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*Original Article*

# Comparison of three-dimensional and two-dimensional templates on auricle reconstruction in patients with unilateral microtia

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**Abstract:** To confirm the advantage of 3D template over the traditional 2D template in auricle reconstruction. Two hundred patients with Marx III unilateral microtia treated in our hospital during the last four years were included in this retrospective study. They were divided into two groups according to the surgery which was assisted by 2D or 3D template. The outcome was evaluated 6 months after the surgery in the following aspects: the mean surgical time, the similarity rate for ear size, nasal-tip to tragus length and auriculocephalic angle, the patient's satisfaction and the quality of life after surgery. The surgical time for the 3D group was 3.2 ± 1.9 hours, significantly shorter than that for the 2D group (4.1 ± 3.7 hours; $P < 0.05$). The similarity rates between both sides were 91.24 ± 1.71%, 96.46 ± 2.51%, and 88.15 ± 10.20% respectively for ear size, nasal tip-tragus length, and auriculocephalic angle in the 3D group. While the corresponding values in the 2D group were smaller and were 87.47 ± 3.66%, 90.16 ± 3.27%, and 78.25 ± 1.26% respectively. The difference was significant in nasal tip-tragus length and auriculocephalic angle ($P < 0.05$), but not for ear size ($P > 0.05$). The patients' satisfaction was better in the 3D group. The averaged GCBI score was 65.6 ± 13.2 in the 3D group, which was significantly higher than the value of 55.3 ± 16.8 in the 2D group ($P < 0.05$). The use of 3D template resulted in a better outcome in the auricle reconstruction surgery.

**Keywords:** Microtia, bone conduction hearing loss, auricle reconstruction, three-dimensional template, two-dimensional template

## Introduction

Microtia is a congenital abnormality of the external ear that has a prevalence rate of 0.83 to 17.4 per 10,000 newborns depending on the country. Microtia is unilateral in 70% of patients, and affects the right ear twice as often as the left ear [1-3]. The severity of microtia, based on the Marx classification [4], ranges from the presence of all features of a normal auricle except for a smaller pinna (grade I), to complete absence of the auricle and external ear canal (grade IV) [5]. Depending on its severity, microtia may cause conductive hearing loss due to an abnormality in the external ear canal and middle ear, or may simply cause cosmetic problems due to auricle malformation. Subjects with unilateral microtia typically have a contralateral ear that is normal. In such cases, subjects often request reconstruction of the affected auricle to improve appearance. The success of the surgery depends on accurate reconstruction of the auricle framework, implantation of the framework with accurate localization, and appropriate coverage of the framework by soft tissue.

Surgeons have made many improvements in the specific procedures during the long history of this surgery. In 1959, Tanzer et al. first introduced a procedure for auricle reconstruction using autogenous costal cartilage [6]. Since then, auricle reconstruction using costal cartilage has become mainstream [2, 7]. Tanzer et al. introduced the use of a template in the original protocol [6]. In this procedure, the surgeon drew a two-dimensional (2D) template on an unused X-ray film using the unaffected ear as reference, and the outline was then cut out and reversed to make a template for surgical correction of the affected ear. The surgeon made the cartilage framework foundation by tracing the outline of this template (described in detail in the "Materials and Methods", below) [8-10]. Although a 2D template allows approximate reconstruction of the auricle, it does not provide detailed reconstruction of the shape of the concha and triangular fossa. Moreover, this method requires an experienced surgeon to sculpt the framework based on memory or visual evaluation of the shape of the unaffected ear. In addition, a 2D template does not provide critical measures needed for accurate implantation of the reconstructed auricle. Therefore, it is challenging to achieve satisfactory symmetricity of the auricles by reconstruction surgery using a 2D template [8, 11-14].

Advances in 3D imaging and printing technology have made it possible to produce more accurate templates for reconstructive surgery. In particular, surgeons in the field of craniofacial surgery have used 3D imaging and printing technology for preoperative planning, outcome simulation, and treatment evaluation [15, 16]. Kelley [17] first used a 3D template for auricle reconstruction surgery in 1993. He placed the template in the skin pocket, and applied suction so the shape of the expected reconstruction could be previewed before the cartilage was cut. In the same year, Kaneko used a 3D template for auricle reconstruction during the assembly of the autologous cartilage framework. Thereafter, auricle reconstruction surgery has gradually shifted from using 2D to 3D templates [8, 15, 18]. However, the 3D templates in these early studies focused on auricle structures. These templates facilitated fine structure reconstruction, but no guide on the accurate location of the framework during implantation.

