OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE
Craniofacial/Pediatric

Autologous Ear Reconstruction and 3D Printing, an Innovative Hybrid Surgical-engineering Reconstructive Approach for Custom-made Ear Models: Our Experience

Francesca Gigola, MD*
Virginia Carletti, MD†
Michele Pezzella, MD‡
Alessandra Martin, MD§
Roberto Lo Piccolo, MD§
Elisa Mussi, PhD¶
Michaela Servi, PhD¶
Yary Volpe, Prof¶
Antonino Morabito, Prof†§
Flavio Facchini, MD§

Background: Microtia is a congenital anomaly of the ear. We present an innovative technique using a 3D personalized framework that could simplify and standardize the sculpting phase, thanks to reverse engineering and additive manufacturing techniques.
Methods: Three-dimensional models were realized by T3Ddy, a joint laboratory between the department of industrial engineering and Meyer Children's Hospital. Data were obtained retrospectively and included patient demographics, primary diagnosis, side of the affected ear, microtia classification, surgical time, length of hospitalization, type of skin approach and framework, complications, aesthetic results, and level of satisfaction using specific questionnaires. Data are reported as median and IQR.
Results: A total of 17 children (female gender: four) underwent auricular reconstruction surgery with autologous cartilage in our center, between 2019 and 2022. Median age at surgery was 14 years [interquartile range (IQR), 13–17], and the median hospitalization length was 5 days (IQR, 3–5). Median surgical time was 420 minutes (IQR, 406–452). Complications occurred in four patients out of 19 procedures, with a complication rate of 21%. Aesthetic results were satisfactory in all cases.
Conclusions: The three-dimensional models allow for an intuitive and precise approach. Having developed specific models for each component of the framework, we aimed to improve the aesthetic result and simplify the surgical intervention, guaranteeing a standardized yet personalized experience for each patient. The interprofessional partnership is fundamental to achieving this result. *(Plast Reconstr Surg Glob Open 2023; 11:e5131; doi: 10.1097/GOX.0000000000005131; Published online 21 July 2023.)*

INTRODUCTION

Microtia is a congenital anomaly of the ear that ranges from minor structural defects to the complete absence of the external ear (anotia).[1] Microtia occurs more frequently in male children and is a unilateral defect in 70%–90% of patients.[3] It can be isolated, but it is part of a syndromic complex in 50% of cases.[4] It is often associated with alterations of the external auditory canal like atresia auris, which can be observed in up to 80% of cases.[5]

Microtia can be treated surgically by three approaches: (1) silicon ear prosthesis, (2) auricle reconstruction with a plastic implant, and (3) reconstruction of the auricle by autologous tissue (harvested costal cartilage).[6] The prosthetic approach is a nonpermanent solution that involves artificial silicone ears attached to the patient by

*From the *Postgraduate School in Paediatric Surgery, University of Florence, Florence, Italy; †Department of Neurosciences, Psychology, Drug Research and Child Health (NEUROFARBA), University of Florence, Florence, Italy; ‡Faculty of Medicine, and Surgery, University of Florence, Florence, Italy; §Department of Paediatric Surgery, Meyer Children's Hospital IRCCS, Florence, Italy; and ¶Department of Industrial Engineering, University of Florence, Florence, Italy.*

Received for publication April 3, 2023; accepted May 30, 2023.

DOI: 10.1097/GOX.0000000000005131

Disclosure statements are at the end of this article, following the correspondence information.

Related Digital Media are available in the full-text version of the article on www.PRSGlobalOpen.com.

a craniofacial fixation implant or medical skin glue. This technique is characterized by low invasiveness and low risk of infection, and thus, it is a suitable solution for patients who cannot undergo surgery.[7]

The alloplastic technique with high-density porous polyethylene (Medpor) implants is a permanent solution using synthetic material implants as a support structure for complete auricle reconstruction.[8] Medpor is a stable, inert, biocompatible material that can be easily integrated into human tissue and promotes the internal growth of tissue.[9] This procedure has shown good aesthetic results[8]; however, the implant may not integrate as well as an autogenous cartilage graft from the rib, leading to high extrusion rates[10] and failure of reconstruction.[11]

Autologous costal cartilage grafts remain the standard clinical practice for ear reconstruction. It is a complex procedure with a long learning curve that requires a high grade of expertise to master.[12] It is composed of two surgical procedures. During the first procedure, a portion of the costal cartilages is harvested from the thoracic region[13] and sculpted into a framework that reproduces the anatomy of a normal ear. The complete framework is inserted in a newly created pocket, where the ear is anatomically located, and the skin is sutured over it.[14,15] The second procedure aims to give projection to the auricular complex and create the retroauricular sulcus.[16] The traditional approach involves creation of a two-dimensional template using a translucent X-ray film placed against the normal ear to trace its contours manually. Such a template guides the surgeon in cutting and sculpting costal cartilage.[17]

Our work aims to present a new technique using three-dimensional (3D) personalized surgical guides, simplifying and standardizing the sculpture of the framework using methods of reverse engineering and additive manufacturing.

