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Original Article

Radiological Investigation of the Variance of Ossicular Position in Microtic Ears

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OBJECTIVE: To radiologically investigate the malformations in microtic ears so as to provide assistance for canaloplasty of the external auditory meatus and tympanoplasty operation.

MATERIALS and METHODS: High-resolution computed tomography (HRCT) data of 48 patients with unilateral congenital microtia and aural atresia were studied. Multi-planar reconstruction (MPR) was performed to investigate the anatomic anomaly. The oblique axial and coronal planes were evaluated, on which the tympanic bone remnant was shown and the ossicular mass appeared with the largest size. The angles between the oblique axial/coronal planes and standard axial/coronal planes were measured and named α and β. The thickness of the atresia plate was measured on the oblique planes. The measurements in the microtic ears were compared with data from the normal side and 40 ears in 20 control individuals without ear malformations as well.

RESULTS: In most of the microtia patients, the α angle in the affected side (19.78°±7.42°) was larger than the α angle in the normal side (15.30°±4.60°), while the β angle in the affected side (16.77°±13.43°) was smaller than the β angle in the normal side (27.46°±6.87°). The thickness of the atresia plate was less than the thickness of the cribriform area in the normal side. A significant correlation was found between the Marx classification and the thickness of the atresia plate.

CONLUSION: HRCT evaluation using MPR is an important complement for the Jahrsdoerfer scoring system. The investigation is of great realistic significance. Preoperative measures for individual patients can provide guidance for canaloplasty and tympanoplasty operation.

KEY WORDS: Multi-planar reconstruction, microtia, high-resolution computed tomography, canaloplasty

INTRODUCTION

Microtia is a common congenital malformation in the clinics of otology. Most patients with microtia have atresia auris and middle ear anomaly, which leads dysaudia of the affected ear [1]. Reconstructive surgery is often required to improve the patients' appearance and hearing. However, canaloplasty and tympanoplasty are considered to be very difficult operations by most otologists [2]. Canaloplasty and tympanoplasty create a new acoustic meatus and reconstruct the tympanic structure. To create the new acoustic meatus, the atretic plate needs to be drilled through to form a bony canal. Classically, the tympanic bone remnant (TBR) on the lateral surface of the mastoid is taken as the landmark for initiation of the drilling. If there is no bony remnant, drilling should begin over the cribriform area (CA) in a superior and anterior direction [3]. Drilling ought to proceed towards the ossicles. However, accessing the ossicles during the operation is challenging, due to unpredictable anatomy and lack of valid intra-operative guidance. Although preoperative high-resolution computed tomography (HRCT) is routinely adopted to evaluate the malformation and make surgery plans, an unsatisfactory achievement ratio has been obtained [4-7].

This study is to radiologically investigate the spatial relationship between the TBR/CA and the ossicles, using the multi-planar reconstruction (MPR) technique, which allows reconstruction of HRCT views from any aspect, thus providing guidance for canaloplasty of the external auditory meatus and tympanoplasty operation.

MATERIALS and METHODS

Clinical Data

This study retrospectively analyzed 48 patients with unilateral congenital microtia and aural atresia from June 2008 to May 2012, including 37 males and 11 females, aged 6–24 years old, 11.94 years ion average. Informed consents of the use of CT images for publication were signed by the patients or the patients' parents. Ethics committee approval was received for this study from the ethics committee of the 306th Hospital of the People's Liberation Army.

