



Computer-aided design and manufacturing technology applied to total nasal reconstruction

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Abstract

The principles of nasal reconstruction include the need to reconstruct three tissue layers, the need to restore entire skin aesthetical units, and, possibly, the replacement with like tissues. Computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies were applied to two total nasal reconstructions in male patients who underwent rhinectomy for cancer. Three-dimensional (3D) data were obtained from computerized tomography (CT) scan-derived DICOM files (Digital Imaging and Communications in Medicine), this allowed us to design the shape of the reconstructive nose in order to mimic the native nose and to plan dimensions and angles. A custom-made titanium plate was manufactured for the structure and a bi-dimensional template for the forehead flap was printed. The patients underwent a total nasal reconstruction in three layers: local flaps for the lining, custom-made titanium plate for the structure, and expanded forehead flap for the skin. Forehead flap pedicle was divided 3 weeks postoperatively under local anesthesia in an outpatient clinic, as well as further minor refinements. The patients underwent a 6-month post-operative CT scan in order to compare the result to the planned nose. No complications were reported. The superimposition demonstrated a 92% match in case 1 and 95% match in case 2 between the reconstructed nose and the planned one. Forehead flap is still the most favorable option for nasal reconstruction, CAD technology allows to implement the planning and makes the procedure easier; moreover, the use of a CAM plate for the structure allows to reconstruct a nose with the desired naso-frontal angle.

Level of evidence: level V, therapeutic study.

Keywords Nasal reconstruction · Forehead flap · CAD-CAM

Introduction

The principles of nasal reconstruction have not changed over time, while many different techniques have been proposed. The nasal reconstruction is one of the first reconstructive

operations performed since the dawn of civilization. The first reports of nasal reconstruction date back to sometime between 1000 and 800 BC, when Sushruta described in his “Samita” the use of a pedicled cheek flap [1], from 1000 BC onward in Kangra (near Delhi) the Kanghiara family used the “Indian method”, now commonly referred to as a paramedian forehead flap [2]. In the Renaissance (1597) in Bologna, Gaspare Tagliacozzi described in his “De curtorum chirurgia per insitionem” the “Italian method” for total nasal reconstruction with a tubed pedicled flap from the arm [3]. In the XX century, the introduction of free tissue transfer has provided multiple options for nasal reconstruction from distant donor sites and in 1994 Pribaz and Fine coined nasal flap prelamination [4], a process in which tissues or other devices are implanted into a vascular territory before it is transferred as a free flap. In the last decade, computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies have been widely applied to

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head and neck reconstructions, becoming the gold standard for mandibular reconstructions. It was demonstrated that CAD/CAM method for mandibular reconstruction improves morphological and functional results compared to traditional reconstructive techniques [5]. The main advantage seems to be the preoperative planning with the simulation of fibular removal and mandibular reconstruction, that is reproduced intra-operatively using mandibular and a fibular osteotomy cutting guides, together with a customized reconstructive plate. CAD/CAM technology has also been applied to other head and neck reconstructions, such as maxillary or orbital reconstruction, due to the high accuracy of the reconstruction [6].

We present our preliminary experience with CAD/CAM technology applied to total nasal reconstruction using an

expanded forehead flap for the skin, custom-made plate for the structure, and local flaps for the inner lining.

Operative technique

CAD/CAM technology was applied to two total nasal reconstructions in male patients who underwent subtotal rhinectomy for squamous cell carcinoma between 2019 and 2020 at the Otolaryngology and Head-Neck Surgery Department of Morgagni Pierantoni Hospital Forlì, Azienda USL Romagna.