MATERIALS AND METHODS

We developed a 3D model aid to help surgeons in all surgical phases. The model was realized by T3Ddy (Pediatric 3D technology), a joint laboratory between the department of industrial engineering and Meyer Children's Hospital.

Data were obtained retrospectively from medical charts. Families gave their informed consent for the procedures and for sharing information for this article. Our institution's medical ethical review board stated that this study is based on routinely collected data, no additional data were collected for the study, and no intervention was given solely for the study. Therefore, institutional review board approval was waived.

Patient variables included demographics, primary diagnosis, affected ear, microtia classification according to Marx classification,[19] auditory function, associated malformations, surgical time, length of hospitalization, complications, aesthetic results, and patients' level of satisfaction using specific questionnaires adapted from Hedén and Sinna,[20] and are shown in Table 1. Only 12 of 17 patients were considered eligible for the satisfaction questionnaire. Five patients were excluded because they underwent surgery less than 30 days before data collection. Data are reported as median and IQR.

Takeaways

Question: Is it possible to standardize the sculpture phase of ear framework, using reverse engineering to create 3D models?

Findings: Models were developed for each framework component with very good aesthetic results, reduced operative times, and rate of complications in line with the current literature. Our patients expressed great satisfaction through surveys.

Meaning: We aimed to improve the aesthetic result and simplify surgical intervention, guaranteeing a standardized yet personalized experience for each patient. Interprofessional partnership is fundamental to achieving this result.

Table 1. Satisfaction Questionnaires Adapted from Hedén and Sinna[20]

Question	Scoring
1. Which of the following alternatives corresponds best with your opinion of the treatment procedure?	0. Very unpleasant 1. Unpleasant 2. Acceptable
2. How would you describe how the treatment has changed how your face looks?	0. A lot worse 1. A little worse 2. Same as before 3. A little better 4. Much better
3. How would you describe how the treatment has changed your opinion of your looks in general?	
4. Are you satisfied with the surgical results of this procedure?	0. No 1. Yes

Our work consists of different phases. The first phase consists of the collection of patient's information and realization of two sets of 3D models: an accurate replica of the patients' costal cartilage and surgical guides based on the contralateral ear or on one of the parent's ears to help the ear reconstruction. In the second phase, these models are used to plan the personalized surgical intervention. Finally, in the surgical phase, the 3D models will guide surgical steps.

3D Models: Costal Cartilages Replica and Surgical Guides

Costal cartilage replicas (from the sixth to the ninth rib) are fabricated after acquiring high-resolution CT images, followed by image processing with segmentation software like Mimics Materialise. The next step is 3D modeling of the mold of the costal cartilages, using 3D modeling software like Geomagic Design X, and finally, fabrication of the mold using additive manufacturing techniques, and casting of mixtures of silicone rubber, corn-starch, and wood powder within the mold to obtain physical replicas of the costal cartilages.

The production process includes acquiring the healthy auricular anatomy of the patient or one of the parents with the 3D scanner Artec Eva and mirroring the auricular region obtained. This is followed by 3D modeling of surgical guides[21] and producing the guides

