Original Article

Rib Cartilage Assessment Relative to the Healthy Ear in Young Children with Microtia Guiding Operative Timing

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Abstract

Background: The optimal age at which to initiate for auricular reconstruction is controversial. Rib cartilage growth is closely related to age and determines the feasibility and outcomes of auricular reconstruction. We developed a method to guide the timing of auricular reconstruction in children with microtia ranging in age from 5 to 10 years.

Methods: Rib cartilage and the healthy ear were assessed using low-dose multi-slice computed tomography. The lengths of the eighth rib cartilage and the helix of the healthy ear (from the helical crus to the joint of the helix and the earlobe) were measured. Surgery was performed when the two lengths were approximately equal.

Results: The preoperative eighth rib measurements significantly correlated with the intraoperative measurements ($P < 0.05$). From 5 to 10 years of age, eighth rib growth was not linear. In 76 (62.8%) of 121 patients, the eighth rib length was approximately equal to the helix length in the healthy ear; satisfactory outcomes were achieved in these patients. In 18 (14.9%) patients, the eighth rib was slightly shorter than the helix, helix fabrication was accomplished by adjusting the length of the helical crus of stent, and satisfactory outcomes were also achieved. Acceptable outcomes were achieved in 17 (14.0%) patients in whom helix fabrication was accomplished by cartilage splicing. In 9 (7.4%) patients with insufficient rib cartilage length, the operation was delayed. In one (0.8%) patient with insufficient rib cartilage length, which left no cartilage for helix splicing, the result was unsatisfactory.

Conclusions: Eighth rib cartilage growth is variable. Rib cartilage assessment relative to the healthy ear can guide auricular reconstruction and personalize treatment in young patients with microtia.

Key words: Cartilage; Computed Tomography; Microtia; Otologic Surgical Procedures; Transplantation

Introduction

Auricular reconstruction is a challenging surgery that must be carried out in stages. Grafting a well-sculpted cartilage framework is the foundation of total auricular reconstruction.[1-5] The growth of the rib cartilages, which serve as the key material in auricular framework sculpting, determines the feasibility and outcomes of the surgery.

The width of the synchondrosis of the sixth and seventh rib cartilages and the length of the eighth rib cartilage are two key reference factors in auricular framework sculpting. The sixth and seventh rib cartilages and their synchondrosis en bloc serve as the base of the reconstructed ear while the eighth rib cartilage serves as the helical element. Sculpting of the scaphoid fossa, triangular fossa, helix, and antihelix determines the basic form of the reconstructed auricle. In clinical practice, if the width of the synchondrosis of the sixth and seventh rib cartilages is insufficient, the base of the reconstructed ear can be formed by splicing the cartilages. As the synchondrosis is not on the upper surface of the reconstructed ear, it does not affect the final appearance of the reconstructed ear and has no significant influence on surgical outcomes. The eighth rib cartilage is the most important factor in total ear reconstruction, as it forms the helix and determines the auricle outline.

There is still some disagreement about the optimal age to undergo auricular reconstruction surgery; at the optimal age, children should have sufficient rib cartilage to allow proper auricular fabrication and exhibit adequate mental development. Observation is recommended until the child is at least 5–8 years old. Brent[6] recommended that auricular reconstruction surgery be performed when the patient

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is between 7 and 8 years of age. Nagata[7] recommends that the operation not be performed on patients younger than 9 years owing to the smaller amount of rib cartilage available in younger children. Recent reference data on rib cartilage development in the normal population are based on retrospective studies and have offered reference with some limitations.[8] At the age of 5–10 years, children with microtia often exhibit delayed development as compared with their healthy peers clinically. In addition, no direct, firm data such as rib cartilage growth in patients with microtia and preoperative healthy ear cartilage framework are available. A predictable method to guide the timing of surgery in young children with microtia is required. In this study, we reconstructed the rib cartilage to match the cartilage framework of the healthy ear in children with microtia, who underwent both auricular reconstruction and hearing reconstruction at ages ranging from 5 to 10 years. Low-dose, multi-slice spiral computed tomography (MSCT) was used to assess rib cartilage development and guide surgery. Surgery was performed in patients with substantial rib cartilage, and favorable results were achieved.