Surgeons began using the 3D templates at our hospital during 2014. We developed our own 3D template to include a guide for constructing the auricle, which mirrors the unaffected ear and that facilitates the precise location of the constructed auricle (in terms of its relationship with the eye and the nasal tip).

To our knowledge, only one previous study directly compared the use of 3D and 2D templates for auricle reconstruction [15]. However, this previous study had a small sample size and the 3D template did not include guides for localization during auricle implantation. A 3D template may provide superior results, but it is about 60 USD more expensive at our institution. There is currently no solid evidence to justify this increased expenditure.

The aim of the present study is to confirm the advantage of our more sophisticated 3D template over the traditional 2D template for auricle reconstruction in a large sample of patients.

## Materials and methods

### *Patients*

This single center retrospective study examined the records of patients with Marx grade III congenital unilateral microtia who underwent autologous rib cartilage auricle reconstruction surgery at Peking Union Medical College Hospital (PUMCH) in Beijing, China, from June 2014 to June 2018. The protocol was approved by the Institutional Review Board of PUMCH (Microtia genetics analysis. Protocol#: JS-795, approved at Jan. 2014).

The records of all patients with Marx III microtia who were treated for auricle reconstruction between June 2014 and June 2018 were extracted from the case management system of our hospital. All included patients were older than 6 years, taller than 1.28 m, and had stable psychological status. Patients were excluded if they had bilateral microtia, hemifacial deformity, or a syndromic form of microtia (Treacher-Collins syndrome, Miller syndrome, Charge syndrome, or Branchio-Oto-Renal syndrome). During this period, reconstruction surgery was performed using a 2D or 3D template, based on the preference of the patient and parents. A total of 257 patients met our inclusion/exclusion criteria; 127 were treated with 2D templates and 130 were treated with 3D templates. The later 100 subjects of the 2D group and the first 100 subjects of the 3D group were compared to reduce the effects of date and surgeon experience when comparing the groups. These two groups had similar demographic characteristics (**Table 1**).

### *Manufacturing the 3D auricular template*

Computed tomography (CT) images (voltage: 100.0 kVp, current: 171.0 mA) from a multidetector row CT (SOMATOM Force, Siemens healthcare, Forchheim, Germany) with standard

**Table 1.** Demographic similarity between the two groups

| Parameters | 2D group (n = 100) | 3D group (n = 100) | *P* value | T value |
|---|---|---|---|---|
| Age (in years) | | | | |
| Mean ± SD | 16.18 ± 3.2 | 18.61 ± 0.49 | 0.379 | 1.97 |
| Range (years) | 9-32 | 6-34 | | |
| Males:Females | 76:24 | 81:19 | | |
| Right side:Left side | 77:23 | 69:31 | | |
| Height (cm) | | | | 11.45 |
| Mean ± SD | 136.12 ± 9.5 | 141.29 ± 1.7 | 0.098 | 1.56 |
| Range (cm) | 128-170 | 128-173 | | |

SD = Standard deviation.

temporal bone imaging protocols were examined. Each image was reconstructed with 0.40-mm-thick sections at 0.3-mm increments on a display field of 20.0 × 20.0 cm. The display window was centered at 700 HU, and had a width of 4000 HU. The positioning datasets, including the spatial coordinates in the left-right, top-bottom, and anterior-posterior directions, were stored according to Digital Imaging and Communication in Medicine (DICOM) standards. The DICOM datasets were imported into Mimics software, version 10.01 (Materialize, Belgium), which allows simultaneous rendering of 2D and 3D images.

The original 3D mask of the auricle and face on the unaffected side was reconstructed by defining the soft tissue threshold (450-320 HU). A new mask was created by transposing the pixels. The guide plate was obtained by Boolean computing and rotating the two masks, followed by cutting at the level of the inner canthus, which was defined as the top edge. The desired 3D digital auricular template of the affected side was acquired by mirroring the healthy side through the midsagittal plane. The 3D digital template data, in Standard Tessellation Language (STL), was printed in thin 0.1-mm layers using a 3D printer (SPS600 Shanxi Hengtong) (**Figure 1**).

*Manufacturing the 2D auricular template*

The 2D template outline was drawn on an unused X-ray film using the unaffected ear as reference (**Figure 2A**), and was then cut with scissors (**Figure 2B**).