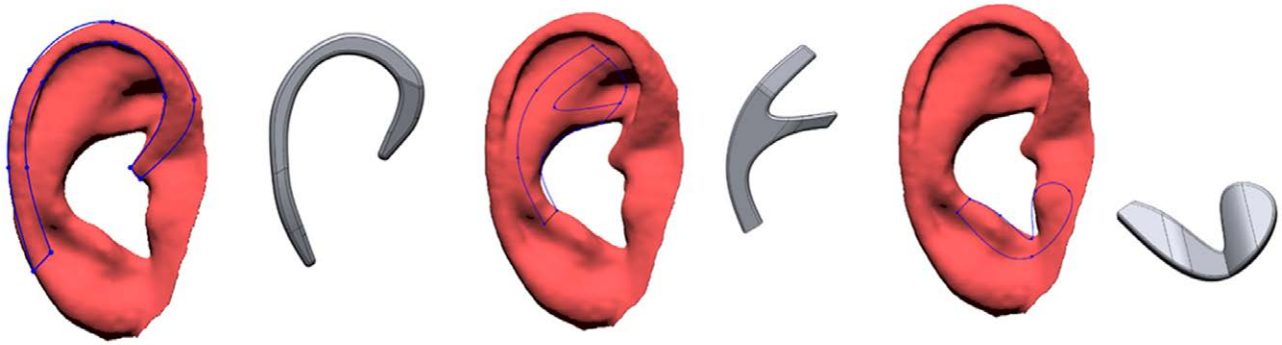

Fig. 1. Modeling process.

with additive manufacturing techniques with ABS-M30i, a biocompatible and sterilizable material. Surgical guides must reflect common characteristics, which have been defined through a trial-and-error process by physicians and engineers. In particular, the final shape of the 3D surgical guides follows the patient's anatomy while simplifying it. In fact, as explained in previous studies,[1,2] surgical guides that replicate the patient's anatomy too closely are not suitable for use in the surgery room because they exhibit micrometric details that cannot be reproduced by the manual process of sculpting cartilage. The simplification of anatomy outside the surgery room allows the physician to avoid performing the mental process of simplification in the moment but to be able to rely on surgical tools to guide him in carving a replicable geometry consistent with the symmetry of the patient's face. The modeling process that is schematized in Figure 1 involves delineation of element contours and computer-aided design (CAD) operation of 3D modeling of surgical guides. For a more detailed description of the modeling procedure, the reader is referred to previous studies.[1,2]

Preoperative Planning and Simulation

To familiarize with the patient's anatomy, we create a model made of a material that mimics the consistency of costal cartilage.[22] The surgeons can train on this replica with the custom-made surgical guides of the framework.[23] This phase allows for choosing the better cartilage for every fragment of the framework, and the whole sculpting process can be reproduced before making the first incision.[24] For surgeons approaching this technique for the first time, the sculpting phase can be reproduced without any risk of spoiling the precious cartilages of the patient while developing the necessary skills.[25]

Surgery

Surgery comprises three phases: cutaneous dissection in the ear region with removing all cartilage remnants; harvesting, sculpting, and carving of the autologous cartilage; and insertion of the newly created ear framework in the skin pocket and suturing[26] (Fig. 2).

The sterilized 3D models are used to define the limits of the skin pocket during cutaneous dissection (Fig. 3). This shows whether the dissection is extended enough to

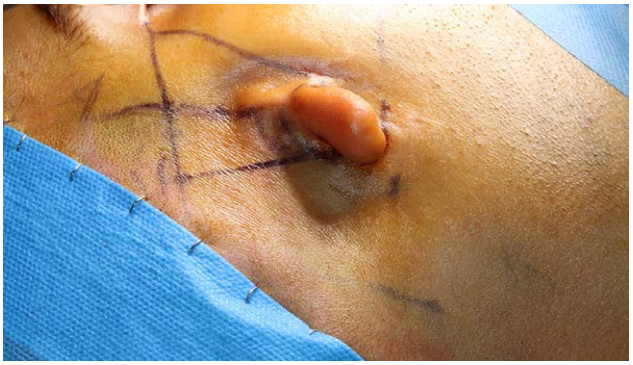

Fig. 2. A case of microtia, grade 3 according to Marx classification.

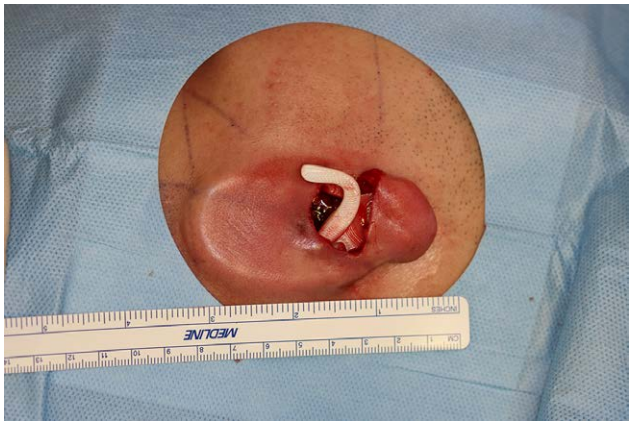

Fig. 3. Defining skin pocket limits during cutaneous dissection.

accommodate the carved costal cartilage in the subsequent phase. It also allows for the visualization of cutaneous imperfections and skin quality. A costal 3D model is used to plan the thoracic incision and cartilage harvesting in the second phase. This grants thorough knowledge of the patient's anatomy beforehand: the models optimize the harvesting stage. This will prevent unnecessary broad incisions.

