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Original Article

3D quantitative measurement for multi-spiral CT images of round window area related structure

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Abstract: Objective: Round window pathway is an important surgical approach in modern ear microsurgery and ear neurosurgery. Detailed grasp of the round window area anatomy and related parameters is key to the success of such surgeries. Methods: In order to provide comprehensive and accurate anatomical information and methods for successful surgery through the round window approach, 64-slice spiral CT multi-planar reconstruction (MPR) technology was adopted in three-dimensional quantitative measurement of the round window area structural anatomies of adults and children, respectively. Measurement data of different age groups were statistically compared, and measurement data of adult group were compared with that of cadaveric head specimens in this study. Results: The results showed that round window area related structures from 3D quantitative measurement by multi-spiral CT with MPR could represent actual anatomical structure measurement results, and provide accurate imaging anatomy information for anatomical positioning in round window area surgery. Conclusions: Facial nerve mastoid is frontward, and round window surgical area can be expanded downward, but caution should be taken to avoid damages to jugular bulb.

Keywords: 3D, round window area related structure, CT

Introduction

Round window pathway is an important surgical approach in modern ear microsurgeries and ear neurosurgeries, such as vibrating sound bridge implantation through a round window approach, cochlear implantation via round window membrane, and cochlear implantation through a round window membrane anterioposterior approach [1-3]. Before surgery, detailed grasp of round window area anatomy and related parameters, accurate positioning and exposure of the round window during surgery is the key to an success of such surgery [4].

In the past, research of anatomical structure of the round window area focused on the microscopic observation and measurement of skull specimens [5], which could not provide individualized anatomical parameters for an accurate positioning of round window. Development of imaging provided new technology and methods for preoperative individualized anatomical parameters. Currently there are many studies on preoperative CT measurement of facial recess related anatomical parameters, while few studies on CT measurement of round window area anatomical structures, and which are limited to adults [6, 7].

In this study, 64-slice spiral CT multi-planar reconstruction (MPR) technology was adopted for 3D quantitative measurement of structural anatomy of the round window area in adults and children, respectively, and the differences of measurement data among different age groups were statistically analyzed in order to provide comprehensive, accurate and effective anatomical information and methods for successful surgeries through the round window approach.

Materials and methods

Ethic statement

The study was approved by the Education and Research Committee, and the Ethics Committee