*Surgical procedure*

Auricle reconstruction surgery was performed using the three-stage tissue expander method. During the first stage, a soft tissue expander was implanted in the mastoid region to obtain sufficient skin flap. Prior to the second stage, each auricular template was sterilized at low temperature. During the second stage (performed at least 2 months later), the auricle was reconstructed using autogenous rib cartilage. During the third stage, detail-correcting surgery was performed to reproduce the helix, antihelix, concha, and tragus. The surgical time from skin incision to the end of the suture was recorded. These surgeries were mainly performed by a single surgeon who has more than 6 years of experience in performing auricle reconstruction surgery.

*Measurements*

Six months after surgery, the quality of the reconstruction was quantified from the symmetricity of the two sides by measurements of ear size, length from nasal tip to tragus (nasal tip-tragus length), and the auriculocephalic angle. Similarity was calculated as:

$$1 - |Vr - Vu| \times 100\%/Vu$$

Where Vr is the value of the reconstructed ear and Vu is the value of the unaffected ear.

The length from the lowest part of the ear lobule to the most distant part of the helix was used to indicate auricle size. For quantification of symmetricity, this value was used with the distance between the nasal tip and tragus and the auriculocephalic angle (defined as the angle formed by two imaginary lines, one from the root of the helix to its lateral edge and the other from the root of the helix to the mastoid plane [12]).

*Questionnaires*

Two questionnaires were administered *via* face-to-face interviews to evaluate subjective patient benefit. These were completed by the patients and their parents 6 months postoperatively. The “Satisfactory questionnaire of reconstructed auricle”, which was given to all patients, asked patients and parents to rate the outcome as “highly satisfactory”, “basically satisfactory”, or “unsatisfactory” and the overall

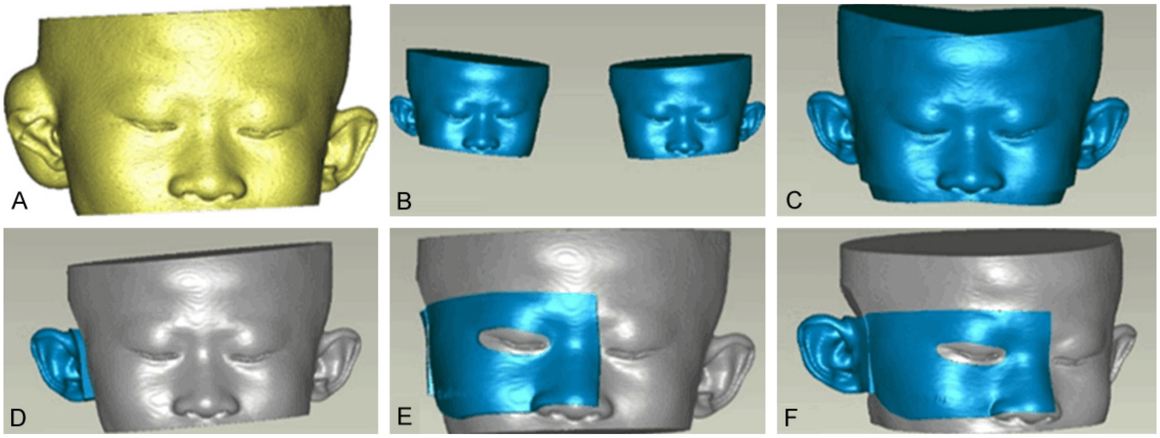


Figure 1. Manufacturing the 3D auricular template. A. An original 3D mask of the auricle and face was reconstructed by defining the soft tissue threshold (450-320 HU). B and C. A new mask was created by transposing the pixels and mirroring the normal auricle to the affected side. D. The reconstructed 3D digital auricle on the affected side was obtained by cutting out other tissues. E. The guide plate was obtained by Boolean computing, rotating the two masks, and then cutting at the level of the inner canthus. F. The auricle and guide parts were packed together, and the reconstructed 3D digital template was finished.

