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Original Article

Multiscale sterilizable 3D printed auricular templates to guide cartilaginous framework sizing and sculpture during autologous microtia reconstruction

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ABSTRACT

Microtia reconstruction using autologous costal cartilage can be one of the most challenging tasks in reconstructive surgery. An intraoperative guide using 2-dimentional drawing of the contralateral ear on an x-ray film remains the current standard of care. In this paper, we present the use of computer-aided design and desktop 3D printing to fabricate low cost, sterilizable auricular carving templates to serve as a peri-operative reference for microtia reconstruction. The design was made as a single component which incorporated the usual anatomic reference points of the ear based on Nagata technique as a Stereo-lithography file format (. STL) for 3D printing. The templates were created in sizes ranging from 55 mm to 70 mm with a 2 mm increment with an average production cost of 0.26 US dollars per material per template and about 4.5 US dollars for the whole set. Individual templates were then 3D-printed using a thermoplastic polyurethane (TPU 95A) semiflexible filament on a desktop fused deposition modeling, Ultimaker 2 + 3D printer. The produced template tolerated the sterilization process with no structural changes as compared to its pre-sterilization con-

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dition. In conclusion, we present cost-effective, sterilizable, multiscale auricular templates to guide the pre- and intra-operative carving of the cartilaginous framework during microtia reconstruction with more accuracy in a time efficient manner, thereby overcoming the drawbacks of using the traditional x-ray film. The templates are readily accessible and sharable for free through open-source software and can be directly 3D-printed using an affordable desktop 3D printer.

Introduction

Microtia is a congenital anomaly of unknown etiology resulting in underdeveloped or malformed external ear that occurs in association with other syndromes or in isolation with approximately 70–90% of the cases being unilateral.[1,2] Beside auditory impairments, the deformity can also impact patients' quality of life and psychological wellbeing.[1,3] The management of microtia consists of a multidisciplinary approach, part of which is the surgical repair which has been shown to significantly improve self-confidence and quality of life of affected individuals.[1] Different surgical approaches available for microtia reconstruction include the use of autologous costal cartilage, artificial implants (i.e., porous polyethylene), or ear prosthesis (i.e., osseointegrated implants), with the former being the most popular method.[4]

Surgical repair of microtic ear using autologous costal cartilage can be one of the most challenging tasks in reconstructive surgery. The design of cartilaginous framework plays a pivotal role in the final appearance and symmetry of the reconstructed ear. Traditionally, a cut x-ray film has been utilized to guide carving the auricular construct as it delineates the overall contour, length and width of the unaffected ear.[5] However, auricular distortion can result from too much pressure exerted over the auricle.[5] Drawing on plain film is also subjective to human errors specially with less experienced surgeons.[5] Such technique is time consuming and necessitates sterilization of the x-ray film made template after it has been cut to be used in the sterile field. The innovative applications of 3-dimentional (3D) printing technology in medicine have made it possible to produce state-of-art patient-specific 3D templates mirroring the unaffected ear to guide intraoperative carving and assembly of the cartilaginous framework.[1–3,5–7] Although, the use of customized 3D models translated into superior outcomes and less operative time compared to the usual x-ray film template, such technology however is not readily available in all institutions; the 2-dimentional (2D) drawing of contralateral side remains the current standard of care.[1–3,5–7]

In this paper, we present the use of computer-aided design and desktop 3D printing to fabricate sterilizable, cost-effective auricular carving templates based on Nagata technique and designed to be available in variable sizes. The aim of these templates is to serve as an intraoperative reference for microtia reconstruction omitting the need for peri-operative making of x-ray film-based template; thus, reducing associated inevitable human errors and operative time.