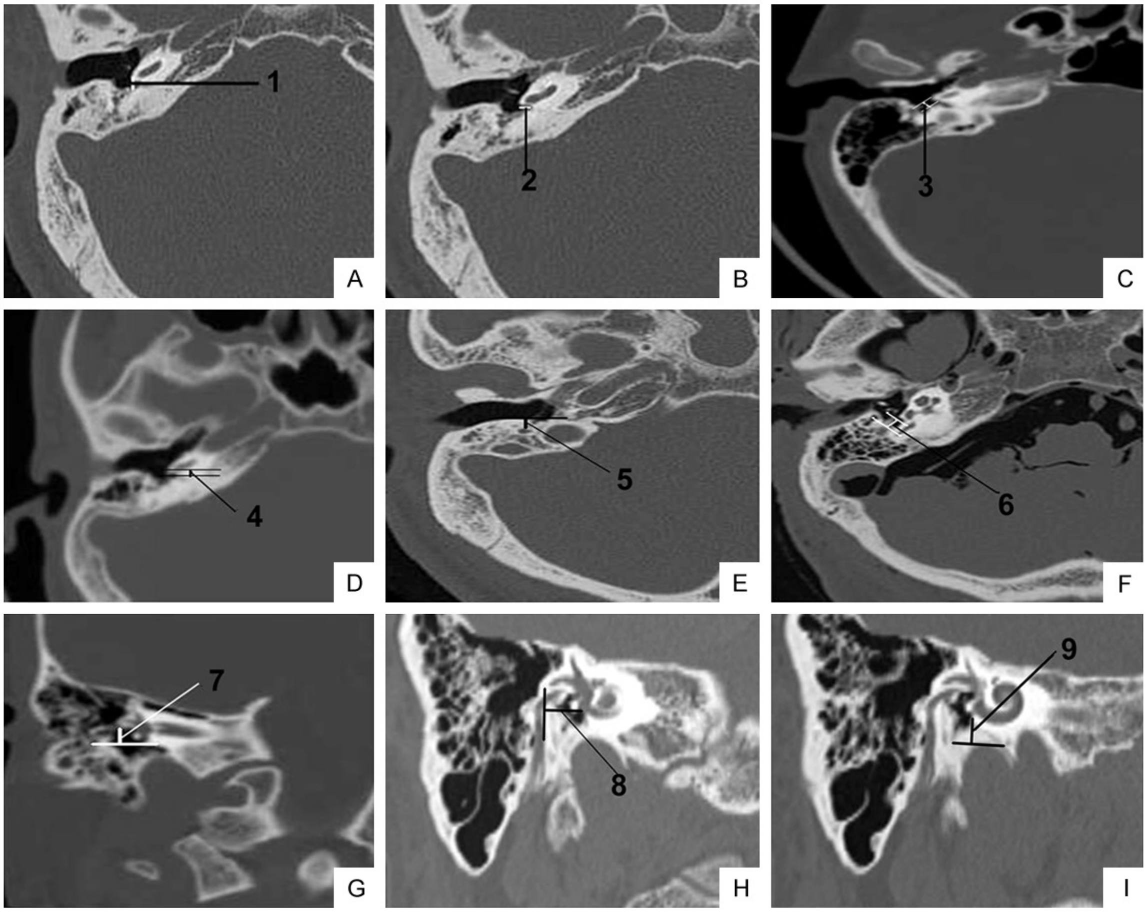

Figure 1. A: On the axial round window niche level, the measurement of the round window niche width (1). B: On the axial round window niche level, measurement of the round window niche depth (2). C: On the axis round window niche level, measurement of the round window niche front wall thickness (3); D: On the axis round window niche level, the vertical distance from the trailing edge of round window niche anterior wall to the trailing edge of cochlea (4); E: On the axis cochlea lower edge level, measurement of the vertical distance of the leading edge of the facial nerve mastoid segment to bony canal wall (5); F: On the axis cone uplift level, cone bulge height measurement (6); G: On the coronal round window niche level, measurement of the vertical distance from the lower edge of the tympanic segment to the lower training edge of round window niche (7); H: On oblique sagittal, the same level as mastoid segment and horizontal segment of facial nerve, round window, oval window and jugular venous ball, measurement of the vertical distance from the leading edge of the facial nerve mastoid segment to the midpoint of the trailing edge of the round window niche (8); I: On oblique sagittal, the same level as mastoid segment and horizontal segment of facial nerve, round window, oval window and jugular venous ball, measurement of the vertical distance from the lower training edge of round window niche to jugular fossa top (9).

of Zhejiang Taizhou Municipal Hospital (approval # ZTMH00942243). A written informed consent was obtained from each patient, which granted a permission to use data obtained in subsequent studies.

Clinical data

140 cases of patients who underwent paranasal sinus CT examinations were enrolled from January 2008 to September 2012 in Taizhou Municipal Hospital. 78 patients were adult (156 ears), aged from 18 to 67 (average age 41.3), including 39 males (average age 40.2) and 39 females (average age 42.4). There were 62 cases of children (124 ears), aged from 1 to 6 (average age 3.2), including 34 boys (mean age 3.6) and 28 girls (mean age 2.8). The exclusion criteria was as follows: 1) pediatric patients < 1 year of age or > 6 years of age; 2) adult patients > 70 years of age; 3) patients with a history of otologic disease (including temporal bone deformities, cancer history, history of trauma, history of vertigo, facial nerveparalysis and hearing loss); 4) patients with malformations and lesions in cranial base.

Table 1. Comparison of round window area structure spacing CT measurements between different age groups ($\overline{\chi}\pm s$, mm)

Measurement item	Adults	Children	*t* value	*P* value
A	2.18±0.32	2.08±0.19	1.843	0.065
B	1.91±0.25	1.29±0.17	1.950	0.041
C	0.70±0.15	0.45±0.09	1.983	0.032
D	0.89±0.31	0.84±0.08	1.735	0.088
E	4.54±0.27	3.65±0.27	2.032	0.023
F	2.23±0.31	2.03±0.35	1.765	0.075
G	2.35±0.42	2.12±0.32	1.832	0.069
H	6.63±0.11	5.38±0.42	1.601	0.095
I	4.12±1.51	4.01±1.24	1.531	0.113

Note: A: the width of the round window niche; B: the depth of the round window niche; C: front wall thickness of the round window niche: D: the vertical distance from trailing edge of the round window niche front wall to the cochlea trailing edge; E: the vertical distance from the leading edge of the facial nerve mastoid segment to the bony canal wall; F: cone uplift height; G: vertical distance between the lower edge of the tympanic segment and the lower training edge of round window niche; H: the vertical distance from the leading edge of the facial nerve mastoid segment to the midpoint of the trailing edge of the round window niche; I: the vertical distance from the lower training edge of round window niche to jugular fossa top.