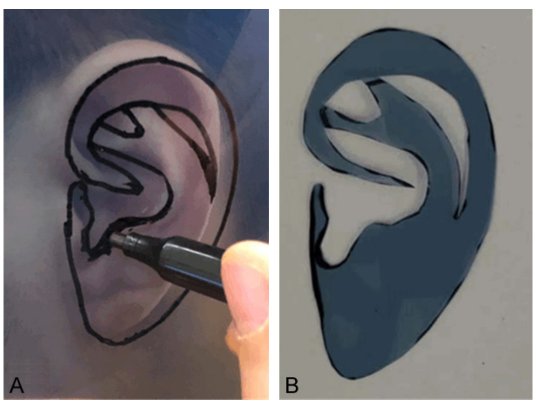


Figure 2. Manufacturing the 2D auricular template. A. A 2D template was drawn on an unused x-ray film according to the patient's unaffected auricle. The outline of the auricle structures, including the concha cavity, helix, antihelix, tragus, triangular fossa and navicular fossa, were drawn on the film. B. The auricle outline was cut down, flipped over, and then used as a 2D template for reconstruction of the opposite auricle.

result on a numerical scale from 1 (very bad) to 5 (excellent)

The 178 patients (90 in the 3D group and 88 in the 2D group) who were younger than 18 years were also assessed using the Glasgow Children's Benefit Inventory (GCBI) questionnaire. This questionnaire, which measures the health-related benefits of an intervention, consists of 18 items in two subscales and has been translated into Chinese [19].

*Statistical analysis*

All data were analyzed using SPSS software, version 21 (IBM, Corp). The normality of data distributions was determined using the Kolmogorov-Smirnov test before subsequent analysis. Continuous variables with normal distributions are presented as means ± standard deviations and compared by a paired *t*-test with Bonferroni corrections. Spearman analysis was used for comparison of non-parametric data. Statistical significance was defined as a *p* value below 0.05.

## Results

In general, auricle reconstruction surgery using a 3D template made it easier to achieve satisfactory symmetricity. **Figure 3** shows images taken immediately after reconstruction surgery of representative patients in each group and **Figure 4** shows images taken 6 months after surgery.

We compared the symmetricity of the two groups based on 3 measurements (**Table 2**). The 3D and 2D groups had no significant difference in similarity of ear size (91.24 ± 1.71% *vs.* 87.47 ± 3.66%, $P > 0.05$), but the 3D group had better similarity in terms of nasal tip-targus length (96.46 ± 2.51% vs. 90.16 ± 3.27%, $P < 0.05$) and auriculocephalic angle (88.15 ± 10.20% vs. 78.25 ± 1.26%, $P < 0.05$). An additional advantage of using the 3D template was the

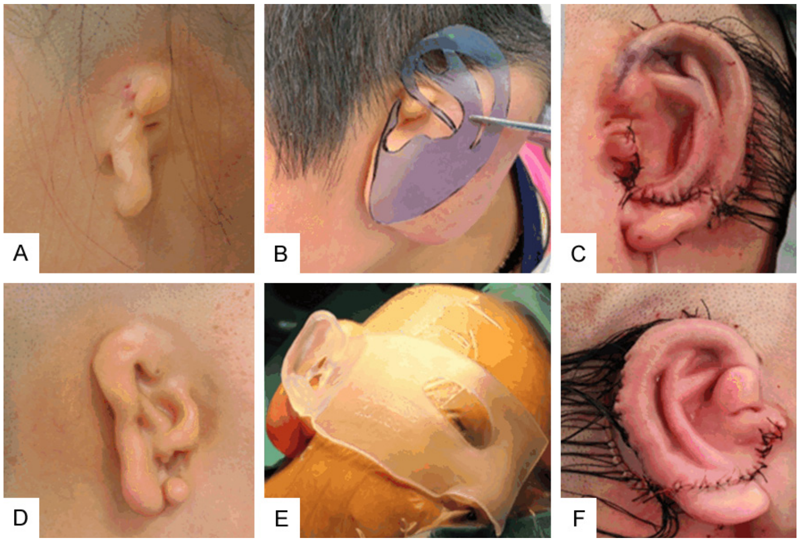


**Figure 3.** Representative patients who underwent auricle reconstruction surgery using a 2D template (A-C) and a 3D template (D-F). (A) Lateral view of the affected auricle before surgery. (B) The 2D template was used to identify the location of the reconstructed auricle. This method does not provide 3-dimensional information about the landscape of the auricle (such as the depth of the concha and triangular fossa), and requires an experienced surgeon for implantation of the reconstructed auricle and the surgeon to sculpt the framework based upon memory or visual evaluation on the shape of the unaffected ear. (C) The auricle after surgery. (D) Lateral view of the affected auricle before surgery. (E) The 3D template was used to identify the location of the reconstructed auricle. This method provides 3-dimensional information of auricle structures and the length from the nasal tip to the tragus, making it easier to fabricate and locate the framework. (F) The auricle after surgery.

