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Three-dimensional autologous cartilage framework fabrication assisted by new additive manufactured ear-shaped templates for microtia reconstruction

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Summary *Background:* During microtia reconstruction, the intraoperative design of the cartilage framework is important for the appearance and symmetry of the bilateral auricles. Templates (traditionally, the X-ray film template) are usually utilized to complete the task, which can provide cues regarding size, cranioauricular angle and positioning to the surgeons. With a combination of three-dimensional (3D) scanning and additive manufacturing (AM) techniques, we utilized two different ear-shaped templates (sheet moulding and 3D templates) during the fabrication of 3D-customized autologous cartilage frameworks for auricle reconstruction.

Methods: Forty unilateral microtia patients were included in the study. All the patients underwent auricle reconstruction using the tissue-expanding technique assisted by the new AM templates. Images were processed using computer-aided design software and exported to print two different AM ear-shaped templates: sheet moulding and 3D. Both templates were assisted by the 3D framework fabrication. The 3D images of each patient's head were captured preoperatively using a 3D scanner. X-ray film templates were also made for the patients. The lengths and widths of the contralateral auricles, X-ray film and sheet moulding templates were measured in triplicate. The error of the template and the contralateral auricle were used to compare the accuracy between the two templates.

Results: Between January and May 2014, 40 unilateral microtia patients aged 6–29 years were included in this study. All patients underwent auricle reconstruction using autogenous costal cartilage. The sterilized AM templates were used to assist in the framework fabrication. The

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operative time was decreased by an average of 15 min compared with the method assisted by the X-ray film template. Postoperative appearance evaluation (based on five indexes: symmetry, length, width, cranioauricular angle and the substructure of the reconstructed ear) was performed by both the doctors and the patients (or their parents). Follow-up (ranging from 9 to 18 months) showed that all of the patients obtained satisfactory results with life-like 3D configuration and symmetric cranioauricular angle. The follow-up showed that no surgery-related complications occurred. Comparing the accuracy of the X-ray film and sheet moulding templates, the average errors of length were 1.8 mm ± 1.44 mm and 0.39 mm ± 0.35 mm, respectively, and the average width errors were 1.32 mm ± 0.88 mm and 0.3 mm ± 0.47 mm, respectively. The new sheet moulding template was more accurate than the X-ray template.

Conclusions: The new sheet-moulding template is much more accurate than the traditional X-ray film template. Framework fabrication assisted by accurate 3D and informative AM templates contributed to individualized cartilage framework fabrication and satisfactory results.

Introduction

Autologous cartilage has been widely used in framework fabrication during auricle reconstruction.[1–3] The size and location of the framework are typically confirmed with auxiliary templates during fabrication. As advocated by Tanzer,[4] a two-dimensional (2D) X-ray film template has traditionally been used to assist in auricular framework fabrication by providing the contour, length and width of the contralateral side. However, some disadvantages of the X-ray film template are apparent. For example, the pressure on the auricle while drawing can cause auricular deformation, and subjectivity errors are inevitable. Furthermore, the auricle is an exquisite organ with over 14 delicate three-dimensional (3D) structures. An X-ray film template can only demonstrate six to eight plane structures of the normal ear. With the development of additive manufacturing (AM), accurate 3D templates can make up for such disadvantages; however, X-ray film templates offer the practical and indispensable advantage of being able to lie directly against the cartilage to assist in the framework sculpture, which makes them irreplaceable by 3D templates.

The 3D template is important in framework fabrication for ear reconstruction using the tissue-expanding technique, which is complemented by the sheet moulding template. Unlike ear reconstruction without tissue expansion,[3] three layers of 3D cartilaginous frameworks are fabricated during ear reconstruction using the tissue-expanding technique.[5] The cranioauricular height and auricular details should be determined properly during framework fabrication. Furthermore, the 3D template could provide the accurate height and 3D details of the contralateral side to help the surgeons improve the appearance of the reconstructed ear.

In this study, to increase the accuracy and integrity of the 3D anatomical information of the template, we designed two different AM ear-shaped templates (sheet moulding and 3D templates) to serve as models during the framework fabrication for microtia reconstruction. This method is more accurate and informative than the use of X-ray film templates and also provides 3D anatomical cues.

In this article, we also share our experience regarding 3D framework fabrication for microtia reconstruction using the tissue-expanding technique.

Patients and methods

Between January and May 2014, 40 unilateral microtia patients were included in this study. All of the patients underwent auricle reconstruction using autogenous costal cartilage and the tissue-expanding technique. The reconstruction was assisted by new AM sheet moulding and 3D templates (Figure 1). The 3D images of the patients were captured before ear reconstruction.

Surface 3D scanning of auricles

We used a surface 3D scanner (Artec Spider, Artec Group, Luxembourg) with a stated resolution of 0.1 mm and a point accuracy of up to 0.03 mm to capture the surface details of the microtic and normal auricles. The data were then processed following a standard surface scan workflow (e.g., manual alignment, global registration, model fusion, texturing, hole filling, edge smoothing and mesh simplification).

The acquired 3D data were then converted into Stereolithography Interface Format (STL) files using the native Artec Studio Version 9.0 software (Artec Group, Luxembourg).

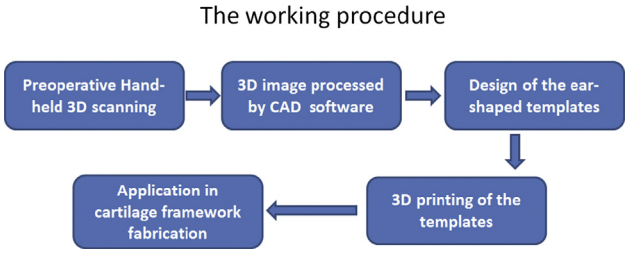

Figure 1 The template production procedure.