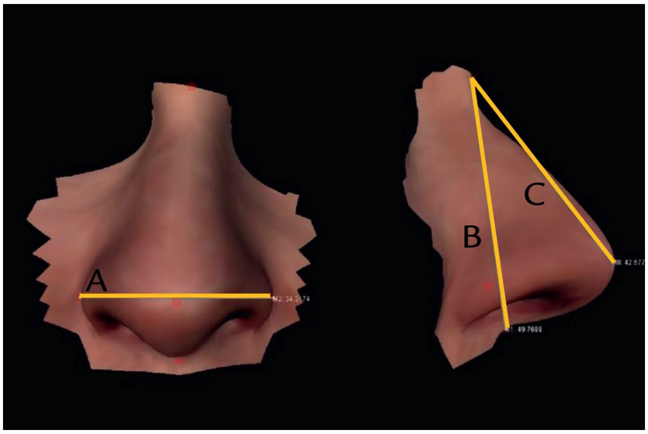

Figure 2. Measurements obtained by measuring distance between key vertices on all nose models. A, Nose width. B, Nose length. C, Nasal bridge length.

which may now be obsolete. Creating new databases of raw scans can have limitations, as identifying and scanning new volunteers can be resource-intensive, raw scans can be difficult to manipulate, and sharing personal data has important ethical considerations.[15] An alternative approach could involve using statistical shape models to generate a database of simple, well-behaved meshes that contain no personal information.

The 3-dimensional morphable face models (3DMFMs) are generative models for face shape and appearance which allow 3D facial reconstruction from 2D and 3D images.[15-18] 3DMFMs can model shape deformations, identify shape differences in shape families, and sample shape variation.[15,16] The Leeds face model (University of Leeds) was generated based on the facial scans (DI3D; Dimensional Imaging Ltd) of over 100 volunteers of varying ages, sexes, and ethnicities. The model uses 219 dimensions that describe an instance of a face. When all numbers are set to 0, the mean face is produced. Each number is scaled as the standard deviation of that dimension, with a value of 1 representing 1 standard deviation from the norm.

To create a nose model database with sufficient facial variation, random numbers were generated for the 219 dimensions at up to both 1 and 2 standard deviations to create a sample of 200 randomly generated faces.[15,16] The area of interest was marked on the Leeds face model (Fig. 1) to indicate the planned outline of the nose models with extension beyond the nasal region to facilitate blending. The randomly generated faces were cropped, and the 200 resultant noses were manually screened to remove implausible or noticeably similar examples.[16] The final 44 noses were summarized in a database guide with thumbnail images and written descriptions of bridge profile, tip projection, nose length-to-width ratio, and key measurements (nose length, nasal bridge length, and nose width) (Fig. 2). The open-access database of nose models was made available for research and clinical use.[19]

The following technical steps outline the process for designing a nasal prosthesis with the database of nose models generated by using a 3DMFM approach. A facial scan of a volunteer has been used as an example, and their nose removed to mimic a nasal defect. The volunteer provided facial photographs to imitate preoperative images to aid CAD. The reader can review the figures to compare the facial prosthesis design to the original facial scan to consider the suitability of this approach.

TECHNIQUE

1. Collect all required data. Make a facial scan with an appropriate facial scanner, such as a handheld structured light scanner (Artec Space Spider; Artec 3D). Process the data, and export the facial mesh (Figs. 3 and 4). Source clinical or patient photographs showing the preoperative nose shape.
2. Review the database guide to select appropriate nose model(s) to trial. Select nose shape by comparing preoperative information to thumbnail images and written descriptions. Consider the nose model measurements and remember that nose models can be resized. In patients with limited preoperative information, use neoclassical canons or geometric rules to support nose model selection but account for ethnic variation and patient's preference.[20-22]
3. Import the facial mesh and nose model(s) into the operator's preferred CAD software program (such as Geomagic Freeform; Oqton). Orient the facial mesh so that it is approximately aligned with the nose models (Fig. 5).
4. Review the nose model(s) and select the most appropriate one based on the operator's expertise,

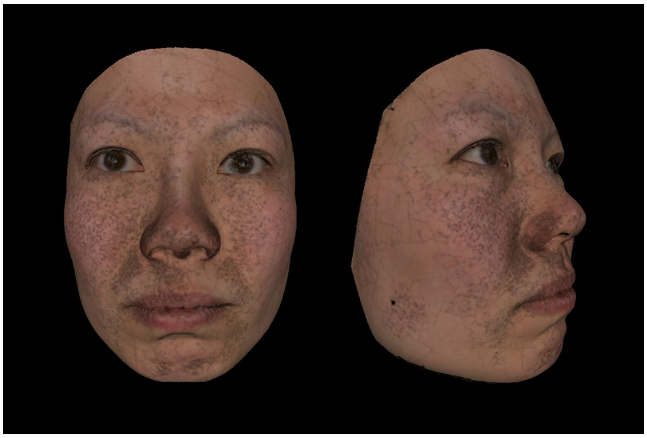

Figure 3. Scan of volunteer with optical scanner (Artec Space Spider; Artec 3D) showing unedited facial features.