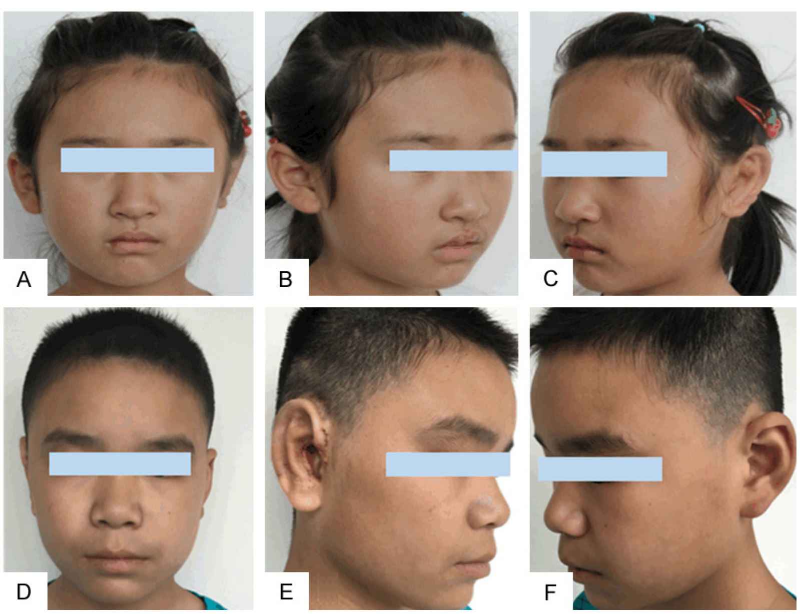


**Figure 4.** Representative patients who underwent auricle reconstruction surgery using a 2D template (A-C) and a 3D template (D-F). (A) Anterior view of a 7-year old girl, 6 months postoperatively. (B) Lateral view of the normal ear. (C) Lateral view of the reconstructed ear. Note the differences in auricle structures (the concha and triangular fossa). (D) Anterior view of an 8-year boy, 6 months after the second stage of auricle reconstruction. (E) Lateral view of the reconstructed ear. (F) Lateral view of the normal ear. Note the similarity of auricle structures.

significantly reduced duration of surgery (3.2 ± 1.9 h *vs.* 4.1 ± 3.7 h, $P < 0.05$).

Eighty-eight patients in the 3D group regarded the reconstructed auricle as "highly satisfactory" and 12 as "basically satisfactory". All 100 patients had scores of 4 (good) or 5 (excellent), and none were dissatisfied. Seventy-two patients in the 2D group regarded the procedure as highly satisfactory, 26 patients as basically satisfactory, and 2 as unsatisfactory. Spearman analysis indicated the 3D group had significantly greater satisfaction ($W = 297.6$, $P < 0.05$).

The GCBI has 24 questions, each with 5 possible answers ranging from "-2" (maximum change for the worst) to "+2" (maximum change for the best). The total score for each patient was divided by the number of the questions and then multiplied by 50, yielding final scores ranging from "-100" to "+100" [20]. Our results indicated that the average GCBI score was significantly greater in the 3D group (65.6 ± 13.2 *vs.* 55.3 ± 16.8; $W = 305.9$, $P < 0.05$; **Figure 5**).

## Discussion

To our knowledge, the present study is the first comprehensive evaluation to compare 2D and 3D templates for auricle reconstruction surgery in patients with unilateral congenital microtia. Previous studies have examined the use of different materials for this surgery. Autogenous rib cartilage is widely used be-

**Table 2.** Parameters of the subjects included in the database

| Measurement | 2D group | 3D group | *P* value | T value |
|---|---|---|---|---|
| Ear size (cm) | | | | |
| Mean ± SD | 6.20 ± 0.40 | 6.70 ± 0.51 | > 0.05 | 0.076 |
| Similar rate (%) | 87.47 ± 3.66 | 91.24 ± 1.71 | > 0.05 | 0.069 |
| Nasal-tragus length (cm) | | | | |
| Mean ± SD | 12.73 ± 0.19 | 13.96 ± 0.83 | < 0.05 | 0.017 |
| Similar rate (%) | 90.16 ± 3.27 | 96.46 ± 2.51 | < 0.05 | 0.006 |
| Auriculocephalic angle | | | | |
| Mean ± SD (degree) | 42.70 ± 0.65 | 45.52 ± 0.92 | < 0.05 | 0.014 |
| Similar rate (%) | 78.25 ± 1.26 | 88.15 ± 10.20 | < 0.05 | 0.001 |
| Surgical time | | | | |
| Mean ± SD (hours) | 4.1 ± 3.7 | 3.2 ± 1.9 | < 0.05 | 0.001 |

SD = Standard deviation.