Methods

Patients and methods

Between January 2011 and September 2014, a total of 121 children (ages, 5–10 years) with microtia underwent both auricular reconstruction and hearing reconstruction in The People's Hospital of Zhengzhou University. In 78 patients, the right ear was involved while, in 43 patients, the left ear was involved. According to the classification and associated deformities category, 84 patients had lobular-type microtia, 33 had concha-type microtia, and four had atypical microtia. There was no difference in gender distribution between different age cohorts.

The patients underwent low-dose MSCT (the details will be discussed in another article). The sixth, seventh, and eighth rib cartilages and the healthy ear cartilage framework were measured using ADW4.2 (GE Medical Systems, USA). The length of the eighth rib was measured bilaterally from the bone–cartilaginous junction to the sternal attachment [Figure 1a]. Additionally, the length of the helix of the healthy ear was measured from the helical crus to the joint of the helix and the earlobe [Figure 1b]. If the length of the eighth rib cartilage was approximately equal to the length of the helix of the healthy ear, and the auricular length of the patient was approximately equal to auricular length of their parents, the surgeon decided to operate. If the length of the eighth rib cartilage was approximately 2.5 cm shorter than the length of the helix of the healthy ear, the operation was postponed by persuading the patient's parents. In one patient whose eighth rib cartilage was approximately 2.3 cm shorter than the length of the helix of the healthy ear, the operation was performed due to the insistence of the patient's parents. The length of the eighth rib cartilage was measured intraoperatively, and the result was compared with the preoperative imaging measurement. The outcomes

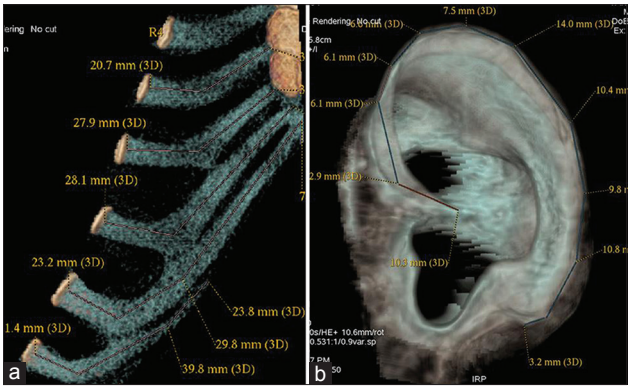

Figure 1: Representative measurement of (a) rib 8 length and (b) the length of the helix of the healthy ear cartilage framework.

of the first-stage surgery in terms of shape, size, orientation, and structural details were assessed by the surgeon as well as the patients' parents.

Surgical procedures

A pattern for reconstruction was prepared by placing an X-ray film against the normal ear and tracing its anatomic landmarks. The template was then reversed and made several millimeters smaller throughout to accommodate the thickness of the skin cover. Once configured, the template was aligned symmetrically with the contralateral ear using the ear's relationship to the nose, the lateral canthus, and the position of the lobule. A costal incision was made during the operation, and the sixth, seventh, and eighth costal cartilages were harvested, carved, and fabricated; the inner perichondrium was left intact. With the sixth and seventh rib cartilages and their synchondrosis en bloc serving as the base frame, the surgeon carved out three-dimensional structures such as the scaphoid fossa, triangular fossa, helix, and antihelix. Then, the surgeon positioned the eighth rib cartilage strip above the helix, and attached a "Y" shaped cartilage to the antihelix and the superior and inferior crura to produce a protruding auricular structure. If a large piece of the cartilage graft was left over, the surgeon banked it underneath the costal subcutaneous for surgery of stage two. The surgeon planned the surgery, according to the Nagata technique. The surgeon designed a W-shaped posterior lobule incision on the skin and subcutaneously injected 0.25% lidocaine hydrochloride (containing epinephrine, 1:200,000) to reduce bleeding and facilitate tissue separation. The surgeon then incised the skin, excised the residual ear cartilage, and separated a suitable subcutaneous pocket. At the central portion of the posterior skin flap, a subcutaneous pedicle was preserved to ensure blood supply to nourish the skin flap. The cartilage framework constructed earlier was placed into the subcutaneous pocket, and the surgeon then turned back the earlobe to connect it with the mastoid flap base, molding it into a smooth shape. Two small polyethylene drains with multiple perforators located near the end were used for occlusion of the overlying skin flap to the framework. One was inserted adjacent to the concha,

