Point of care virtual surgical planning and 3D printing in facial gender confirmation surgery: a narrative review

Doga Kuruoglu[1], Maria Yan[1], Samyd S. Bustos[1], Jonathan M. Morris[2], Amy E. Alexander[3], Basel Sharaf[1]

[1]Division of Plastic Surgery, Department of Surgery, Mayo Clinic, Rochester, MN, USA; [2]Division of Neuroradiology, Anatomic Modeling Lab, Department of Radiology, Mayo Clinic, Rochester, MN, USA; [3]Anatomic Modeling Lab, Department of Radiology, Mayo Clinic, Rochester, MN, USA

Contributions: (I) Conception and design: D Kuruoglu, B Sharaf, JM Morris; (II) Administrative support: B Sharaf, JM Morris; (III) Provision of study materials or patients: JM Morris; (IV) Collection and assembly of data: D Kuruoglu, AE Alexander, B Sharaf, JM Morris; (V) Data analysis and interpretation: AE Alexander, D Kuruoglu; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Basel Sharaf, MD, DDS, FACS. Division of Plastic Surgery, Department of Surgery, Mayo Clinic,200 First Street SW, Rochester, MN 55905, USA. Email: Sharaf.Basel@mayo.edu.

Abstract: Facial gender confirmation surgery (FGCS) is a powerful set of procedures in the armamentarium of plastic surgeons that can transform the male face into a gender-congruent female face and provide the transgender individual with improved quality of life, positive body image and help in social integration. The goals of the FGCS procedures are to address the individual patients' concerns and expectations about their facial appearance, offer safely executed surgery, minimize complications, and optimize surgical outcomes. Pre-operative computed tomography (CT) scanning and three-dimensional (3D) reconstruction before facial feminization or masculinization delineates important skeletal and sinus anatomy and can also be a useful tool in patient consultation. Virtual surgical planning (VSP) is a valuable tool in facial surgery. From free flap bony reconstruction after tumor resection and orthognathic surgery to craniosynostosis planning, VSP has become widely utilized in modern day cranio-maxillofacial surgery. The use of patient-specific cutting guides and implants helps in improving symmetry and safety of these procedures. Furthermore, 3D printed models are valuable tools in patient education and counseling prior to surgery. In this article we describe our approach to FGCS through the integration of point of care (POC) VSP and 3D printing (3DP) to help deliver safer and accurate FGCS outcomes.

Keywords: Facial gender confirmation surgery (FGCS); forehead contouring; three-dimensional (3D) printing; point of care (POC) virtual surgical planning (VSP); POC 3D printing (3DP)

Submitted Sep 11, 2020. Accepted for publication Jan 26, 2021.
doi: 10.21037/atm-20-6369
View this article at: http://dx.doi.org/10.21037/atm-20-6369

Introduction

As of 2016 it was estimated that 1.4 million people in the United States identify themselves as transgender (1). Some of the main challenges that transgender individuals face are the mismatch between their gender identity and their physical appearance and acceptance in society. Facial features play an important role in helping transgender individuals integrate into society. Various procedures including genital reassignment, chest feminization, and facial gender confirmation surgery (FGCS) have been described to help patients with gender dysphoria achieve gender congruence and body image satisfaction. FGCS has a significant impact on the quality of life of gender dysphoric patients (2).