Data on the patient's native nose before cancer and rhinectomy were collected from previous head computerized



Fig. 1 Seventy-three-year-old man with recurrence of skin squamous cell carcinoma involving the nasal septum and dorsum and lymph node metastasis (cT4aN2bM0). Previously, he underwent partial rhinectomy and reconstruction of the left ala with left forehead flap in other institution



Fig. 2 The patient underwent subtotal rhinectomy and bilateral neck dissection resulting in pN3b, ENE+, and sub-galeal positioning of a tissue expander on the upper right forehead (atypical position due to the scars of previous surgery)



Fig. 3 Adjuvant radiotherapy on *N* was administered. The reconstruction was delayed after 6 months from the end of radiotherapy on the neck, during this period the columella showed progressive distortion, gradually bending towards the left side

tomography (CT) scans (done for other reasons in the past) for three-dimensional (3D) rendering of the craniofacial skeleton and soft tissues. Furthermore, patients underwent a post-rhinectomy CT scan, performed using a multi-detector computed tomography scanner (HiSpeed CT scanning station; General Electric, Milan, Italy). Volumetric data were acquired (0.625-mm slice thickness, 0.312-mm slice spacing, 0-degree gantry tilt, 512 × 512-pixel resolution).

Data collected by the CT scans consisted in Digital Imaging and Communications in Medicine (DICOM) data that were shared with a dedicated engineer to create three-dimensional virtual models of the facial skeleton and the nose to be reconstructed, and to design a reconstructive plate for the structure (using these software: Mimics 20.0 Materialise NV Leuven Belgium; Magics 23.01 Materialise Leuven Belgium; 3-matic 12.0 Materialise NV Leuven Belgium; Geomagic Freeform 2019 0.1.67 3D Systems, Inc.-South Carolina, US; Rhinoceros 5.0 Robert McNeel & Associates Washington US; Keyshot 7 Luxion California, US; SharkCad Pro 10 WD Encore Software, Inc. Minneapolis US).

The shape of the nose to be reconstructed was designed starting from the desired naso-frontal and naso-labial angles, in order to mimic the native nose. The nose was planned smaller than the native one, in order to reduce the risks of complications due to tension on skin flaps.

We used ultrasounds to measure the thickness of the forehead expanded flap, and in both patients, it was 7 mm. By subtracting the thickness of the flap that will reconstruct the skin layer to the planned nose, a custom-made fenestrated



Fig. 4 Reconstruction of the entire nasal skin with a forehead flap was planned, the flap would have been sutured to the residual columella using an open rhinoplasty-like incision. We had an agreement with the patient that the goal was to provide him with a reconstructed nose resembling as much as possible the native one. The shape of the reconstructed nose was designed (CAD) in order to mimic the native nose and to plan dimensions and angles. A custom-made plate for the structure was designed

plate for the structure of the dorsum was designed. The plate was designed with points of reference to allow only the planned positioning on the naso-frontal region: five holes (1.5–2 mm diameter) were created for fixation of the plate with titanium screws [7].

The maximum length of the screws to avoid entering the frontal sinus was calculated.

The 3D planning was discussed by the reconstructive surgeons and the dedicated engineer with conference calls. The surgeons validated the final project, and the reconstructive plate was then manufactured in titanium Ti64 by direct metal laser sintering using an EOSINT M280 system (Electro-Optical Systems, GmbH, Munich, Germany).

Another identical temporary plate was printed in polyamide PA12 (using HP JET FUSION 3D 4200 Hewlett-Packard) to be sterilized and used intra-operatively as a sizer.

Moreover, the surface of the planned nose was developed into a bi-dimensional shape and the bi-dimensional template

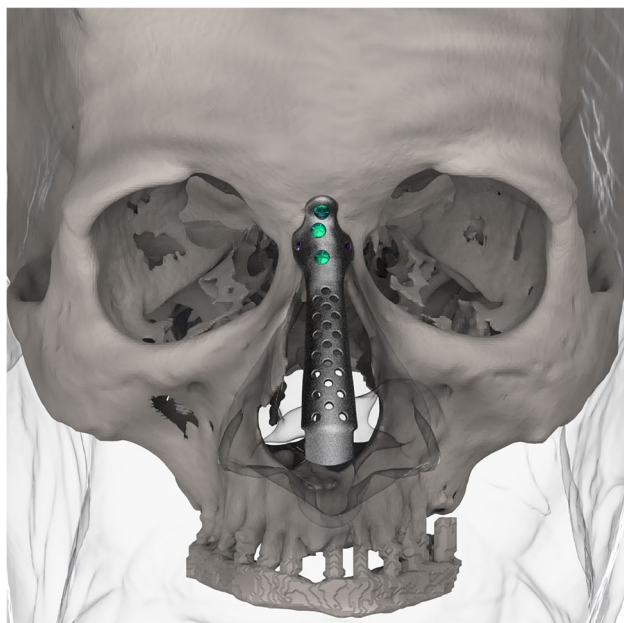


Fig. 5 The titanium Ti64 plate and the polyamide PA12 sizer plate were manufactured

for the forehead flap was printed on paper and used for pre-operative drawings, centering it on the doppler signal of the supratrochlear pedicle [8].