and the other was inserted at the scapha. Postoperatively, a disposable 5-ml syringe was used to frequently aspirate the collected fluid through the drains, and the proper tension was maintained. The drains were removed after 1–3 days when the volume of drainage was <1 ml. The flap blood supply was monitored postoperatively, and the stitches were removed 7 days after the operation.

Statistical analysis

All statistical analyses were performed using the SAS statistical software package, version 8.0 (SAS Institute, Cary, NC, USA) for Windows. We used the *t*-test to assess differences in rib cartilage development and helix growth between the groups. Correlation and linear regression analyses were performed between the actual cartilage length measured intraoperatively and the cartilage length measured preoperatively. A $P < 0.05$ was considered as statistically significant.

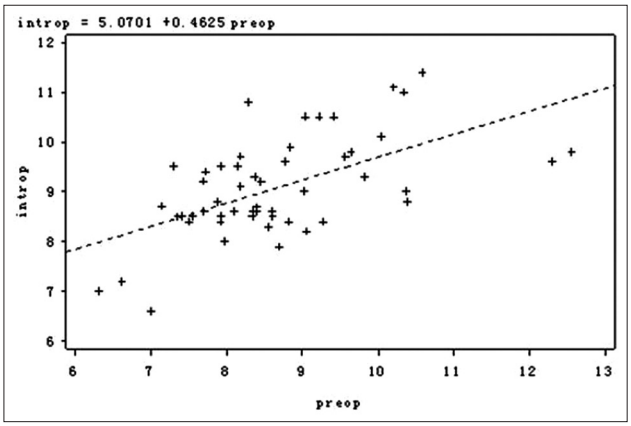

Figure 2: The measurement of rib 8 preoperation was significantly correlated with intraoperatively measured cartilage length.

Results

The length of the eighth rib cartilage measured preoperatively on imaging examination was approximately equal to the intraoperative measurement. The two lengths were significantly correlated [Pearson correlation coefficient: 0.58, $P < 0.05$; Figure 2], indicating the credibility of the imaging measurement.

From the ages of 5–10 years, the growth of the eighth rib was not linear [Figure 3]. This is probably due to the variability in the detachment of the eighth rib from the sternum as it transitions into a false rib. Overall, there were no gender differences in the length of the eighth rib. Individual differences among age groups are summarized in Table 1, and growth curves are presented in Figure 3a. In addition, there was no difference in the length of the eighth rib between the right and left sides. The individual group means are summarized in Table 2, and growth curves are presented in Figure 3b.

From the ages of 5–10 years, the growth of the helix in the healthy ear was not linear. Overall, there were no gender differences in the length of the helix. Individual differences among age groups are summarized in Table 3, and growth curves are presented in Figure 4. The length of the helix of the healthy ear was measured from the helical crus to the joint of the helix and the earlobe. The average helix length was 9.1 cm (range, 6.0–14.3 cm).