Virtual surgical planning (VSP) has gained increased popularity and incorporation into routine craniomaxillofacial surgery over the last 2 decades. Multiple studies have reported on the utility and outcomes of VSP for various procedures in head and neck reconstruction, orthognathic surgery, cranial vault reconstruction and esthetic surgery (3-6). Frontal, periorbital, malar and mandibular contouring are some of many FGCS procedures in the armamentarium of plastic surgeons. Even though most of the published studies of FGCS did not explicitly report post-operative complications, one can extrapolate from the craniomaxillofacial trauma literature that these procedures may possess similar risks and potential post-operative complications such as infection, facial nerve or sensory nerve injuries, cerebrospinal fluid leak, bony resorption or nonunion (7-10). The goal of FGCS is to provide improved quality of life and psychosocial health for transgender women (2,11-13). It is paramount for the surgeons performing FGCS to follow safe surgical techniques, decrease morbidity and complications and provide consistent surgical outcomes. VSP has been reported to reduce operative time, offer better understanding of the patient's anatomy, enhance predictability and reproducibility with improved safety and surgical outcomes. In fact, in their comparison study on 50 male cadaveric heads undergoing anterior frontal sinus wall setback, lateral supraorbital contouring, mandibular angle reduction, and osseous genioplasty narrowing, Gray *et al.* (14) reported that the frontal sinus wall setback surgeries with VSP were more efficient (reduced operative time), more accurate (expected volumetric change to actual volumetric change) and safer (less intracranial entry) when compared to the procedures with no preoperative VSP. They also reported that the mandibular angle reduction surgeries with VSP were safer (less inferior alveolar nerve injury) and more accurate when compared to the procedures with no preoperative VSP. In this study, we aim to describe our approach to FGCS utilizing point of care (POC) VSP and 3D printing (3DP). A summary of the more common procedures outlining the advantages of POC virtual surgical planning and three-dimensional (3D) printing is presented. We present the following article in accordance with the Narrative Review reporting checklist (available at http://dx.doi.org/10.21037/atm-20-6369).

Materials and methods

Three-dimensional applications and process

The process of VSP and generating 3D-printed models or surgical guides from a digital blueprint starts with image acquisition, typically from a maxillofacial computed tomography (CT). This is followed by extraction of the regions of interest (segmentation), which divides an image into regions of similar properties and helps to outline anatomic structures and areas of interest. After segmentation, the data is converted to a 3D Standard Tessellation Language (STL) file. VSP takes place with the use of ProPlan CMF or Surgicase software (Materialise, Leuven, Belgium). The surgeon and the biomedical engineers meet in person or online to finalize the surgical plan and the design of 3D models and surgical guides. After the VSP is completed, the fabrication of the surgical guides takes place using 3-matic (Materialise, Leuven, Belgium). A summary report is generated after 3DP that includes the details of the anatomic regions of interest, type of 3D application generated, laterality, type of cross-sectional image used and its specifications. Relatively inexpensive 3D printed models can be generated for mock surgery which allows the surgeon to perform mock surgery on the 3DP model prior to surgery. Modification of the surgical plan or the cutting guides can then be made.

Common surgical procedures in FGCS

The most common bony FGCS procedures to help in male to female facial transformation include frontonasal-orbital contouring, mandibular contouring/angle reduction, and osseous genioplasty. Other skeletal procedures include orthognathic (jaw) surgery and zygomatic width reduction. Soft tissue procedures that may be performed simultaneously or in a staged fashion include forehead shortening, brow lift, blepharoplasty, rhinoplasty, upper lip shortening, and fat grafting to the cheeks, lips, or other facial areas as indicated. In addition, tracheal shave (laryngochondroplasty) is often necessary. Procedures that we currently use POC VSP and 3DP will be discussed.