The patients underwent a total nasal reconstruction in three layers (local flaps for the lining, custom-made titanium plate for the structure, and expanded forehead flap for the skin).

Nasal fibroscopy was performed weekly in the first post-operative month, in order to check the intra-nasal flap vitality and wound healing.

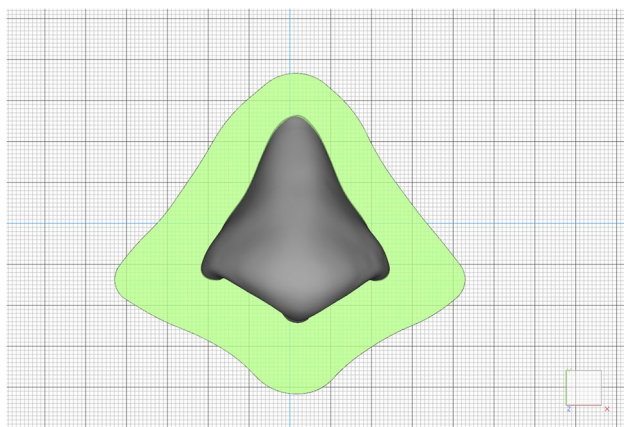


Fig. 6 The surface of the planned nose was developed into a bi-dimensional shape and the bi-dimensional template for the forehead flap was printed on paper, to be used pre-operatively for the drawings



Fig. 7 Linear ultrasound was used to map the right supratrochlear pedicle, the template was used to draw the flap on the forehead. Local hinge flaps were planned from the cheeks to reconstruct the lining

Forehead flap pedicle was divided 3 weeks after in local anesthesia in the outpatient clinic as well as further minor refinements were performed as required.

Number of minor procedures and complications were recorded.

The patients underwent a 6-month post-operative CT scan and nasal fibroscopy.

The plate position in post-operative CT scan 3D data was compared to the planned one for evaluating the precision of the method as the percentage of the difference between the postoperative plate position and virtual planning.

The patients underwent a 6-month post-operative rhinomanometry to evaluate the functional outcome.

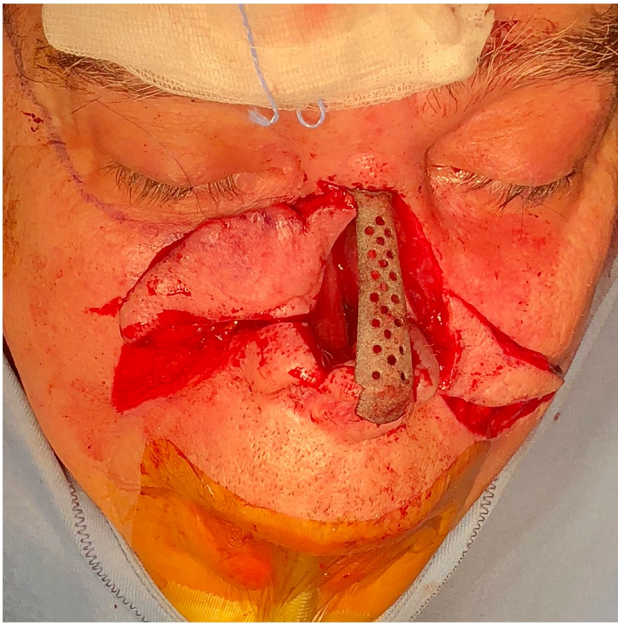


Fig. 8 The sizer plate was set in position (thanks to the points of reference only the planned positioning on the naso-frontal region was permitted), it was extremely useful to size the local flaps for the lining in order to minimize dead spaces

Representative cases

Case one is described in Figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11. Case two was treated with the same method: Figs. 12, 13 and 14.