In 76 (62.8%) of the 121 patients in the study, the length of the eighth rib cartilage was approximately equal to that of the helix of the healthy ear, as measured preoperatively. Satisfactory surgical outcomes were achieved in all 76 of these patients, who underwent complete helix fabrication

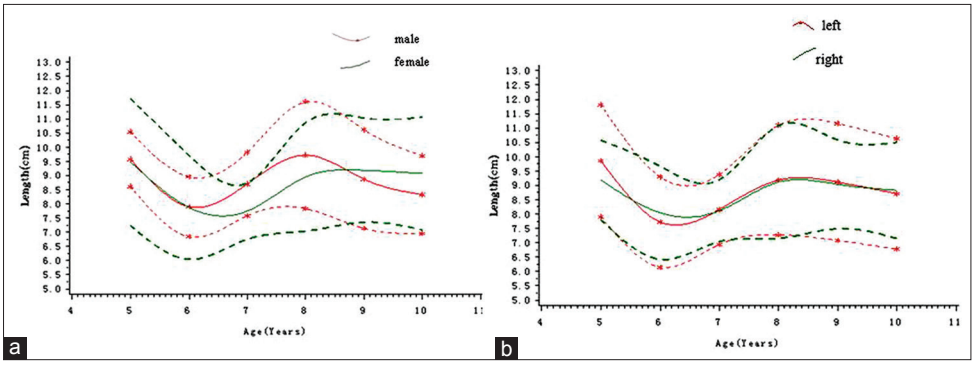

Figure 3: (a) Gender-based growth curve for rib 8; (b) laterality based growth curve for rib 8.

Table 1: Gender stratified rib 8 length differences by age

Gender	Length (cm) by age (years) (mean ± SD)					
	5	6	7	8	9	10
Male	9.47 ± 2.28	7.87 ± 1.86	7.74 ± 1.01	8.95 ± 1.94	9.19 ± 1.86	9.07 ± 2.01
Female	9.57 ± 0.98	7.90 ± 1.08	8.70 ± 1.15	9.72 ± 1.94	8.88 ± 1.79	8.33 ± 1.40
t	0.16	0.06	2.57	1.18	0.51	1.36
P	>0.05	>0.05	<0.05	>0.05	>0.05	>0.05

SD: Standard deviation.

Table 2: Laterality stratified rib8 length differences by age

Laterality	Length (cm) by age (years) (mean ± SD)					
	5	6	7	8	9	10
Left	9.86 ± 1.99	7.72 ± 1.60	8.16 ± 1.25	9.18 ± 1.94	9.12 ± 1.08	8.71 ± 1.95
Right	9.19 ± 1.41	8.04 ± 1.65	8.12 ± 1.10	9.12 ± 2.00	9.04 ± 1.57	8.83 ± 1.69
t	1.22	1.85	0.12	0.26	0.17	0.36
P	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

SD: Standard deviation.

Table 3: Gender stratified helical length differences by age

Gender	Length (cm) by age (years) (mean ± SD)					
	5	6	7	8	9	10
Male	9.70 ± 2.08	9.10 ± 0.74	8.82 ± 0.53	9.04 ± 0.72	9.18 ± 0.85	9.27 ± 0.93
Female	8.73 ± 0.81	9.18 ± 0.72	9.26 ± 0.97	9.35 ± 1.32	9.78 ± 0.59	8.74 ± 1.49
t	1.22	0.26	1.20	0.72	1.68	1.03
P	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

SD: Standard deviation.

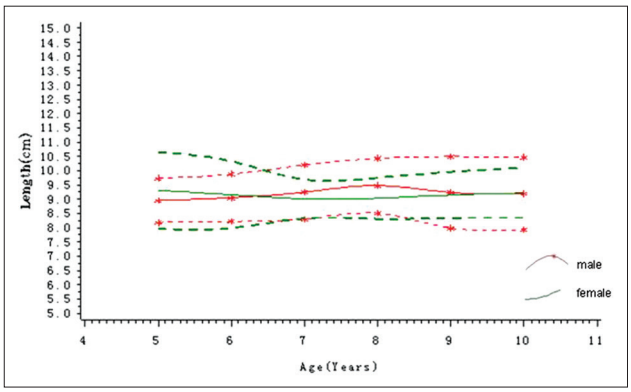

Figure 4: Growth curve for the helix of the healthy ear cartilage framework.