Frontonasal-orbital contouring

The frontonasal-orbital complex differs significantly between men and women. The anatomic basis of such variation was elucidated in Douglas Ousterhout studies in 1987 when he described gender differences in forehead anatomy (15). Unlike the female forehead, the male forehead displays increased supraorbital bossing, larger frontal sinus, flatter and lower-set brows, deeper orbits, and an M-shaped hairline (7,15). The goal of feminizing foreheadplasty is to eliminate the masculine characteristics of the forehead in a transwoman. Anterior or temporal hairline recession and facial proportions should be taken into consideration when planning surgical access to the forehead. The areas of patient's concerns should be discussed at the initial surgical consultation. This includes a comprehensive facial assessment of the facial tissues, both skeletal and soft, including standardized facial photographs. A hairline incision may be required to reduce the forehead length and advance the hairline if needed. In addition, attention to brow shape, brow or eyelid ptosis and asymmetry should be taken into account. The forehead contour, forehead length, shape and level of anterior hairline as well as eyebrow shape are evaluated as one aesthetic subunit. Surgical approaches to feminize each of these anatomic areas will have an impact on the overall facial appearance. Depending on the thickness of the morphology of the forehead and anterior table bony thickness [forehead types I, II or III (15)] either contouring of the anterior table or set back of the anterior table is planned. The risks, benefits, and alternatives of these 2 procedures should be discussed with the patient prior to surgery. In patients with less forehead prominence and thicker anterior table, bony contouring is usually sufficient. In the thinner anterior table and more bossed forehead, anterior table osteotomy with setback maybe required. At times, both reduction of the bony forehead and augmentation strategies of the midforehead with either autologous dermal fat grafts or alloplastic materials may be necessary. In addition, the naso-frontal transition should be assessed and soft tissue augmentation of the nasofrontal area may be required to achieve a smoother profile in the feminized nasofrontal region. A Maxillofacial CT is required to evaluate the frontal bone, frontal sinus anatomy and assess for sinus disease. Subsequently, POC VSP is performed with our biomedical engineers and neuroradiologists to help delineate the frontal sinus boundary. Sterilizable cutting guides are 3D-printed in house to help in accurate surgical execution of the virtual plan. This process is performed in house at our institution (POC) which expedites the planning phase and allows for making adjustments if needed prior to surgery. At times, mock surgery can be performed on the 3D-printed models (*Video 1*) to rehearse the surgical plan or help the surgeon in choosing between burring *vs.* osteotomy of the frontal bone. The patient is seen a second time prior to surgery and presented with their 3D printed model or the virtual plan. We found this to be very helpful in allowing the patient to understand the different surgical approaches, their anatomy, and help in making decisions with regard to the final surgical plan. When this process is done at the POC, meaning that the VSP and 3DP process are performed at the same institution where the patient care is provided, it allows for a more efficient and less time-consuming process. Unlike VSP and 3DP that are outsourced to third-party companies, POC VSP and 3DP allows for the surgeon and the radiologist to communicate more effectively about the case at hand, eliminating the need for coordinating 1-2 web meetings with third-party companies. In addition, POC 3DP bypasses shipping time needed, and allows for expedited process from CT scan to final model fabrication for intra-operative use. The fabrication of the models allows for education of patients, their families, surgical trainees and the clinic staff about FGCS. Furthermore, having physically printed 3D models helps in better communication about the specifics of the case among specialties involved such as plastic surgery, radiology, otorhinolaryngology, anesthesia, biomedical engineering, nursing and operating room staff. This helps in building a team of personnel experienced with this type of surgery. We concur with Gray *et al.* (14) that the use of VSP and 3DP helps the surgeon in morphologic typing, improved efficiency and accuracy of FGCS. Adapting this technology to FGCS may improve patient satisfaction and help in keeping these procedures safe with minimal complications (8,16-19).

Assessment of the frontal sinus dimensions and the anterior table thickness should be performed before performing any approach to forehead contouring. Pre-operative CT imaging is crucial to assess frontal sinus anatomy, septa, and anterior table thickness. Risks of forehead contouring should be discussed with the patient and can include bone resorption, malunion or nonunion of bones, alopecia, asymmetry, infection, mucocele formation, and potential need for re-operation. Patient should also be informed about the other facial gender confirmation procedures that can be performed during this surgery, including scalp advancement, blepharoplasty, brow lift, fat grafting, rhinoplasty, midface and mandibular contouring if needed (*Figures 1*,2 and *Video 1*).

A generated colored measurement map allows for safer execution of the plan and precise burring or osteotomy of the frontal bone. The surgical guides facilitate accurate execution of the plan as well (*Figure 1D*) (14). As shown in *Figure 1A*, bony thickness less than 1-mm is colored in red whereas thickness more than 4-mm is colored in green.

Mandibular contouring, angle reduction

The masculine mandible is wider, with thicker bone and more angular when compared to the feminine mandible (20,21). Also, the soft tissue covering the bone, especially in the masseter muscle region is usually thicker in males (22).