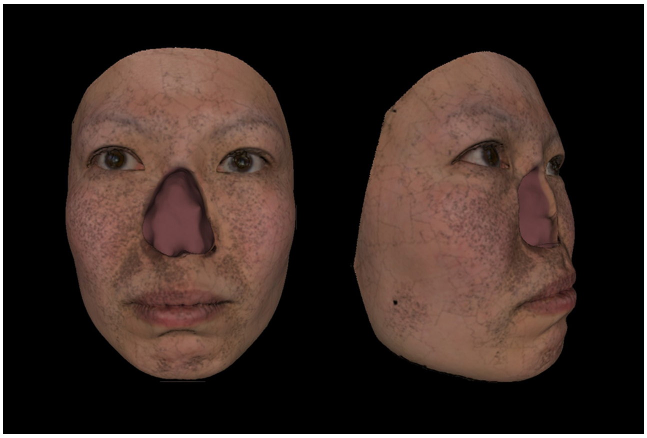

Figure 4. Facial part removed to mimic full nasal defect for reconstruction.

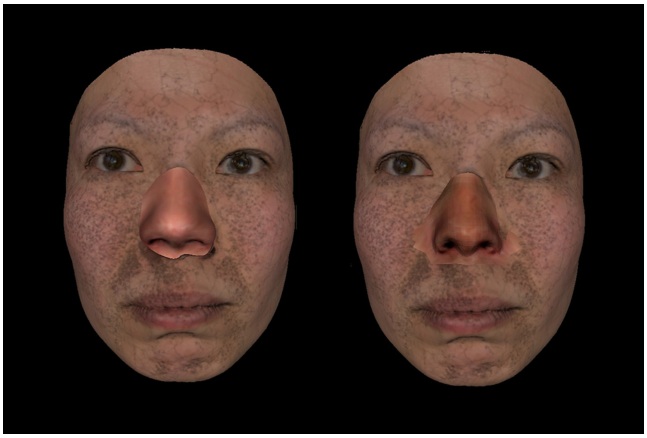

Figure 5. Facial mesh aligned with nose models with open-source software program for editing meshes (MeshLab; https://www.meshlab.net/). Two examples of nose models trialed from database.

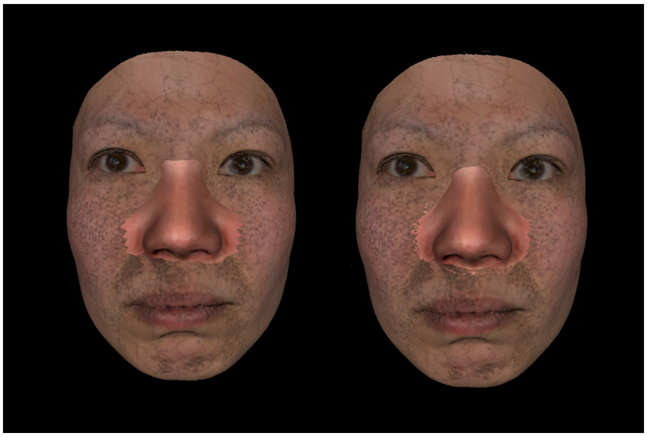

Figure 6. Preferred nose model aligned and blended to facial mesh with computer-aided design sculpting tools (Meshmixer; Autodesk Inc).

patient's wishes, and any available preoperative photographs.

5. Resize or rescale the selected nose model as required and fine-align to the facial mesh. To guide positioning of the nose model, review Figure 1 which illustrates the region that has been cropped from the randomly generated faces. The addition of a midsagittal reference plane may help identify the correct rotational positioning of the nose model.
6. Blend the margins of the nose model to the facial mesh with the CAD software program (Geomagic Freeform; Oqton) and sculpting tools (Fig. 6). Thicken the fit surface of the nose model to the desired thickness to ensure structural integrity of the silicone material and adapt to the facial mesh.
7. Modify the design to incorporate any retentive components and adjust the nasal features (such as the nasal contours or nostrils) to the needs of the patient (Fig. 7).
8. Once completed, use the CAD file to produce a 3D printed replica or negative mold according to the operator's preferred digital workflow and 3D printing materials (such as Model V2 Resin; Formlabs).