Materials and methods

The design consisted of a single component that incorporated the usual anatomic reference points of the ear all in one unit as a Stereo-lithography file format (. STL) for 3D printing. The individual subunits are based on the essential anatomical landmarks described in Nagata technique including the helix and crus helix unit; the antihelix and superior and inferior crus unit; and the incisura intertragica and tragus unit.[8]

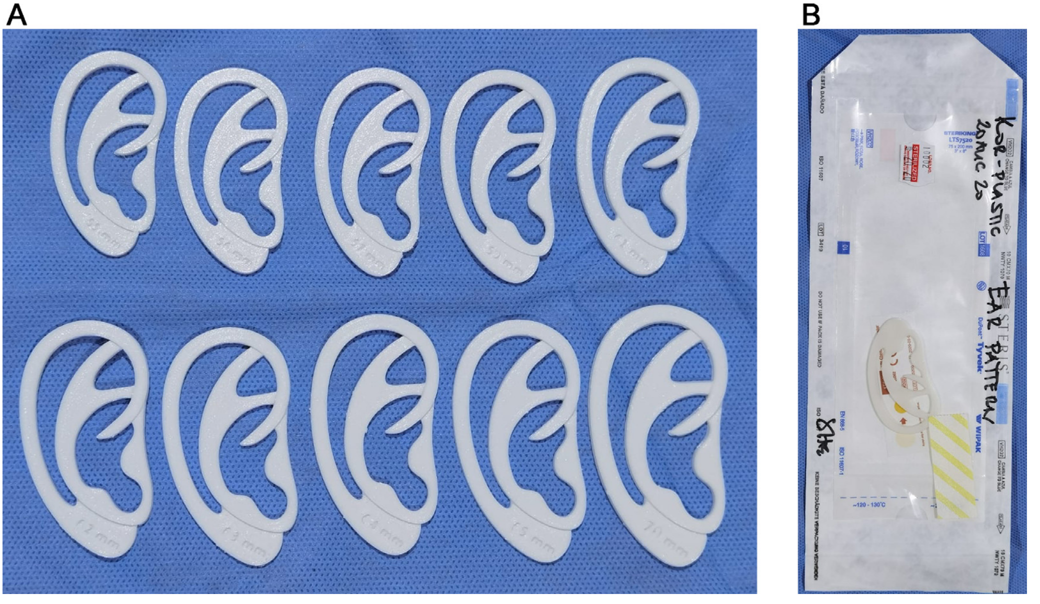

Fig. 1. A. Shows an example of the produced 3D-printed auricular templates of variable sizes. B. Intact template following sterilization.

Individual templates were then 3D-printed using a thermoplastic polyurethane (TPU 95A) semi-flexible filament on a desktop fused deposition modeling, Ultimaker 2 + 3D printer. The templates were created in different sizes ranging from 55 mm to 70 mm with a 2 mm increment and a thickness of 2 mm (Fig. 1a). An appropriate size can be chosen by a trial of matching the template with the patient's contralateral ear in the preoperative visit (Fig. 2). In cases of bilateral microtia, one of the parents' ear can be used as a reference point to estimate the appropriate template size.

The template was cleaned, secured in autoclave bag, and then tested for sterilization. The tool was autoclaved with STERIS Amsco V-PRO 1 Plus low temperature sterilization system. The sterilization process involved a 28-minutes cycle with a temperature that ranged from 48.5 to 51.5 °Ce and a pressure that started at 1 Torr with a rise that ranged from 6.3 to 15 Torr and a transition of more than 500 Torr. The produced template tolerated the sterilization process very well with no structural changes as compared to its pre-sterilization condition as shown in (Fig. 1b).

Discussion

Since its introduction in the 1980s, 3D printing technology has evolved dramatically increasing its accessibility and application in the surgical field.[9] In craniofacial surgery, the valuable utility of this tool has been reported in a plethora of procedures such as cranioplasty, facial bone fractures, orthognathic surgery, maxillary and mandibular reconstruction as well as microtia reconstruction.[6,10–14] Its myriad applications include the creation of customized surgical tools, tactile replicas of pathologies that aid in patient education, surgical training models, as well as patient-specific models used for peri-operative planning.[6,10–14] Another pioneering aspect is the production of 3D printed patient-customized implants.[10,14] In microtia reconstruction, many modalities to produce patient-specific 3D models of the unaffected ear to guide surgical repair have been reported. Nevertheless, customization requires more resources which might not be readily available, rendering its applicability and widespread use limited. To date, 2D drawing of the unaffected ear on an x-ray film remains the current standard of care.