Table 2. Comparison between adult round window area structure spacing CT measurement data and existing adult cadaver measurement data ($\overline{\chi}\pm s$, mm)

Measurement item	CT image data	Existing cadaver data	*t* value	*P* value
A	2.18±0.32	2.26±0.33	0.783	0.441
B	1.91±0.25	1.93±0.36	0.735	0.501
C	0.70±0.15	0.73±0.21	0.728	0.523
D	0.89±0.31	0.91±0.24	0.771	0.478
E	4.54±0.27	4.68±0.34	0.628	0.598
F	2.23±0.31	2.31±0.31	0.680	0.523
G	2.35±0.42	2.41±0.37	0.681	0.516
H	6.63±0.11	6.70±0.19	0.762	0.493
I	4.12±1.51	4.26±1.78	0.832	0.321

Note: A: the width of the round window niche; B: the depth of the round window niche; C: front wall thickness of the round window niche: D: the vertical distance from trailing edge of the round window niche front wall to the cochlea trailing edge; E: the vertical distance from the leading edge of the facial nerve mastoid segment to the bony canal wall; F: cone uplift height; G: vertical distance between the lower edge of the tympanic segment and the lower training edge of round window niche; H: the vertical distance from the leading edge of the facial nerve mastoid segment to the midpoint of the trailing edge of the round window niche; I: the vertical distance from the lower training edge of round window niche to jugular fossa top.

CT scan and restructuring method

CT scans and restructuring methods: American GE LightSpeed 64 row full body CT scanner was used. The subject in supine position underwent a paranasal sinus cross-section spiral CT scan. The scan base line was parallel to the hard palate, ranging from the upper edge of frontal sinus to the upper edge of hard palate. Isotropic scanning parameters confirmed from literature [8] were adopted, with a voltage of 120 kV, current 200 mA, collimator width 0.62 mm, thickness 0.625 mm/16i, bed-speed 5.625 mm/s, pitch 0.562, matrix 512 × 512, FOV 18 cm × 18 cm. The bone imaging algorithms was used for reconstructuring imaging. Scan data were transmitted to Advantage 4.1 image post-processing workstation, and MPR in free mode along with various long axis was performed on the axial, coronal, or oblique sagittal of 3D control panel.

Measurements of CT image data

Major anatomical structures were measured by a compass and a vernier caliper with 0.02 mm accuracy on the collected high-resolution CT slice according to the scale indicated on CT. Measurement was repeated three times to take an average value.

Measurements on CT axial image: 1) Measurement on the round window niche level included round window niche width [1] (**Figure 1A**), depth of round window niche [2] (**Figure 1B**), round window niche front wall thickness [3] (**Figure 1C**), vertical distance from trailing edge of round window niche front wall to cochlea trailing edge [4] (**Figure 1D**); 2) Measurement on the lower edge level of cochlear included vertical distance from leading edge of facial nerve mastoid segment to bony canal wall [5] (**Figure 1E**); 3) Measurement on cone uplift level included cone bump height [6] (**Figure 1F**).

Measurement on CT coronal image: vertical distance between lower edge of tympanic segment and lower training edge of round window niche was measured [7] (**Figure 1G**).

Measurements on CT oblique sagittal image: on the same level with mastoid segment of facial nerve, round window, oval window and jugular venous ball, vertical distance from leading edge of facial nerve mastoid segment to midpoint of trailing edge of round window niche was measured [8] (**Figure 1H**), as well as vertical distance from lower training edge of round window niche to jugular fossa top [9] (**Figure 1I**).

Statistical methods

Statistical software SPSS.17.0 was used for statistical analysis, and sample distribution was subjected to normality test. Normally distributed measurement data were expressed as mean ± standard deviation ($\overline{\chi}$ ±s). T Test was used for statistical analysis of differences between measurement data of adults and children, as well as differences between adult CT measurement data and existing adult cadaver measurement data. Person straight line statistical analysis was applied for correlation between vertical distance (from leading edge of facial nerve mastoid segment to midpoint of trailing edge of round window niche) and vertical distance (from lower training edge of round window niche to jugular fossa top). $P < 0.05$ was considered statistically significant.