DISCUSSION

The digital nose model database may support operators with an understanding of prosthetic principles and general CAD techniques to design nasal profile dressings and intermediate or definitive nasal prostheses. While no absolute contraindications exist for using this database, other CAD techniques may be more appropriate in specific clinical contexts. Preoperative scans may be better suited to situations where a patient's nasal anatomy is not distorted and facial scanning can be coordinated before surgery.[3] With combined midfacial defects, the database could be used in conjunction with other techniques (such as mirroring) but could be more

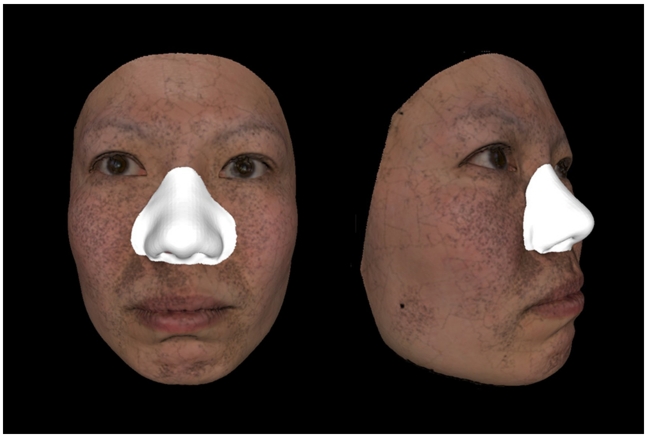

Figure 7. Additional features added and fit surface of nose model thickened into printable computer-aided design file with custom software program.

complex because of disruption of key landmarks and lines of symmetry.[13]

Although an explicitly defined method for nose model selection is lacking, this database can be used with standard prosthetic principles, neoclassical canons, and geometric rules.[20-22] These should be interpreted with caution and modified to account for interethnic variation and differences in patients' preference.[20-22] As all nose models have a standardized orientation, operators can rapidly trial multiple options to identify a sensible starting point for CAD. The polygon file format will be compatible with a variety of software programs, and the straightforward, well-behaved meshes will be ideal for resizing and manipulating with CAD tools. The nose models will be less detailed than raw meshes, and additional features (such as folds and creases) may need to be added.

While the Leeds face model has been created based on the scans of over 100 volunteers of varying ages, sexes, and ethnicities, the sample may be insufficient to create a truly representative model that fully explains the shape variations of nasal features.[15,18] The low prevalence of some features within the database (such as concave bridges) may be attributed to fewer instances within the sample population and consequently a lower probability of being generated. The 3DMFM dimensions were varied at up to 2 standard deviations to generate a variety of nose models including less commonly encountered shapes. The number of nose models was then reduced to balance shape variety with clinical usability. The database could be refined as training set sizes are increased or demographically specific 3DMFMs are produced.[18]

Further improvements could be implemented to semiautomate key CAD steps. Software programs could be developed to automatically select, align, and rescale nose models based on the selection of facial landmarks. Vertices corresponding to the nostrils could be deleted programmatically. Augmented reality programs could aid nose model selection and facilitate greater patient input.[23] Finally, 3DMFMs could design facial prostheses in a semiautomated and statistically meaningful way based on the characteristics of the patient's surrounding facial features.[17] Further research is underway to assess the accuracy and repeatability of using 3DMFMs to aid facial prosthesis design in laboratory and clinical settings.

SUMMARY

The generation of a user-friendly, open-access digital database of nose models based on a 3DMFM approach is described. The CAD technique offers a sensible starting point for facial prosthesis design and may be useful where preoperative information is limited. Research is ongoing to assess the use of 3DMFMs in aiding facial prosthesis design.