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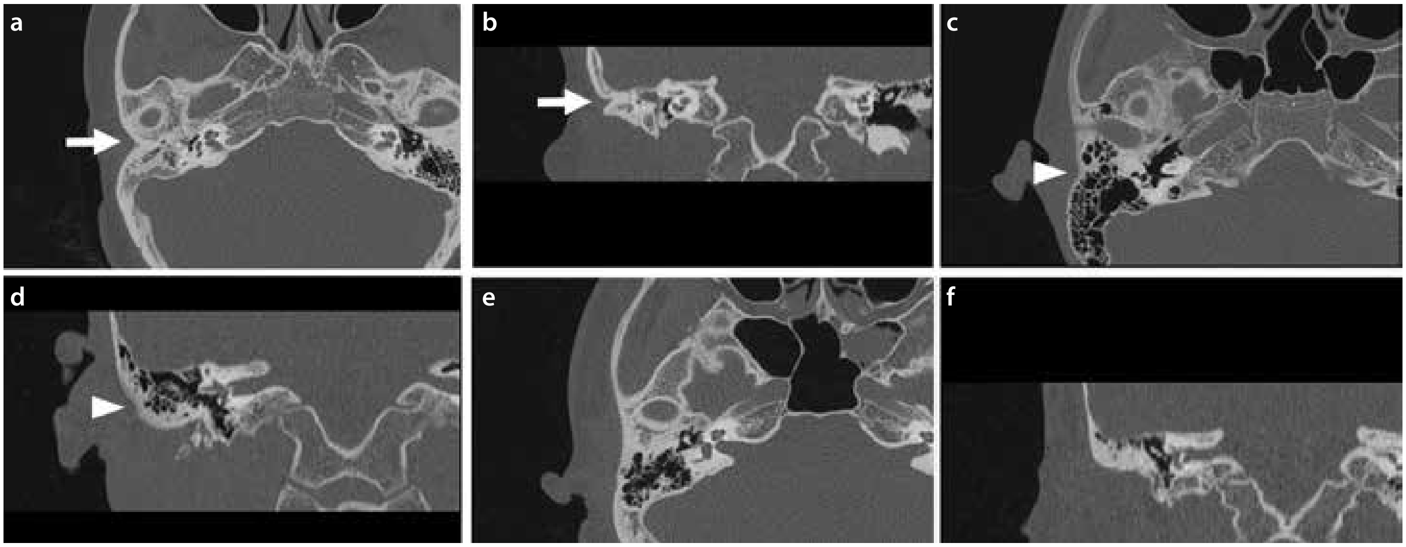

Figure 1. a-f. Radiological investigation of the malformation of the temporal bone (a). Axial view and coronal view show an atresia auris patient with a deep foramen cecum-shaped tympanic bone remnant, as indicated by the arrows (b). Axial view (c) and coronal view show an atresia auris patient with a shallow depression-shaped tympanic bone remnant, as indicated by the arrowheads (d). Axial view (e) and coronal view show an atresia auris patient without distinguishable tympanic bone remnant (f)

HRCT Scan

High-resolution computed tomography volume scan was performed using a Siemens SOMATOM ™ Definition flash (2×128-slice) dual-source scanner. The head^InnerEarUHR (spiral mode for ultra-high resolution inner ear studies) protocol was followed. Parameters were: 120 kV, 70 mA, rotation time 1.0 sec, pitch factor 0.85, slice width 0.6 mm, acquisition 12x0.6 mm, slice collimation 0.6 mm, feed/rotation 3.1 mm, and increment 0.60 mm. The scanning was performed parallel to the orbitomeatal line, involving the mastoid portion and petrous pyramid of the temporal bone. After the acquisition of the original data, the CT data were reconstructed using the U75u sharp++ advanced smoothing algorithm (ASA). In the workstation, the CT images were straightened by rotating the images and adjusting the baselines in the three dimensions to make them upright and symmetric. Since microtia is an asymmetric disorder that usually involves the temporal bone and mandible, it is hard to make it completely symmetric. However, the inner ear is seldom involved. In this study, the cochleas were taken as anatomic landmarks for adjusting the head position.

MPR and Measurement

Standard and oblique axial/coronal computed tomography (CT) images were used to investigate the anatomic anomaly in the Synapse medical image workstation software (FUJIFILM Medical Systems, Inc., Stamford, CT, USA). On the MPR-view panel, four windows were displayed. The upper left window was the original axial view, the upper right was a reformatted coronal view, the lower right was the reformatted sagittal view, and the lower left was the reconstructed oblique view. The oblique view could be oblique axial, oblique coronal, oblique sagittal, or free plane at any direction. In this study, oblique axial and coronal views were used.

To radiologically investigate the anomaly of the atresia auris, a landmark point on the lateral surface of the temporal bone was firstly defined. The landmark point was associated with the same landmark for initiation of the drilling when performing the canaloplasty. In most of the cases, a distinguishable TBR could be located and used as the outer landmark point. The TBR could be a deep bony foramen cecum or a shallow bony depression on the lateral surface of the mastoid, posterior to the glenoid fossa of the temporomandibular joint and root of the zygoma (Figure 1a-d). The endpoint of the TBR was defined as the outer landmark point of the atresia plate. For those cases without distinguishable TBR (Figure 1e-f), drilling should begin over the cribriform area. However, the cribriform area was radiologically quite indistinguishable from the rest of the temporal bone. Furthermore, the cribriform area contained countless points. The lack of uniqueness made defining the landmark point impracticable. Thus, this study only evaluated the CT images from the individuals with distinguishable TBR.