No complications were recorded. Nasal fibroscopy performed weekly in the first post-operative month



Fig. 9 The sizer plate was removed and the final titanium plate was easily positioned, the holes created to fix the sizer plate were also used to position the definitive one. Also, the lining flaps were anchored to the plate using non-resorbable sutures



Fig. 10 Post-operative result at 27 months: front view

demonstrated intranasal flaps vitality and proper wound healing in both patients.

Patient 1 underwent four minor office procedures in local anesthesia: division of the forehead flap pedicle, scar revision, bilateral alar sulcus reconstruction, alar thinning procedure, and z plasty at the foot of the left ala nasi, in order to lower reposition it.

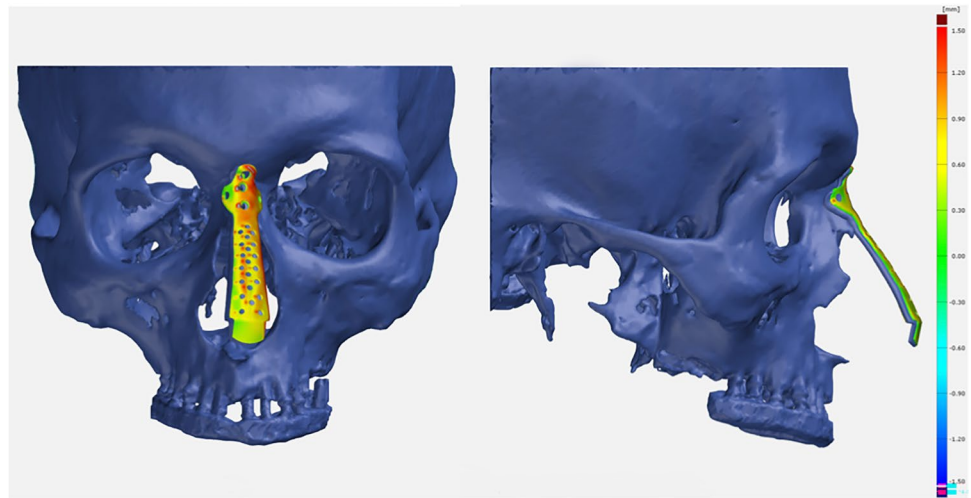
While patient 2 underwent three minor procedures in local anesthesia: division of the forehead flap pedicle, debulking of left ala nasi, and bilateral alar sulcus reconstruction.

The percentage of superimposition between the final result (CT scan at 6 months) and the planned plate position was 92% in patient 1 and 95% in patient 2.

Nasal fibroscopy performed at 6 months showed a stable healing of the inner sutures in both patients.

Rhynomanometry at 6 months recorded a satisfactory functional outcome in terms of nasal airflow in both patients. At present, patient 1 is at 32 months follow-up and patient 2 at 27 months follow-up with stable and aesthetically pleasant results (Figs. 11–14).

Fig. 11 GOM software (Zeiss Group) allows to superimpose the final plate position (derived from a CT scan at 6 months) and the pre-operative planned plate position: the average surface comparison on CAD for this patient was 92%



Discussion

Nowadays, it is widely accepted that nasal reconstruction should be performed in three layers and the forehead is still considered the most favorable donor site for nasal skin reconstruction because of the best possible skin color match

for the entire aesthetical nasal unit. Many modifications of the forehead flap technique have been described: median, paramedian, expanded, and propeller [9]. We personally prefer the expanded flap for multiple reasons: firstly, the flap is thinner, more pliable, and more similar to the skin layer to be replaced, secondly, the vascularization is enhanced and the harvesting is easier; lastly, a delayed reconstruction allows to



Fig. 12 Sixty-four-year-old man who underwent an incomplete rhinectomy for a septal squamous cell carcinoma and sub-galeal positioning of a tissue expander



Fig. 13 Post-operative result at 27 months: front view

perform multiple biopsies before the reconstructive phase in order to achieve a high safety of the oncological radicality.