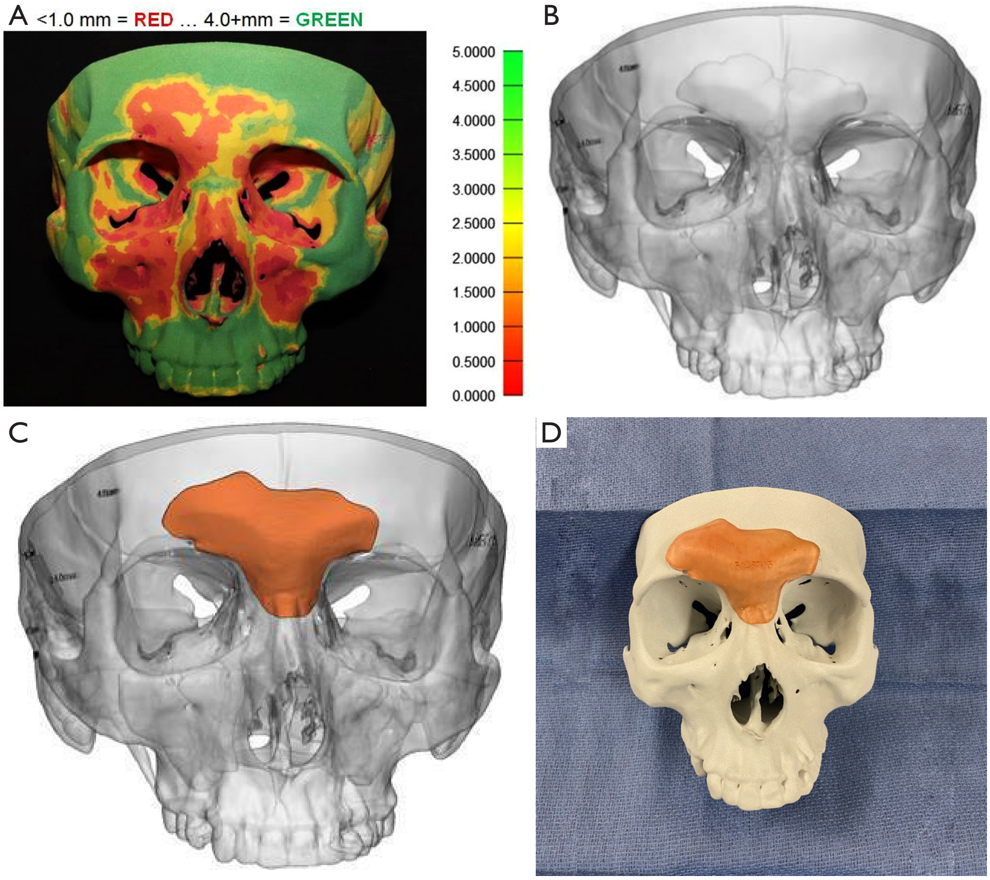

Figure 1 Application of point of care VSP and 3D-printing for frontonasal-orbital contouring. (A) Point of care VSP and 3D-printed model with generated heat maps showing the relative thickness of the anterior table, (B) VSP showing the extent of the frontal sinus, (C) sterilizable cutting guide that can be used intra-operatively, and (D) pre-operatively for mock surgery. VSP, virtual surgical planning.

Figure 2 Point of care 3D-printed guide for frontal bone contouring. In this case, an anterior hairline approach with was used with planned brow lift and hairline advancement.

Mandibular contouring in FGCS plays an important role in making the lower facial frame more tapered and less angular. The goal is to achieve a less square jaw appearance with more oval or rounder shape. This usually requires ostectomy of the mandibular angle and osseous reduction of the lateral cortex of the mandibular ramus if needed. To reduce the angle, a trans-oral approach is used. We utilize the Piezosurgery® (Piezosurgery Incorporated, Columbus, OH) for bony osteotomies and pineapple burrs or reciprocating rasps for bony contouring. Some patients with bulky master muscles will benefit from serial botulinum toxin masseter injections to feminize the lower facial contour (*Figures 3,4*). Potential injury to the inferior alveolar nerve should be discussed with the patient. The use of VSP and 3D printed models for mock surgery can be helpful to modify the surgical plan and reduce the risk of nerve injuries (14).

Figure 3 Point of care 3D-printed patient specific mandibular model. Note the chin asymmetry. The model is shown to the patient at the pre-operative visit to outline the surgical plan, explain the risks, and allow for an in depth discussion.