The 3D set comprises different fragments: complete framework, base, helix, antihelix, tragus, and antitragus complex (Fig. 4). These fragments are used to guide the carving process; this phase can be realized by more than

Fig. 4. The 3D ear set.

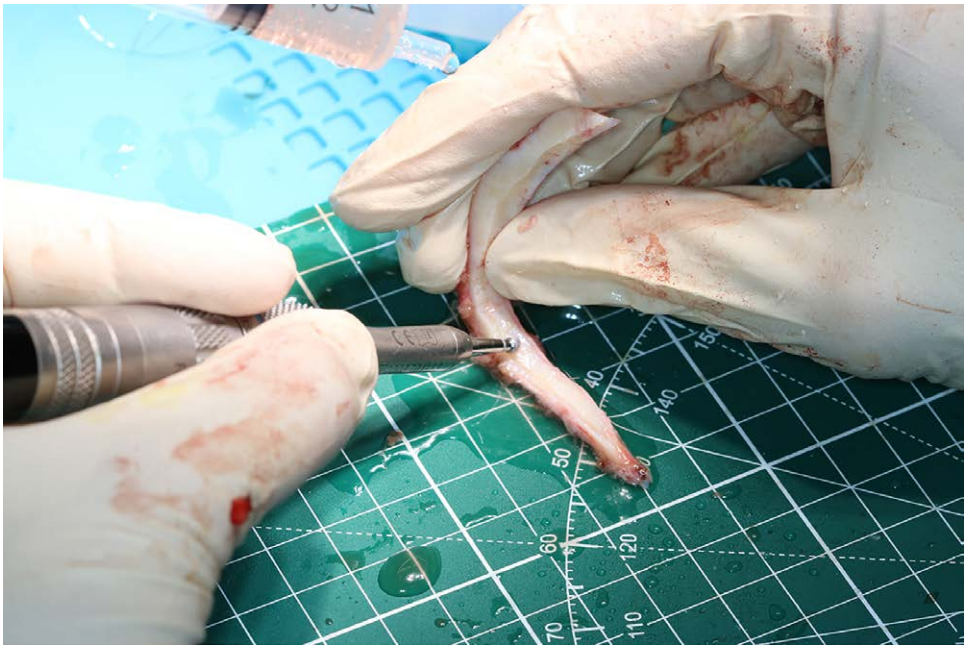

Fig. 5. A phase of the carving process.

one surgeon at a time, reducing surgical timing because each piece will guide the realization of its cartilage counterpart (Fig. 5). In our team, the first operator usually sculpts the base and the helix, and the second operator the antihelix and the tragus-antitragus complex. After carving and sculpting, fragments compose the final framework using metallic 5.0 suture wires (Fig. 6).

The complete framework is inserted into the skin pocket; two 10Ch silicon drains are left in place, and the skin is sutured using 5.0 PDS (Fig. 7). The newly constructed ear is patched up with paraffin gauze medication.[27] Patients are usually discharged on the third postoperative day and followed up at the outpatient clinic twice per week in the first 2 weeks until complete wound healing.

RESULTS

Between January 2019 and November 2022, 17 children (female gender: four) underwent auricular reconstruction surgery with autologous cartilage in our center. In two

Fig. 6. Final framework.