For the lining, local flaps are preferred when available; otherwise, free flaps such as the radial forearm free flap [10] or a superthin pure skin perforator flap can be used [11].

In the reported method, the main novelties are the use of pre-operative 3D planning and the use of a customized titanium plate for the structure. In the historical first reports of nasal reconstruction, the structure was not mentioned [12]. The Italian method precisely described the harvesting of the tubed-pedicled flap from the arm and the transferring of a consistent amount of tissue in order to be adequately modelled as wearing leather outer covers [3]. Nowadays, in the case of functional reconstruction of the nose, the structural layer should be considered mandatory. The nasal reconstruction usually needs either a graft (usually costal cartilage) or a vascularized bone (for example the composite radial free flap used for the lining). The main disadvantage of autologous tissues for the structure is that it is mandatory to place them in the most stable position and stability can represent a real challenge. A cantilever-shaped graft can be mandatory to support the tip, therefore the naso-frontal angle can not be exactly planned and the one that guarantees the best stability has to be chosen.

Moreover, grafts are often too thick to be properly vascularized and may undergo a certain resorption rate, or, rarely, cause chronic infections with consequently surgical revision and failures [13].

The use of a titanium plate for the structure in a total nasal reconstruction is a novelty and few reports have been published on this topic [14, 15].

The plate is a foreign body and has therefore the potential risk of exposure, but on the other hand, reconstructive surgeons have expertise with the use of titanium plates covered by soft tissue flaps in head and neck surgery, when a bone flap is not available. It is common knowledge that, when a foreign body is introduced/used, the key to success is rigorous asepsis and safe and stable coverage [16]. In our preliminary experience, no complications occurred postoperatively.

The surgical method presented in this article offers several clinical advantages; first of all, the results showed that the reproducibility of the method seems promising. The procedure allowed to carefully restore the desired naso-frontal angle, technically more difficult with other methods. Moreover, the plate is designed with points of reference to allow only the planned positioning on the naso-frontal region, and its fixation allows a strong stability.

Also, the titanium mesh will resist the forces of contraction better than bone or cartilage [16]. On the other hand, the soft tissue flaps used to reconstruct the lining and the skin



Fig. 14 Post-operative result at 27 months: side view

should be well vascularized and not radio-treated in order to reduce the risk of exposure of the plate.

Other advantages were analyzed qualitatively but not quantitatively on the basis of the surgeon's experience.

The virtual environment permitted an ideal preoperative planning for the reconstruction, that is, in our opinion, the key point of the described method, allowing also less experienced surgeons to perform such a complex reconstruction. In fact, the dimensions of the forehead flap were calculated on the 3D planning in order to avoid any tension on the flap and the sutures and the naso-frontal angle was planned based on the native nose in order to achieve the best patient's compliance and acceptance of the reconstructed nose.

The importance of the sizer plate is crucial as the lining flaps may be more accurately harvested, limiting the air exposure of the titanium that will be lastly placed.

In these two cases, we did not need to modify the contribution from CAD intraoperatively; however, our team experience with CAD-CAM mandibular reconstruction may give a valid contribution in foreseeing soft tissue needs during the pre-operative planning phase.

A limitation is that the paper is a report on two cases and data do not allow to draw any definitive conclusion regarding the risk of delayed extrusion of the titanium plate, further evidence should be collected.

Conclusions

Forehead flap is still the most favorable reconstructive method for nasal skin reconstruction thanks to the color match of the skin and the possibility to replace the entire aesthetical nasal unit.

CAD technology allows to implement precision of the planning and makes the procedure easier and safer.

The use of a custom-made plate for the structure allows to reconstruct a nose with the desired naso-frontal and nasolabial angles that means more resembling the native one.

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Declarations

Ethics approval The study was exempted by a local ethics committee. 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.

Patient Consent Informed consent was obtained from all individual participants included in the study. Additional informed consent was obtained for the use of their images.

Conflict of interest Rossella Sgarzani, Giuseppe Meccariello, Giannicola Iannella, Manlio Gessaroli, Claudio Vicini, Davide Melandri, and Andrea Morellini declare that they have no conflict of interest.

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