Mostly, TBR and ossicles were located on different standard axial planes (referring to the skull base plane). After copying the axial view (Figure 2a) to the oblique window, the oblique axial view can be adjusted in the coronal window. There was an oblique line in the coronal window, which corresponded to the oblique view (Figure 2b). The oblique line could be rotated around the landmark point, which referred to the line of intersection of the axial and sagittal planes that went through the landmark point. The oblique axial view changed while rotating the oblique line in the coronal window. The rotation was performed until both the landmark point and ossicles were displayed on the same oblique axial image (Figure 2c). The ossicular mass could be observed on a series of oblique axial planes. The oblique plane on which the ossicular mass appeared to be the largest size was used. The distance between the landmark point and the middle point of the wall of the tympanic cavity was measured using the ruler tool. The distance was considered the thickness of the atresia plate (Figure 2c). The axial rotation angle (α) was defined as the difference between the oblique line and standard axial line in the coronal window (Figure 2b).

A similar method as above was used to rotate the oblique coronal view in the axial window (Figure 3 a-c). The coronal rotation angle (β) was defined as the difference between the oblique line and standard coronal line in the axial window. The measurement of the thickness of the atresia plate was duplicated in the oblique coronal view.

Figure 2. a-c. Multi-planar reconstruction of the oblique axial plane. The original axial view: the horizontal/vertical yellow line refers to the standard coronal/sagittal plane (a). The reformatted coronal view: the horizontal/vertical yellow line refers to the standard axial/sagittal plane (b). The red line refers to the oblique axial plane, which can be rotated around the line of intersection of the axial and sagittal planes. The included angle between the red line and the horizontal yellow line refers to the α angle. The reconstructed oblique axial view, corresponding to the red line in the pattern b (c). The thickness of the atresia plate is measured on the oblique view. The green points indicate the tympanic bone remnant on the lateral surface of the mastoid. The white arrow indicates the ossicular mass

Figure 3. a-c. Multi-planar reconstruction of the oblique coronal plane. The original axial view: the horizontal/vertical yellow line refers to the standard coronal/sagittal plane (a). The red line refers to the oblique coronal plane, which can be rotated around the line of intersection of coronal and sagittal planes. The included angle between the red line and the horizontal yellow line refers to the β angle. The reformatted coronal view: the horizontal/vertical yellow line refers to the standard axial/sagittal plane (b). The reconstructed oblique coronal view, corresponding to the red line in the pattern a (c). The measurement of the thickness of the atresia plate was duplicated in the oblique coronal view. The green points indicate the tympanic bone remnant on the lateral surface of the mastoid. The white arrow indicates the ossicular mass

For the opposite normal side, the suprameatal spine was taken as the landmark point. An oblique axial plane was obtained, on which the suprameatal spine and ice cream-shaped malleus-incus were displayed. An oblique coronal plane was also obtained, which included the suprameatal spine and triangular or heart-shaped malleus-incus. The corresponding oblique axial angle and oblique coronal angle were considered as angles α and β on the normal side. On the oblique planes, the distance between the suprameatal spine and the middle point of the wall of the tympanic cavity was measured using the ruler tool. The distance was considered the thickness of the cribriform area of the normal side.

The HRCT data of 20 patients with a clinical diagnosis of sudden hearing loss and imaging diagnosis of no apparent anatomic anomaly were selected as normal controls. The patients were aged from 9 to 24. The α and β angles, as well as the thickness of the cribriform area, were measured using the same method as on the normal side of microtia patients.

All measurements were performed by the first three authors. Inter-observer reliability was evaluated by comparing the α angle of the 48 patients' CT data, measured by the three authors. The coefficient of variation was 3.9%, which indicated valid intra-observer reliability. The mean values of the three authors' measurements of the α and β angles and the thickness of the atresia plate/thickness of the cribriform area were used for statistical analysis.

Classification of the Microtia Malformation

The severity of the microtia was classified according to the Marx classification system: Grade I, normal-shaped but smaller pinna; Grade II, some anatomical structures still recognizable; grade III, only a rudiment of soft tissue is present; and Grade IV, no external ear or auditory canal [8]. The grading evaluation of the microtia was based on the 3D reconstructed CT image. The classification was determined by all of the 8 authors.