REFERENCES

1. Nuseir A, Hatamleh MM, Alnazzawi A, Al-Rabab'ah M, Kamel B, Jaradat E. Direct 3D printing of flexible nasal prosthesis: optimized digital workflow from scan to fit. *J Prosthodont*. 2019;28:10–14.
2. Unkovskiy A, Spintzyk S, Brom J, Huettig F, Keutel C. Direct 3D printing of silicone facial prostheses: a preliminary experience in digital workflow. *J Prosthet Dent*. 2018;120:303–308.
3. Ciocca L, Bacci G, Mingucci R, Scotti R. CAD-CAM construction of a provisional nasal prosthesis after ablative tumour surgery of the nose. A pilot case report. *Eur J Cancer Care (Engl)*. 2009;18:97–101.
4. Cheah CM, Chua CK, Tan KH, Teo CK. Integration of laser surface digitizing with CAD/CAM techniques for developing facial prostheses. Part 1: design and fabrication of prosthesis replicas. *Int J Prosthodont*. 2003;16: 435–441.
5. Liu H, Bai S, Yu X, Zhao Y. Combined use of a facial scanner and an intraoral scanner to acquire a digital scan for the fabrication of an orbital prosthesis. *J Prosthet Dent*. 2019;121:531–534.
6. Ciocca L, Scotti R. Oculo-facial rehabilitation after facial cancer removal: updated CAD/CAM procedures: a pilot study. *Prosthet Orthot Int*. 2014;38: 505–509.
7. Bai S-Z, Feng Z-H, Gao R, et al. Development and application of a rapid rehabilitation system for reconstruction of maxillofacial soft-tissue defects related to war and traumatic injuries. *Mil Med Res*. 2014;1:11.
8. Watson J, Hatamleh MM. Complete integration of technology for improved reproduction of auricular prostheses. *J Prosthet Dent*. 2014;111:430–436.
9. Farook TH, Jamayet NB, Abdullah JY, Rajion ZA, Alam MK. A systematic review of the computerized tools and digital techniques applied to fabricate nasal, auricular, orbital and ocular prostheses for facial defect rehabilitation. *J Stomatol Oral Maxillofac Surg*. 2020;121:268–277.
10. Tanveer W, Ridwan-Pramana A, Molinero-Mourelle P, Koolstra JH, Forouzanfar T. Systematic review of clinical applications of CAD/CAM technology for craniofacial implants placement and manufacturing of nasal prostheses. *Int J Environ Res Public Health*. 2021;18:3756.
11. Palousek D, Rosicky J, Koutny D. Use of digital technologies for nasal prosthesis manufacturing. *Prosthet Orthot Int*. 2014;38:171–175.
12. Reitemeier B, Götzel B, Schöne C, et al. Creation and utilization of a digital database for nasal prosthesis models. *Onkologie*. 2013;36:7–11.
13. Farook TH, Jamayet NB, Abdullah JY, Asif JA, Rajion ZA, Alam MK. Designing 3D prosthetic templates for maxillofacial defect rehabilitation: a comparative analysis of different virtual workflows. *Comput Biol Med*. 2020;118:103646.
14. Fantini M, De Crescenzio F, Ciocca L. Design and rapid manufacturing of anatomical prosthesis for facial rehabilitation. *Int J Interact Des Manuf*. 2013;7: 51–62.
15. Egger B, Smith WAP, Tewari A, et al. 3D Morphable Face Models - past, present and future. *ACM Trans Graph*. 2020;9:1–39.

16. Blanz V, Vetter T. A morphable model for the synthesis of 3D faces. In: *SIGGRAPH '99: proceedings of the 26th annual conference on computer graphics and interactive techniques*. New York: ACM Press/Addison-Wesley Publishing Co; 1999:187–194.
17. Mueller AA, Paysan P, Schumacher R, et al. Missing facial parts computed by a morphable model and transferred directly to a polyamide laser-sintered prosthesis: an innovation study. *Br J Oral Maxillofac Surg*. 2011;49:e67–e71.
18. Booth J, Roussos A, Ponniah A, Dunaway D, Zafeiriou S. Large scale 3D Morphable Models. *Int J Comput Vis*. 2018;126:233–254.
19. Jablonski RY, Bojke C, Pavitt SH, Nattress BR, Keeling AJ. *Digital database of nose models for nasal prosthesis design generated with 3D morphable face model approach*. Leeds: University of Leeds; 2023. Available at: https://doi.org/10.5518/1228. Accessed March 30, 2023.
20. Ding A, Zhang Y. What is the perfect nose? Lesson learnt from the literature. *Rhinol Online*. 2020;3:25–30.
21. Fang F, Clapham PJ, Chung KC. A systematic review of inter-ethnic variability in facial dimensions. *Plast Reconstr Surg*. 2011;127:874–881.
22. Zwahlen RA, Tang ATH, Leung WK, Tan SK. Does 3-dimensional facial attractiveness relate to golden ratio, neoclassical canons, 'ideal' ratios and 'ideal' angles? *Maxillofac Plast Reconstr Surg*. 2022;44:28.
23. Jiwan N, Ark A, Middup R, et al. A comparative study on the effectiveness of augmented reality on denture tooth selection. *Eur J Prosthodont Restor Dent*. 2021;29:143–151.

Corresponding author:
Dr Rachael Y Jablonski
Leeds School of Dentistry
Clarendon Way
University of Leeds
Leeds, LS2 9LU
UNITED KINGDOM
Email: rachaeljablonski@gmail.com

https://doi.org/10.1016/j.prosdent.2023.02.019