using the eighth rib. In 18 (14.9%) patients, whose eighth rib cartilage was approximately 1.0 cm shorter than the length of the helix of the healthy ear, helix fabrication was accomplished by adjusting the length of the helical crus of stent; satisfactory outcomes were also achieved in these patients. Acceptable surgical outcomes were achieved in the 17 (14.0%) patients whose eighth rib cartilage was approximately 1.5 cm shorter than the length of the helix of the healthy ear. Helix fabrication was accomplished in these patients by combining the eighth rib cartilage and a spliced cartilage. In the 9 (7.4%) patients, whose eighth rib cartilage was approximately 2.5 cm shorter than the length of the healthy ear cartilage framework, the operation was delayed. In one (0.8%) patient, whose eighth rib cartilage was 2.3 cm shorter than the length of the healthy ear cartilage framework and in whom the operation could not be delayed due to the insistence of the parents, with insufficient length intraoperation, there was no cartilage left for splicing. The early surgical outcome in this patient was not adequate owing to our limited experience in early-stage operations.

In patients with satisfactory surgical outcomes, the mean length of the eighth rib, as measured intraoperatively, was 9.03 ± 1.03 cm.

Case Reports

Case 1

A 6-year-old boy with microtia.

The preoperative computed tomography (CT) measurement showed that the length of the eighth rib cartilage was 8.38 cm, and the length of the helix of the healthy ear was 8.47 cm. Intraoperative measurement of the eighth rib cartilage showed that its length was approximately 9.0 cm. The surgical outcome in this patient was good [Figure 5].

Case 2

A 6-year-old boy with microtia.

The preoperative CT measurement showed that the length of the eighth rib cartilage was 7.04 cm, and the length of the helix of the healthy ear was 9.3 cm. Due to the insistence of the patient's parents, the operation could not be delayed in this patient. The surgical outcome was not adequate owing to the insufficient length of the eighth rib cartilage, the lack of cartilage left for splicing, and our limited experience in early-stage operations [Figure 6].

Discussion

In auricular reconstruction, the carving and fabrication of a rib cartilage framework in the first-stage surgery is of vital importance. If the rib cartilage is insufficient for the second-stage surgery, a biological material can be used as a replacement.[8-13] Thus, the harvesting of sufficient rib cartilage is beneficial for cartilage framework carving and shaping in the first-stage; late trimming to make up the deformity is difficult.

The width of sixth and seventh rib cartilage synchondrosis and the length of the eighth rib cartilage are key factors