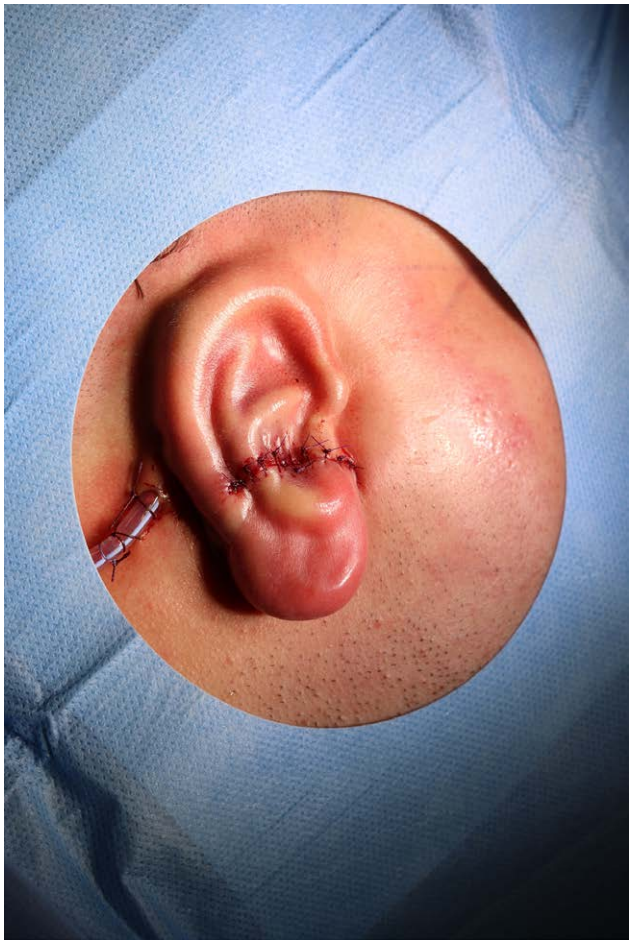

Fig. 7. Final result.

cases, surgery was performed twice due to bilateral malformation. In three cases, the malformation was bilateral; in four cases, the defect affected the left ear, and in 10 cases, the right ear. All patients but two presented microtia as an isolated defect; one patient was affected by Goldenhar syndrome and one by Oto-mandibular Syndrome. According to Marx classification,[19] three patients presented type 2 and 14 presented type 3 microtia; in three cases, the external auditory canal was present. The auditory function of all patients was evaluated before surgery: eight presented conductive hypoacusia, and eight had complete hearing loss from the affected ear. In contrast, in one case, the auditory function was preserved. Four patients had bone-anchored hearing aids. No family history of microtia or auricular malformation was identified in all selected patients except two. Median age at surgery was 14 years (IQR, 13–17). The patient's characteristics are summarized in Table 2.

All patients were admitted the day before surgery, and routine preoperative blood examinations were conducted (complete blood count, coagulation tests, blood group, and cross tests); antibiotic prophylaxis was performed on all patients with 1.5 g of cefazolin 30 minutes before the first incision and another 1.5 g of cefazolin after 3 hours.

According to the classification developed by Francoise Firmin,[12] surgery was conducted using a type 2 skin approach in 11 cases (two times on one patient with bilateral defect), type 3A in four cases (two times on one patient with bilateral defect), and type 3b in two. Early postoperative complications (defined as complications occurring in the first seven postoperative days) occurred in four patients out of 17 procedures, with a complication rate of 23.5%. They consisted of wound dehiscence in three cases and punctiform necrosis of the root of the helix in one case. In two cases, the dehiscence was treated

Table 2. Patient Characteristics

Patient	Gender	Age at Surgery (y)	Side	Associated Malformations	Microtia Classification	External Auditory Canal	Atresia Auris	Auditory Function	Auditory Rehabilitation	Inheritance Pattern
1	M	18	Right	Oto-mandibular syndrome	Grade 3	Absent	No	Conductive hypoacusia	No	Absent
2	F	13	Bilateral	No	Grade 2	Absent	Grade 3	Conductive hypoacusia	BAHA	Absent
3	M	17	Bilateral	No	Grade 2	Absent	Grade 2	Conductive hearing loss	BAHA	Absent
4	M	17	Left	No	Grade 3	Absent	Grade 2	Conductive hearing loss	No	Present
5	F	14	Left	No	Grade 2	Absent	Grade 3	Conductive hearing loss	BAHA	Absent
6	M	14	Right	No	Grade 3	Absent	Grade 2	Conductive hearing loss	BAHA	Absent
7	M	14	Right	No	Grade 3	Absent	Grade 3	Conductive hearing loss	No	Absent
8	M	10	Right	No	Grade 3	Absent	No	Conductive hypoacusia	No	Absent
9	M	16	Bilateral	No	Grade 3	Present	NA	Normal	No	Present
10	M	15	Right	No	Grade 3	Present	NA	Conductive hearing loss	No	Absent
11	M	10	Left	No	Grade 3	Present	No	Conductive hearing loss	No	Absent
12	F	11	Left	No	Grade 3	Absent	No	Conductive hearing loss	No	Absent
13	M	22	Right	Goldenhar syndrome	Grade 3	Absent	No	Conductive hypoacusia	No	Absent
14	M	25	Right	No	Grade 3	Absent	No	Conductive hypoacusia	No	Absent
15	M	13	Right	No	Grade 3	Absent	No	Conductive hypoacusia	No	Absent

Microtia stage was defined according to the Marx classification; atresia auris was defined according to Altman classification.
BAHA, bone anchored hearing aids; M, masculine; F, feminine.

with an auricular fascia flap topped with a thin skin graft, and in one case, the patient was submitted to a Z-plasty. The necrosis was first treated with infiltration of platelet gel without success; this was followed by debridement of the necrosis and reconstruction with an auricular fascia flap topped with a thin skin flap.