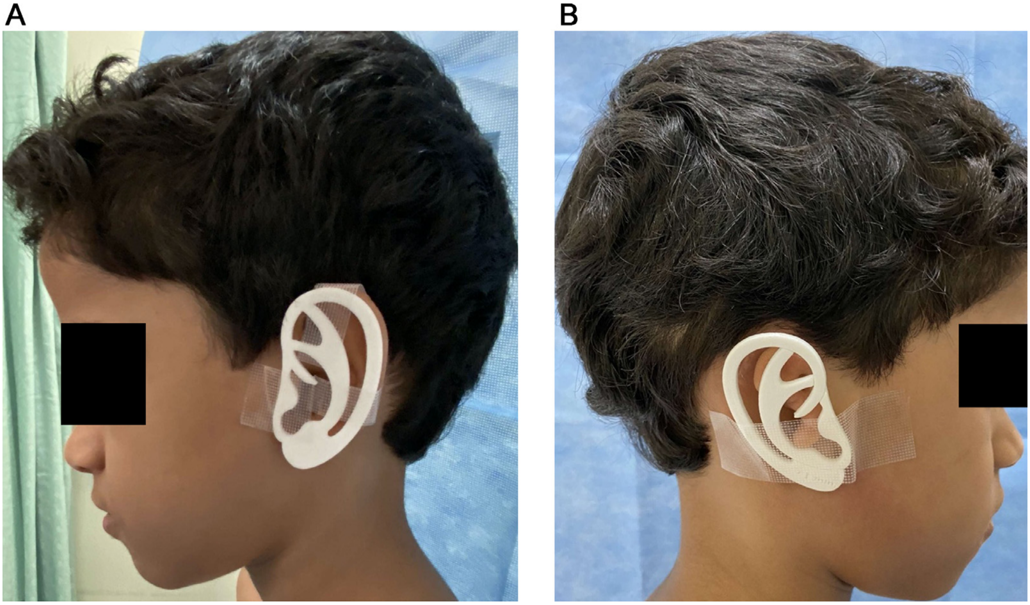

Fig. 2. A. Shows the utility of the produced template in guiding the size choice of the planned framework that was selected based on the size of the unaffected ear in the preoperative visit with the feasibility of adjusting that size to anticipate future growth B. Shows the same patient with the selected template based on the normal side reflected on the affected side.

Utilizing previous anthropological analyses of the external ear, Chen et al. produced ear templates sized from 52 to 72 mm with a 2 mm interval to guide intraoperative microtia reconstruction.[15] However, in their technique, an ear template was produced by initially carving a paraffin wax into the desired auricle shape and size; then, reverse casting was done using silicon mold. Following that, the final ear template was produced with the use of urethane resin casting. This process can be tedious as it requires multiple steps and proficient carving skills to produce such models which are still subject to human errors. Herein, we propose a different take in which a carving template designed in several sizes can be directly 3D printed using an open-source software and an affordable desktop 3D printer. The utilization of this technology allows for mass production and offers less associated costs as it is readily accessible for free through open-source software. The model production was associated with an average printing time of 35 min and an average cost of 0.26 US dollars per material per template with about 4.5 US dollars for the whole set. These sterilizable 2D templates aid in determining the size of the reconstructed ear with more accuracy in a time efficient manner without the drawbacks of using the traditional x-ray film. Furthermore, they can also serve as a valuable tool in cases of bilateral disease which renders other strategies that rely on mirroring the contralateral ear for template design ineffective. The guiding template can also be used to anticipate future growth by selecting a slightly larger template than normal ear to guide framework construction. Additionally, these models can also be utilized in simulation laboratories to facilitate training of junior surgeons.

Conclusion

To our knowledge, this is the first paper to describe the use of affordable 3D printing technology to produce ready-to-use, sterilizable auricular carving and framework sizing templates to guide in perioperative sculpture of the cartilaginous framework during microtia reconstruction. Future studies are directed towards assessing the clinical utility and practicality of the presented templates.

Ethical approval

N/A.

Patient consent

Authors confirm consent was obtained.

Declaration of Competing Interest

All authors declare that they have no conflicts of interest to disclose.

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