Statistical Analysis

All data were analyzed using Statistical Package for the Social Sciences (SPSS) 17.0 for Windows (SPSS Inc., Chicago, IL, USA). Pearson correlation analysis was adopted to investigate the relationship between the angles, thickness of the atresia plate and Marx grade. Paired-samples t-test was used to compare the data between the affected and normal sides. Independent samples t-test was used to compare the data from the normal side of the patients and the control group.

RESULTS

In the 48 unilateral congenital microtia patients, 24 microtia were located in the left ear and 24 were in the right ear. According to the Marx classification, 4 ears were classified Grade I, 21 were Grade II, 23 were Grade III, and 0 were Grade IV. Radiological investigation found that there was a distinguishable TBR in 41 out of the 48 patients (85.4%). All of the 7 microtic ears without a radiologically distinguishable TBR were classified Grade III.

In the microtic ears, the α angle ranged from 8° to 44°, 19.78°±7.42° on average, while the β angle ranged from -7° to 45°, 16.77°±13.43° on average. The thickness of the atresia plate was 12.73 mm±3.05 mm. In most of the microtia patients, the α angle on the affected side was larger than the α angle on the normal side (mean difference was 4.48°±7.33°, $p<0.001$, paired-sample t-test), while the β angle on the

Table 1. α, β, and thickness of the astresia plate or thickness of cribriform area of the microtic ears and normal ears.

	α(°)	β(°)	**Thickness* (mm)**
Group A (41)	19.78±7.42	16.77±13.43	12.73±3.05
Group B (41)	15.30±4.60	27.46±6.87	13.50±2.78
Group C (40)	13.99±6.93	26.39±6.59	13.63±1.76

Group A, Microtic ear. Group B, normal ear of unilateral microtia patients. Group C, 40 ears in 20 individuals with normal ear anatomy. *Thickness refers to the thickness of the atresia plate in group A, thickness of cribriform area in group B and C

Table 2. Spearman correlation analysis between the Marx's classification and the parameters of the atresia plate

Marx's Classification	α(°)	β(°)	**Thickness* (mm)**
I (n=4)	20.64±10.56	24±12.14	7.93±0.04
II (n=21)	19.86±6.66	14.31±12.01	12.84±2.93
III (n=16)	19.47±8.05	15.69±13.04	13.78±2.45

*There was a significant correlation between the Marx's classification and the thickness of the atresia plate (coefficient correlation 0.384, p=0.013)

affected side was smaller than the β angle on the normal side (mean difference was -10.69°±11.22°, p<0.001, paired-sample t-test). The thickness of the atresia plate was less than the thickness of the cribriform area on the normal side (mean difference was -0.77 mm±1.65 mm, p=0.005, paired-sample t-test) (Table 1).

Spearman correlation analysis suggested that there was no significant correlation between the Marx classification and α or β angle of the microtic ears (p=0.740 and 0.213, respectively). However, a significant correlation was found between the Marx classification and the thickness of the atresia plate (coefficient correlation 0.384, p=0.013) (Table 2). In other words, a microtic ear with a more severe external ear malformation had a thicker atresia plate.

There was no significant difference in age distribution between the microtia (12.9±4.23 years old) and normal control groups (14.2±3.91 years old) (p=0.176). In the 20 individuals in the control group, the anatomic structures of the left and right ear were basically symmetric. The α and β angles and the thickness of cribriform area presented no difference between the left and right side (p=0.879, 0.890, and 0.307, respectively, paired-sample t-test). There were no significant differences between the normal ears of the unilateral microtia patient and normal control ears in the α and β angles and thickness of the cribriform area (p=0.318, 0.474, and 0.813, respectively, independent-sample t-test). The measurements are displayed in Table 1.

DISCUSSION

Malformations of the middle ear can be investigated using conventional radiological procedures, such as HRCT. The Jahrsdoerfer radiological scoring system, based on the findings of HRCT of the temporal bone and the appearance of the external ear, provides a very important preoperative guideline for selecting patients for canaloplasty and tympanoplasty [4-7]. However, the auditory ossicle and the canal for facial nerve are such fine structures that HRCT provides limited investigation of spatial relationships between the most important structures. The auditory ossicle can only be displayed on 3-10 layers in each direction. A missed diagnosis or misdiagnosis still happens. Incorrect scoring could be marked due to inferior image resolution, thus leading to improper surgical method selection and lower chances of success. In contrast, MPR of CT images can provide more complete data of this region. By adopting the MPR technique, observation of the middle ear anatomic structure could be performed from an infinite visual angle; thus, MPR of CT images is an important complement for the Jahrsdoerfer scoring system and the diagnosis of microtia.