Median hospitalization length was 4.5 days (IQR, 3–5). Median surgical time was 433 minutes (IQR, 409–450), including the preparatory sketches and the Doppler sonography of the superficial temporal artery. Characteristics of surgery are shown in Supplemental Digital Content 1. (**See table, Supplemental Digital Content 1**, which displays skin approach and type of framework used were defined based on Firmin Classification. Some patients appear twice in the table because they were operated on bilaterally. Surgical timing was calculated, including preparatory sketches and the Doppler sonography of the superficial temporal artery. **http://links.lww.com/PRSGO/C669**.) Median follow-up was 13 months (IQR, 3–18).

The median score of satisfaction according to the adapted version of Hedén and Sinna[20] was 9.5 out of 11 (IQR, 7–10.25). Six of 12 patients graded their satisfaction level over 10 out of 11. The questionnaire's results are listed in Table 3.

Table 3. Satisfaction Questionnaire Answers

Patient	Question 1	Question 2	Question 3	Question 4	Total Score
1	Acceptable	Same as before	Same as before	Yes	7/11
2	Acceptable	Much better	Same as before	Yes	9/11
3	Acceptable	Much better	Same as before	Yes	9/11
4	Acceptable	Much better	Much better	Yes	11/11
5	Acceptable	Same as before	Same as before	Yes	7/11
6	Acceptable	Much better	A little better	Yes	10/11
7	Acceptable	Much better	A little better	Yes	10/11
8	Unpleasant	Same as before	Same as before	Yes	6/11
9	Acceptable	Much better	Much better	Yes	11/11
10	Acceptable	Much better	A little better	Yes	10/11
11	Acceptable	Same as before	A little better	No	7/11
12	Acceptable	Much better	Much better	Yes	11/11

Questionnares were adapted from Hedén and Sinna[20]; the last three were excluded because of short follow-up.

DISCUSSION

Auricle reconstruction with autologous material is technically one of the most complex procedures in reconstructive surgery.[28] Three-dimensional surgical guides have been introduced in the clinical practice as aids in the training phase and the carving process.[29] In fact, 3D template is created using a systematic CAD procedure to reconstruct with the utmost precision the patient characteristics, guiding the surgeon in the harvesting and carving phases. Furthermore, with 3D models, the surgeon has all the information about the three-dimensional shape of the ear, including the height and thickness of the anatomical elements of the ear structure.

The literature shows that 3D printed auricular templates and ear models have been used in many ways in recent years. Jeon et al[18] proposed a mirrored, sterilizable 3D print of the ear that can be used as a guide during reconstructive surgery. You et al[30] proposed a simplification of this approach by using a lidar iPhone camera instead of expensive 3D scanners to simplify and reduce the costs of this kind of surgery. Alhazmi et al[31] introduced a prefabricated, standard template that is sterilizable and printable in many sizes.

One of the main aspects of the novelty of our procedure is the possibility to fabricate custom-made and personalized 3D models of the single components that must be sculpted during the surgery. The 3D surgical guides ensure excellent symmetry in carving with a highly coherent result with the ear taken as model.[32]

Furthermore, with the classic 2D model, it is crucial to reduce the dimensions of the traced contours because skin thickness must be taken into consideration.[3] With our customized frameworks, the final measures of each component are previously calculated to have accurate proportions, which will grant a more harmonic result.

In our center, with the help of these aids, we could train pediatric surgeons who had never practiced any pediatric ear reconstruction before, who now are permanent members of the ear reconstruction team. Our 3D models allow us to improve the learning curves of surgeons in training, fast-forwarding the acquisition of the artistic abilities needed in this kind of surgery.

With the 3D printed model of the whole framework, it is possible to create an extremely accurate skin pocket even before opening the thorax and harvesting the cartilages. Many surgeons can actively participate during the sculpting phase: different operators can reproduce 3D printed components of the ear that the first operator will later unite. This could help reduce sculpting times. To further reduce operating times, we plan to combine the first and second phases and work simultaneously on the cutaneous dissection in the ear region and cartilage harvesting.