**Figure 5.** Questionnaire results of patients who underwent auricle reconstruction surgery using a 2D template (n = 100) and a 3D template (n = 100). A. In the 3D group, 88 patients rated the reconstructed auricle as "highly satisfactory" and 12 as "basically satisfactory". In the 2D group, 72 patients rated the reconstructed auricle as "highly satisfactory" 26 patients as "basically satisfactory", and 2 as "unsatisfactory" (Spearman analysis: W = 297.6, $P < 0.05$). B. Average GCBI score was 65.6 ± 13.2 in the 3D group and 55.3 ± 16.8 in the 2D group (Spearman analysis: W = 305.9, $P < 0.05$).

cause it provides a near-ideal appearance and avoids problems of compatibility [21]. In the present study, the material and the procedures used during all the three stages of the operation were identical except for the template. Our large sample size ensures the reliability of the results. We used the most sophisticated, state-of-art 3D template to guide fabrication of the auricle framework, and to assure the reconstructed auricle was implanted at the correct position. Our expectation was that use of this template would improve the outcome of the surgery. Our outcomes suggest that the higher price of this template is justified by the significant benefits, including a significantly reduced surgical duration, significantly better symmetricity, and significantly higher satisfaction by patients and their parents.

Plastic surgeons consider auricle reconstruction a great challenge due to the special location and complex 3D structure of ears [1, 12, 21, 22]. The 2D template is easy to make without sophisticated equipment, but cannot provide detailed guidance for making the auricular framework because it does not provide stereoscopic information, such as the location and the depth and shapes of concha and fossa. This makes it more difficult to fabricate an auricle framework from a 2D template. The rapid development of advanced image post-processing technologies and 3D printing technology (also called rapid prototyping), have provided more advanced tools for the production of personalized 3D templates [13, 23]. The manufacture of 3D clinical models has provided enhanced patient-specific and personalized treatment in other areas [24, 25]. In this study, we used mirroring and 3D printing technology to produce 3D auricle templates, and evaluated the surgical benefit by comparison with traditional 2D templates.

The use of 3D auricular templates can prevent human errors produced by outlining the 2D film template. The stereo information provided by the 3D template makes it much easier to copy the unaffected ear in terms of size, and the depths and locations of the concha and the fossa, even by an inexperienced surgeon. Previous studies reported that use of a 3D template for auricle reconstruction provided greater surgical accuracy and reduced operating time because of the detailed information of the template [8, 23]. However, these 3D templates focused only on auricle structure, whereas we included the entire face in our 3D templates (**Figure 1**). Thus, in our patients the location was guided by the spatial relationship of the auricle, eye, and nasal tip. To our knowledge, no previous study has systematically evaluated the benefit of such 3D templates. Because of this advance, we achieved better symmetricity, as determined by measurements of nasal tip-tragus length and auriculocephalic angle. The reconstructed auricle needs about one year for finalization [15], and some of the patients described here are still in the process of finalization. Long-term follow up is needed, so we did not compare the more subtle structural features in this study. This topic will be addressed in a future long-term follow-up study.

We intend to establish a database with these 3D auricular templates, and group them according to different anatomical features, for use in future operations. Our method also provides several parameters, including ear size, nasal tip-tragus length, and auriculocephalic angle, which could be used to analyze morphological changes of auricles over time. In the present series, the 3D auricular template contributed considerably to the engraving and localization of the cartilage framework and the harvesting of rib cartilage for auricle reconstruction surgery. In addition, patients with bilateral microtia or severe hemifacial microsomia may benefit from our 3D template database by optimization of appearance, size, and other factors.

## Conclusions

In conclusion, relative to 2D templates, 3D templates provided more sophisticated reconstruction of the normal ear, and considered the relationships of the ear to the eye and nasal tip. The 3D templates provided better reconstructive results and reduced surgical time.

## Disclosure of conflict of interest

None.

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