The measurement suggested that Marx classification of the auricles and the thickness of the atresia plates had a positive correlation. Microtic ears with more severe malformation in the auricle had thicker atresia plates, which could be due to narrow or even atresia middle ear cavity and underdeveloped TBR on the outer surface of the temporal bone.

During the investigation, we found that there was no distinguishable TBR on the outer surface of the temporal bone in some of the Grade III microtic ears (7/23). In this study, to investigate the malformation of the atresia plate, the definition of a landmark point was essential. To facilitate the canaloplasty, the landmark point defined on the CT data should also be a distinguishable anatomic landmark during the canaloplasty. The TBR was the first and feasible choice. For microtic ears without radiologically distinguishable TBR, further study is needed to figure out a new method for identification of the landmark point.

The α and β angles in the microtic ear suggested that most of the canaloplasty should be performed in a superior and anterior direction, which is basically in agreement with otologists' experience [3]. However, in our investigation, the β angle in 5 of the 48 ears was negative, which means that the canaloplasty should be performed in an inferior and anterior direction in these cases.

As we know, the TBR in the affected ear does not equal the suprameatal spine in the normal ear. Thus, the measurements in the two sides are not ideally comparable. In the microtic ears, anatomical variation involves not only the ossicles but also the TBRs. The relationship between the two anatomical variations is not clear. Thus, the spatial relationship between the ossicles and the TBR is not constant. However, the measurements of the α and β angles and the thickness of the atresia plate are of great significance for guiding the operation of a canaloplasty of the external auditory meatus and tympanoplasty. The direction of the canaloplasty could be determined according to the α and β angles-the relationship relative to the standard axial and coronal planes. The drilling depth could be alerted by the measured result of the thickness of the atresia plate. From June 2012 to December 2013, we have performed preoperative measurement of the α and β angles and the thickness of the atresia plate for each individual microtia patient with atresia auris. The measurements were adopted to guide the drilling in canaloplasty, which had facilitated the operation greatly. A much higher success rate of accessing the ossicles was achieved, when compared to previous data. This study will be reported soon.

In conclusion, radiological Investigation of the malformations in microtic ears with atresia auris could help evaluation of the spatial relationship between the TBR and ossicles, which could provide guidance for canaloplasty and tympanoplasty operation.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of the 306th Hospital of the People's Liberation Army.

Informed Consent: Written informed consent was obtained from patients and their parents who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - L.Z., W.W.; Design - L.Z.; Supervision - W.W.; Materials - H.W., H.H.; Data Collection and/or Processing - G.W., B.L.; Analysis and/or Interpretation - D.Z., R.D.; Literature Review - L.Z.; Writing - L.Z.; Critical Review - W.W.

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REFERENCES

1. Yeakley JW, Jahrsdoerfer RA. CT evaluation of congenital aural atresia: what the radiologist and surgeon need to know. J Comput Assist Tomogr 1996; 20: 724-31. [CrossRef]
2. Kelley PE, Scholes MA. Microtia and congenital aural atresia. Otolaryngol Clin North Am 2007; 40: 61-80. [CrossRef]
3. McKinnon BJ, Jahrsdoerfer RA. Congenital auricular atresia: update on options for intervention and timing of repair. Otolaryngol Clin North Am 2002; 35: 877-90. [CrossRef]
4. Jahrsdoerfer RA, Yeakley JW, Aguilar EA, Cole RR, Gray LC. Grading system for the selection of patients with congenital aural atresia. Am J Otol 1992; 13: 6-12.
5. Jahrsdoerfer RA, Hall JW III. Congenital malformations of the ear. Am J Otol 1986; 7: 267-9.
6. Shonka DC Jr, Livingston WJ III, Kesser BW, The Jahrsdoerfer grading scale in surgery to repair congenital aural atresia. Arch Otolaryngol Head Neck Surg 2008; 134: 873-7. [CrossRef]
7. Ishimoto S, Ito K, Yamasoba T, Kondo K, Karino S, Takegoshi H, et al. Correlation between microtia and temporal bone malformation evaluated using grading systems. Arch Otolaryngol Head Neck Surg 2005; 131: 326-9. [CrossRef]
8. Marx H, Die Missbildungen des ohres. In: Denker, AKO, editors. Handbuch der Spez Path Anatomie Histologie. Berlin, Germany: Springer; 1926.