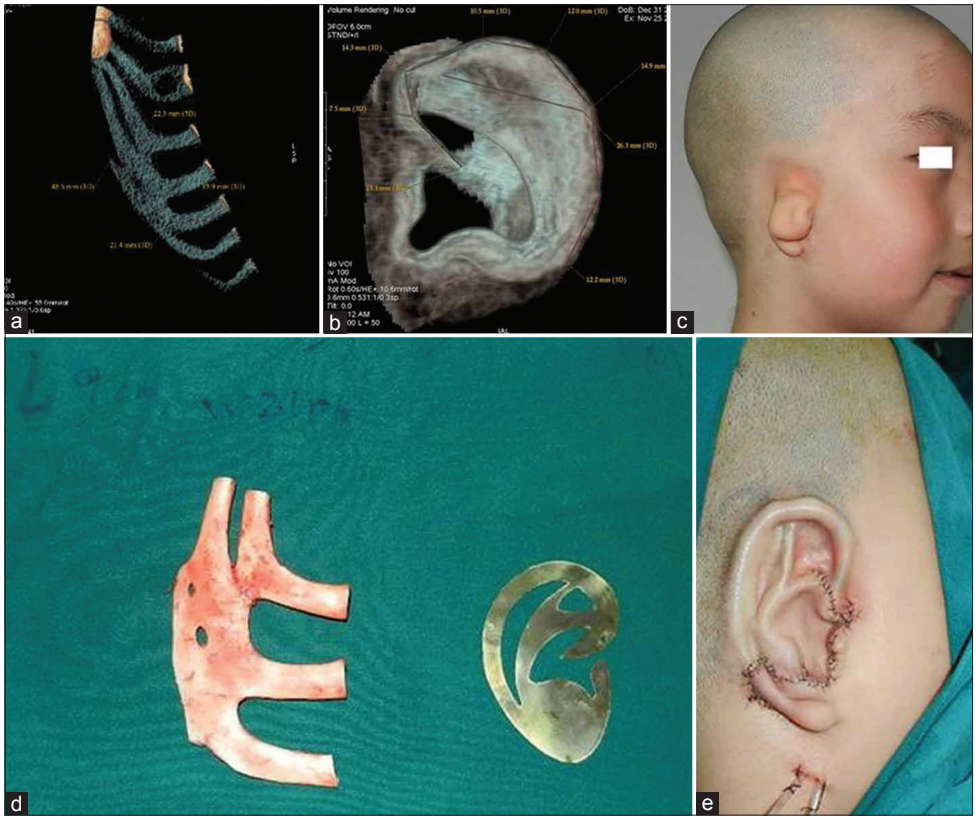

Figure 5: (a) Computed tomography reconstruction measurement of rib cartilage; (b) computed tomography reconstruction measurement of helix in healthy ear cartilage framework; (c) preoperation; (d) Intraoperative measurement; (e) postoperation immediately.

determining auricular framework reconstruction. The base of the reconstructed ear framework can be formed by splicing the synchondrosis of the sixth and seventh rib cartilage. As it is not on the upper surface, it does not affect framework reconstruction or surgical outcomes. The eighth rib cartilage is the most important factor in total ear reconstruction; it forms the helix in the reconstructed ear and determines the auricular outline. If the eighth rib cartilage is sufficiently long, the reconstructed helix can extend up to the lobule. If the eighth rib cartilage is shorter than the helix of the healthy ear, there will be a slender contour at the junction of the helix of the reconstructed ear to the lobule. Precise measurements of the width of the synchondrosis of the sixth and seventh rib cartilages and especially, the length of the eighth rib cartilage relative to the healthy ear can guide the timing of operation in young children with microtia.

There is still disagreement about the age at which to carry out auricular reconstruction surgery.[1,6,14-17] The disagreement mainly focuses on sufficient rib cartilage development and the patient's mental development, which are closely related to age. Observation is recommended until school age. Recent data on rib cartilage development in the normal population are based on retrospective studies and are associated with some limitations. Children with microtia at the age of 5–10 years often exhibit delayed development as compared with their healthy peers. No direct, firm data such as rib cartilage growth in children with microtia and the preoperative healthy ear cartilage framework are available. From the ages of 5 to 10 years, growth curve data showed that the growth of the eighth rib and the helix in the healthy ear was not linear. The data on helix growth are consistent with recognized data on auricular development. Interindividual differences in rib cartilage development mean that the timing of the operation must be determined on a case-by-case basis. In our study, only 76 (62.8%) of a total of 121 patients underwent complete helix fabrication using the eighth rib and had satisfactory surgical outcomes, demonstrating that personalized treatment is necessary.

In total auricular reconstruction, if the eighth rib cartilage is sufficiently long, the reconstructed helix can extend up to the lobule. If the eighth rib cartilage is much shorter than the effective length of the helix in the healthy ear, there will be a slender contour at the junction of the helix of the reconstructed ear and the lobule. However, if the length of the eighth rib cartilage is only slightly insufficient, helix reconstruction can be accomplished by adjusting the length of the helical crus of the reconstructed stent, with acceptable surgical outcomes.