Figure 4 Mandibular ramus contouring and angle reduction through a transoral approach.

Osseous genioplasty

The masculine chin is usually wider and more square-shaped whereas the feminine chin is more trapezoidal that is shorter in height and less angular than the male chin. Reduction genioplasty in both the vertical and horizontal planes helps achieve these feminine features (17). Depending on the bony morphology and desired reduction, either contouring or osseous genioplasty may be required (20,23). The procedure is usually performed through a transoral approach (*Figure 5*). The use of 3D models and cutting guides help in planning osteotomies near the inferior alveolar nerve. Custom plates can be fabricated, or standard plates can be pre-bent on the models and sterilized for use during the actual procedure. Potential complications after reduction genioplasty include mental nerve injury, damage to tooth roots, infection, mentalis muscle dysfunction, nonunion or bone resorption of the osteotomized bony segments (7). Overall patient satisfaction after chin procedures was reported to be high (7,17,24).

Results and conclusions

Point-of-care VSP and 3DP has been invaluable in our experience. It allows the surgeon to study the bony morphology, plan the surgical procedures, and use sterilizable guides to improve surgical accuracy. Furthermore, it allows the surgeon and the patient to review the surgical plan and deliberate the planned FGCS procedures and discuss alternatives using their 3D printed models. This enables improved patient understanding and education prior to surgery. It also offers the surgeon the opportunity to perform mock surgery on the 3D printed models to optimize the surgical plan. Furthermore, it allows

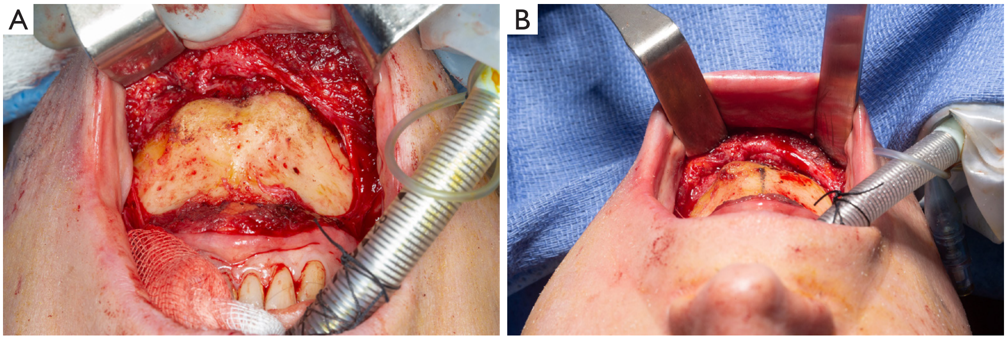

Figure 5 Osseous genioplasty. (A) osseous genioplasty reduction, whether by bony contouring such as in this case or bony osteotomy can be safely performed through a transoral approach, (B) the square chin (left side) is reduced to a narrower and more rounded shape (right side).

the surgical trainees to rehearse the surgery and improve their skills using patient specific models. In our practice, we use POC VSP and patient-specific 3D-printed models, cutting guides and templates much like pilots rely on flight simulations. The aim is to improve surgical precision.

Acknowledgments

Funding: None.

Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editors (Drs. Oscar J. Manrique, John A Persing, and Xiaona Lu) for the series "Transgender Surgery" published in *Annals of Translational Medicine*. The article has undergone external peer review.

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at http://dx.doi.org/10.21037/atm-20-6369