The 3D reproduction of the costal cartilages gives a further aid in the surgical approach,[24] both during the training phase and in the perioperative preparation of the costal designs and cartilage harvest. Surgeons can familiarize themselves with the cartilages that will be used. With such precise models, the harvesting process is also improved with better perioperative sketches.

Our median surgical time was 433 minutes (IQR, 409–450); this calculation includes the preparatory sketches and the Doppler sonography of the superficial temporal artery. This does not allow us to calculate the total duration of surgery, starting from skin incision until skin suturing at the end.

The complication rate was 23.5%, comparable to the data reported in the literature for ear reconstructions without skin expansion and middle ear reconstruction (complication incidence is 16.2% on average with a range of 0%–72.9%).[33–35] However, there is a large variability in the literature regarding complication rates in autologous cartilage ear repair for microtia patients.[37]

The principal limitation of this approach is the process that leads to the production of the surgical guides. Even though the cost of the printed model is not expensive (around 100 euros for a complete set of surgical guides), the infrastructure involved in the development of these aids can be a limitation for some hospitals. In our center, the production of the final models requires a high-definition 3D scanner, CAD-based software, a 3D printer with a suitable material that does not deform when sterilized, and an engineer that deals with the whole fabrication process. The fabrication process usually takes around a week.

All the parts of the future ear are accurately pondered and put in a form that is highly accessible to the surgeon. Every aspect of the surgery can be influenced and improved by using these devices. Using these 3D models simplifies the surgical process, and these aids could also be a support for those centers with no experience that are willing to introduce this surgery.

CONCLUSIONS

Additive manufacturing and its applications in the medical field are already an essential clinical reality, but this is also an area of development with features yet to be explored. Thanks to this new way of developing specific models for each framework component, we aimed to improve the aesthetic result and simplify the surgical intervention, guaranteeing a standardized yet personalized experience for each patient. The interprofessional partnership is fundamental to achieving this result.

Virginia Carletti
Viale Gaetano Pieraccini 24
50139, Florence, Italy
E-mail: virginia.carletti@unifi.it

DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

REFERENCES

1. Chen X, Zhang R. Microtia epigenetics: an overview of review and new viewpoint. *Medicine (Baltimore)*. 2019;98:e17468.
2. Luquetti DV, Heike CL, Hing AV, et al. Microtia: epidemiology and genetics. *Am J Med Genet A*. 2012;158A:124–139.
3. Bartel-Friedrich S. Congenital auricular malformations: description of anomalies and syndromes. *Facial Plast Surg*. 2015;31:567–580.