The effective length of the helix of the healthy ear, as measured from the helical crus to the joint of the helix and the earlobe ranged from 6.0 cm to 14.3 cm (average, 9.1 cm). The mean length of the eighth rib, as measured intraoperatively, in patients with satisfactory surgical outcomes was 9.03 ± 1.03 cm. Therefore, we assumed that if the length of the eighth rib cartilage is significantly <9 cm, it will affect

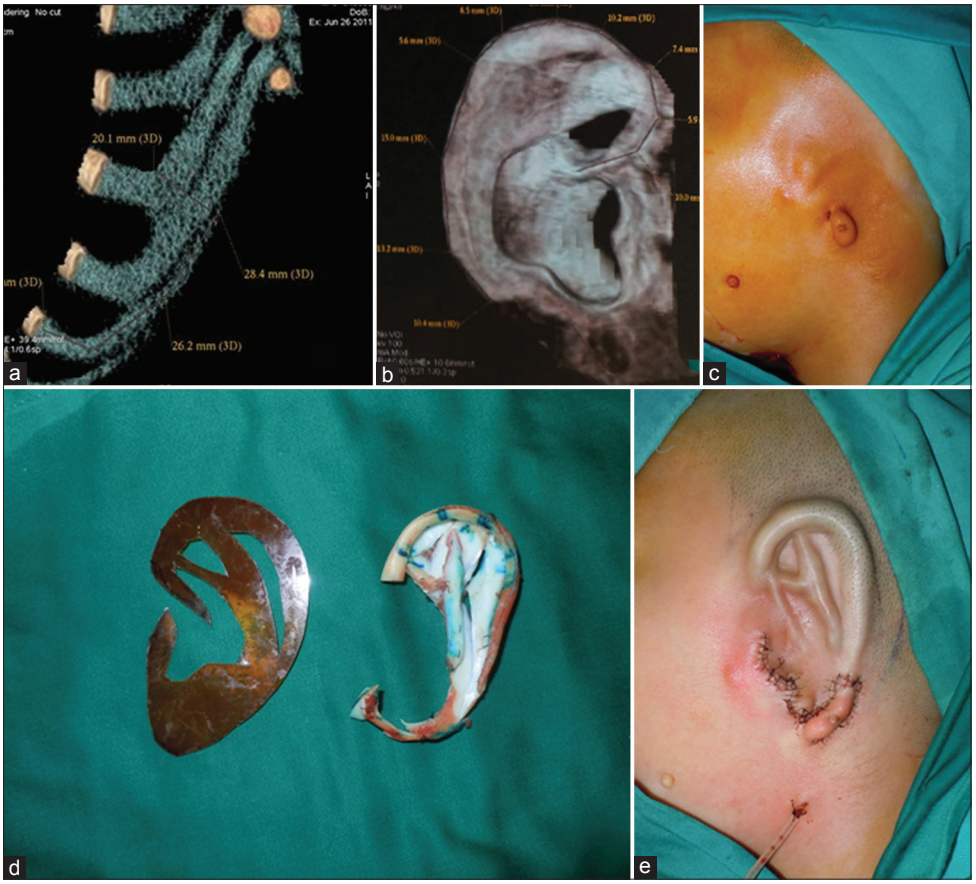

Figure 6: (a) Computed tomography reconstruction measurement; (b) computed tomography reconstruction measurement of helix in healthy ear cartilage framework; (c) preoperation; (d) cartilage framework fabricated and no more cartilage left intraoperation; (e) postoperation immediately.

helix shaping and the reconstructed ear cartilage framework, and consequently, the surgical outcomes.

The length of the eighth rib cartilage is difficult to anticipate, and the growth of the eighth rib cartilage is variable. The preoperative CT measurements of the eighth rib cartilage were highly correlated with the actual length of the costal cartilage as measured intraoperatively. Thus, MSCT provided highly accurate clinical information about the costal cartilage. The use of rib cartilage measurements with reference to data of the healthy ear allows the initiation of ear reconstruction surgery as early as possible. Rib cartilage assessment in reference to the healthy ear offers a method for guiding the timing of auricular reconstruction to provide personalized treatment.