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/atm-20-6369). The series "Transgender Surgery" was commissioned by the editorial office without any funding or sponsorship. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Flores AR, Herman JL, Gates GJ, et al. How Many Adults Identify As Transgender in the United States? Williams Institute [Internet] 2016; Available online: https://williamsinstitute.law.ucla.edu/wp-content/uploads/Trans-Adults-US-Aug-2016.pdf
2. Ainsworth TA, Spiegel JH. Quality of life of individuals with and without facial feminization surgery or gender reassignment surgery. Qual Life Res 2010;19:1019-24.
3. Fu X, Qiao J, Girod S, et al. Standardized Protocol for Virtual Surgical Plan and 3-Dimensional Surgical Template-Assisted Single-Stage Mandible Contour Surgery. Ann Plast Surg 2017;79:236-42.
4. Efanov JI, Roy AA, Huang KN, et al. Virtual Surgical Planning: The Pearls and Pitfalls. Plast Reconstr Surg Glob Open 2018;6:e1443.
5. Stranix JT, Stern CS, Rensberger M, et al. A Virtual Surgical Planning Algorithm for Delayed Maxillomandibular Reconstruction. Plast Reconstr Surg 2019;143:1197-206.
6. Sharaf B, Levine JP, Hirsch DL, et al. Importance of computer-aided design and manufacturing technology in the multidisciplinary approach to head and neck reconstruction. J Craniofac Surg 2010;21:1277-80.
7. Morrison SD, Vyas KS, Motakef S, et al. Facial Feminization: Systematic Review of the Literature. Plast Reconstr Surg 2016;137:1759-70.
8. Capitán L, Simon D, Kaye K, et al. Facial feminization surgery: the forehead. Surgical techniques and analysis of results. Plast Reconstr Surg 2014;134:609-19.
9. Kane AA, Lo LJ, Chen YR, et al. The course of the inferior alveolar nerve in the normal human mandibular ramus and in patients presenting for cosmetic reduction of the mandibular angles. Plast Reconstr Surg 2000;106:1162-74; discussion 1175-6.
10. Rosado P, de Vicente JC, Villalaín L, et al. Posttraumatic frontal mucocele. J Craniofac Surg 2011;22:1537-9.
11. Spiegel JH. Challenges in care of the transgender patient seeking facial feminization surgery. Facial Plast Surg Clin North Am 2008;16:233-8, viii.
12. Fisher M, Lu SM, Chen K, et al. Facial Feminization Surgery Changes Perception of Patient Gender. Aesthet Surg J 2020;40:703-9.
13. Chen K, Lu SM, Cheng R, et al. Facial Recognition Neural Networks Confirm Success of Facial Feminization Surgery. Plast Reconstr Surg 2020;145:203-9.
14. Gray R, Nguyen K, Lee JC, et al. Osseous Transformation with Facial Feminization Surgery: Improved Anatomical Accuracy with Virtual Planning. Plast Reconstr Surg 2019;144:1159-68.
15. Ousterhout DK. Feminization of the forehead: contour

changing to improve female aesthetics. Plast Reconstr Surg 1987;79:701-13.
16. Dempf R, Eckert AW. Contouring the forehead and rhinoplasty in the feminization of the face in male-to-female transsexuals. J Craniomaxillofac Surg 2010;38:416-22.
17. Becking AG, Tuinzing DB, Hage JJ, et al. Transgender feminization of the facial skeleton. Clin Plast Surg 2007;34:557-64.
18. Cho SW, Jin HR. Feminization of the forehead in a transgender: frontal sinus reshaping combined with brow lift and hairline lowering. Aesthetic Plast Surg 2012;36:1207-10.
19. Habal MB. Aesthetics of feminizing the male face by craniofacial contouring of the facial bones. Aesthetic Plast Surg 1990;14:143-50.
20. Altman K. Facial feminization surgery: current state of the art. Int J Oral Maxillofac Surg 2012;41:885-94.
21. Hage JJ, Becking AG, de Graaf FH, et al. Gender-confirming facial surgery: considerations on the masculinity and femininity of faces. Plast Reconstr Surg 1997;99:1799-807.
22. Vasavada AN, Danaraj J, Siegmund GP. Head and neck anthropometry, vertebral geometry and neck strength in height-matched men and women. J Biomech 2008;41:114-21.
23. Deschamps-Braly J. Feminization of the Chin: Genioplasty Using Osteotomies. Facial Plast Surg Clin North Am 2019;27:243-50.
24. Shams MG, Motamedi MHK. Case report: feminizing the male face. Eplasty 2009;9:e2.

Cite this article as: Kuruoglu D, Yan M, Bustos SS, Morris JM, Alexander AE, Sharaf B. Point of care virtual surgical planning and 3D printing in facial gender confirmation surgery: a narrative review. Ann Transl Med 2021;9(7):614. doi: 10.21037/atm-20-6369