4. Hartzell LD, Chinnadurai S. Microtia and related facial anomalies. *Clin Perinatol*. 2018;45:679–697.
5. Zhang TY, Bulstrode N, Chang KW, et al. International consensus recommendations on microtia, aural atresia and functional ear reconstruction. *J Int Adv Otol*. 2019;15:204–208.
6. Baluch N, Nagata S, Park C, et al. Auricular reconstruction for microtia: a review of available methods. *Plast Surg (Oakv)*. 2014;22:39–43.
7. Federspil PA. Auricular prostheses in microtia. *Facial Plast Surg Clin North Am*. 2018;26:97–104.
8. Mussi E, Furferi R, Volpe Y, et al. Ear reconstruction simulation: from handcrafting to 3D printing. *Bioengineering (Basel)*. 2019;6:E14.
9. Romo T, Presti PM, Yalamanchili HR. Medpor alternative for microtia repair. *Facial Plast Surg Clin North Am*. 2006;14:129–136, vi.
10. Ma Y, Lloyd MS. Systematic review of medpor versus autologous ear reconstruction. *J Craniofac Surg*. 2022;33:602–606.
11. Ali K, Trost JG, Truong TA, et al. Total ear reconstruction using porous polyethylene. *Semin Plast Surg*. 2017;31:161–172.
12. Firmin F, Dusseldorp J, Marchac A. *Auricular Reconstruction*. 1st ed. Thieme:37–39.
13. Cubitt JJ, Chang LY, Liang D, et al. Auricular reconstruction. *J Paediatr Child Health*. 2019;55:512–517.
14. Bly RA, Bhrany AD, Murakami CS, et al. Microtia reconstruction. *Facial Plast Surg Clin North Am*. 2016;24:577–591.
15. Firmin F. State-of-the-art autogenous ear reconstruction in cases of microtia. *Adv Otorhinolaryngol*. 2010;68:25–52.
16. Chen ZC, Goh RCW, Chen PKT, et al. A new method for the second-stage auricular projection of the Nagata method: ultra-delicate split-thickness skin graft in continuity with full-thickness skin. *Plast Reconstr Surg*. 2009;124:1477–1485.
17. Yamada A. Autologous Rib Microtia construction: nagata technique. *Facial Plast Surg Clin North Am*. 2018;26:41–55.
18. Jeon B, Lee C, Kim M, et al. Fabrication of three-dimensional scan-to-print ear model for microtia reconstruction. *J Surg Res*. 2016;206:490–497.
19. Alexander G, Anton G, Beck K, et al. *Krankheiten des Gehörorgans: Erster Teil: Anatomie· Entwicklungsgeschichte Physiologie·Pathologie· Untersuchungsmethoden. Therapie*. Vol. 6. Springer-Verlag, 2013:378–389.
20. Hedén P, Sinna R. An open, prospective study to evaluate the effectiveness and safety of hyaluronic acid for pectus excavatum treatment. *Aesthet Surg J*. 2019;39:NP189–NP201.
21. Facchini F, Morabito A, Buonamici F, et al. Autologous ear reconstruction: towards a semiautomatic CAD-based procedure for 3D printable surgical guides. *CAD'20*. 2020:1–5.
22. Servi M, Mussi E, Furferi R, et al. A CAD-based tool for tissue-mimicking replica of human costal cartilage. In: Rizzi C, Campana F, Bici M, et al, eds. *Design Tools and Methods in Industrial Engineering II*. Springer International Publishing. *Lecture Notes in Mechanical Engineering*. 2022:199–208.
23. Berens AM, Newman S, Bhrany AD, et al. Computer-aided design and 3D printing to produce a costal cartilage model for simulation of auricular reconstruction. *Otolaryngol Head Neck Surg*. 2016;155:356–359.
24. Mao X, Li X, Jia J, et al. Validity and reliability of three-dimensional costal cartilage imaging for donor-site assessment and clinical application in microtia reconstruction patients: a prospective study of 22 cases. *Clin Otolaryngol*. 2020;45:204–210.
25. Erdogan B, Morioka D, Hamada T, et al. Use of a plastic eraser for ear reconstruction training. *Indian J Plast Surg*. 2018;51:66–69.
26. Firmin F. [Auricular reconstruction in cases of microtia. Principles, methods and classification]. *Ann Chir Plast Esthet*. 2001;46:447–466.
27. Anghinoni M, Bailleul C, Magri AS. Auricular reconstruction of congenital microtia: personal experience in 225 cases. *Acta Otorhinolaryngol Ital*. 2015;35:191–197.
28. Ebrahimi A, Kazemi A, Rasouli HR, et al. Reconstructive surgery of auricular defects: an overview. *Trauma Mon*. 2015;20:e28202.
29. Flores RL, Liss H, Raffaelli S, et al. The technique for 3D printing patient-specific models for auricular reconstruction. *J Craniomaxillofac Surg*. 2017;45:937–943.
30. You P, Liu YCC, Silva RC. Fabrication of 3D Models for microtia reconstruction using smartphone-based technology. *Ann Otol Rhinol Laryngol*. 2022;131:373–378.
31. Alhazmi B, Alshomer F, Alawirdhi B. Multiscale sterilizable 3D printed auricular templates to guide cartilaginous framework sizing and sculpture during autologous microtia reconstruction. *JPRAS Open*. 2021;28:121–125.
32. Zhou J, Pan B, Yang Q, et al. Three-dimensional autologous cartilage framework fabrication assisted by new additive manufactured ear-shaped templates for microtia reconstruction. *J Plast Reconstr Aesthet Surg*. 2016;69:1436–1444.
33. Tripathee S, Xiong M, Zhang J. Microtia ear reconstruction using tissue expander and autologous costal cartilage: our experience and comparing two age groups. *World J Plast Surg*. 2019;8:324–330.
34. Fu YY, Li CL, Zhang JL, et al. Autologous cartilage microtia reconstruction: complications and risk factors. *Int J Pediatr Otorhinolaryngol*. 2019;116:1–6.
35. Long X, Yu N, Huang J, et al. Complication rate of autologous cartilage microtia reconstruction: a systematic review. *Plast Reconstr Surg Glob Open*. 2013;1:e57.