Additionally, the possibility of chest deformity should be taken into account in patients in whom the rib cartilage is harvested too early. Chest wall deformities have been reported in 8% of patients in whom the costal cartilage was harvested between the ages of 6 and 12 years.[18]

In summary, the growth of the eighth cartilage is variable, and rib cartilage assessment in reference to the healthy ear can guide the timing of ear reconstruction and enable the provision of personalized treatment in young patients with microtia. This method is predictable, ensures an acceptable shape of the reconstructed auricle.

References

1. Brent B. Auricular repair with autogenous rib cartilage grafts: Two decades of experience with 600 cases. Plast Reconstr Surg 1992;90:355-74.
2. Brent B. Technical advances in ear reconstruction with autogenous rib cartilage grafts: Personal experience with 1200 cases. Plast Reconstr Surg 1999;104:319-34.
3. Nagata S. Modification of the stages in total reconstruction of the auricle: Part I. Grafting the three-dimensional costal cartilage framework for lobule-type microtia. Plast Reconstr Surg 1994;93:221-30.
4. Nagata S. Modification of the stages in total reconstruction of the auricle: Part II. Grafting the three-dimensional costal cartilage framework for concha-type microtia. Plast Reconstr Surg 1994;93:231-42.
5. Nagata S. Modification of the stages in total reconstruction of the auricle: Part III. Grafting the three-dimensional costal cartilage framework for small concha-type microtia. Plast Reconstr Surg 1994;93:243-53.
6. Brent B. Microtia repair with rib cartilage grafts: A review of personal experience with 1000 cases. Clin Plast Surg 2002;29:257-71, vii.
7. Nagata S. A new method of total reconstruction of the auricle for microtia. Plast Reconstr Surg 1993;92:187-201.
8. Andreoli SM, Mills JC, Kilpatrick LA, White DR, Patel KG. CT measured normative cartilage growth in children requiring costochondral grafting. Otolaryngol Head Neck Surg 2013;149:924-30.
9. Zhang Q, Zhang R, Xu F, Jin P, Cao Y. Auricular reconstruction for microtia: Personal 6-year experience based on 350 microtia ear reconstructions in China. Plast Reconstr Surg 2009;123:849-58.
10. Tai Y, Tanaka S, Fukushima J, Kizuka Y, Kiyokawa K, Inoue Y, *et al.* Refinements in the elevation of reconstructed auricles in microtia. Plast Reconstr Surg 2006;117:2414-23.

11. Li D, Zhang R, Zhang Q, Xu F, Xu Z, Tang X. Titanium mesh strut: A novel instrument for firm elevation of the reconstructed auricle. Aesthetic Plast Surg 2012;36:746-9.
12. Lim SY, Mun GH, Hyon WS, Bang SI, Oh KS. The elevation of the constructed auricle with a temporoparietal fascial flap wrapping a resorbable plate. J Plast Reconstr Aesthet Surg 2006;59:505-9.
13. Zhang Q, Zhang R, Xu F, Jin P, Wu J, Li D, *et al.* Firm elevation of the reconstructed auricle with a retroauricular fascial flap wrapping an EH (a mixture of epoxide acrylate malelic and hydroxyapatite) composite wedge. J Plast Reconstr Aesthet Surg 2010;63:1452-8.
14. Bauer BS. Reconstruction of microtia. Plast Reconstr Surg 2009;124 1 Suppl:14e-26.
15. Nagata S. Modification of the stages in total reconstruction of the auricle: Part IV. Ear elevation for the constructed auricle. Plast Reconstr Surg 1994;93:254-66.
16. Firmin F. Ear reconstruction in cases of typical microtia. Personal experience based on 352 microtic ear corrections. Scand J Plast Reconstr Surg Hand Surg 1998;32:35-47.
17. Firmin F. Auricular reconstruction in cases of microtia. Principles, methods and classification. Ann Chir Plast Esthet 2001;46:447-66.
18. Thomson HG, Kim TY, Ein SH. Residual problems in chest donor sites after microtia reconstruction: A long-term study. Plast Reconstr Surg 1995;95:961-8.

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