Results

Quantitative measurement and comparison of round window area structures

Related CT measurement indicators of round window areas in adults and children are shown in **Table 1**. Round window niche depth, former wall thickness of round window niche, and vertical distance from outer edge of facial nerve mastoid segment to bony canal wall in Adult group were greater than those in the children's group. There were no significant differences between the two groups for the rest measurement data (**Table 1**).

Comparison between adult round window area from CT MPR data and existing adult cadaveric head measurement

Results of comparison between adult CT quantitative measurement results and existing cadaver measurements [9-12] are shown in **Table 2**. The results showed that the difference between adult CT measurement data and adult cadaveric head specimens' data in literature was not statistically significant.

Correlation between vertical distance from leading edge of facial nerve mastoid segment to midpoint of trailing edge of round window niche, and vertical distance from lower training edge of round window niche to jugular fossa top

Correlation coefficient between vertical distance from leading edge of facial nerve mastoid segment to midpoint of trailing edge of round window niche and vertical distance from lower training edge of round window niche to jugular fossa top is $r=0.031$ ($P=0.061$), indicating no significant correlation between them.

Discussions

Clinical values of 3D measurement of temporal bone multi-slice spiral CT imaging anatomy

Temporal bone anatomy is complex, and mastering temporal bone surgery area anatomical knowledge as well as preoperative individual anatomical features of patient surgical field is fundamental to success of the surgery. To grasp anatomical knowledge of temporal bone surgical area needs repeated cadaver dissection trainings and researches, but it is more and more difficult to access cadaver specimens. Therefore opportunity for anatomical training of surgeons on cadaver temporal bone is less [10], and there are shortcomings of small sample size, poor reproducibility, inconvenient research as well as unavailable individual anatomical parameters on cadaver anatomy training [6]. With a rapid development of imaging technology, multi-slice spiral CT technology, with its good repeatability, easy access to large samples and living research subjects, is more in line with actual situation of surgery. In this study, living adults' anatomy data from CT 3D measurement was compared with existing adult cadaver anatomical data. Results indicated no statistically significant difference between them, which is consistent with research results of Xing et al [7]. Results of this study showed that 3D measurements of multi-slice spiral CT images might represent actual anatomical measurement distance. Because of large differences of individual anatomical structure and the distance, preoperative CT temporal bone scan and 3D quantitative surgery area measurement can supply comprehensive, real and accurate individualized anatomical parameters to surgeons, which provide a reliable and practical anatomical study method to improve success rate of temporal bone surgeries and reduce surgical complications.

Clinical significance of quantitative measurement of the round window niche

Round window niche is a hidden and complex bone niche crypt below promontory of middle ear cavity. Round window membrane is located in fossa, and it is covered with bony wall of round window niche. Observed from outside inwards, round window membrane is generally not seen [9]. Purposes of round window area surgery require to expose round window membrane, so bone on upper edge and leading edge of round window niche must be grinded off to fully expose round window membrane during surgeries. Related anatomy and surgical findings showed that smaller front wall thickness is, wider and shallower round window niche is, easier to expose round window membrane [13]. Thickness, width and depth of adults round window niche anterior wall were measued as (0.70±0.15) mm, (2.18±0.32) mm and (1.91±0.25) mm respectively; for children round window niche wall thickness, width and depth were (0.45±0.09) mm, (2.08±0.19) mm and (1.29±0.17) mm respectively. Some researchers have measured adults round window niche front wall thickness, width and depth as 0.91 mm; 96 mm, 189 mm [11], and for children (0.43±0.07) mm, (2.02±0.20) mm, (1.25±0.19) mm [14], which are similar to findings of the authors [14]. Results of this study showed that round window niche front wall thickness and depth were statistically significant among different age groups. The difference for children was less than adults, which indicates that it is easier to expose round window membrane in children than in adults. As for surgeons, it is more conducive for intraoperative round window membrane exposure and improving success rate of surgeries by multi-slice spiral CT preoperative quantitative measurement of round window niche front wall thickness, width and depth to estimate range of bone in round window niche which needs to be grinded off as well as to evaluate degree of exposure difficulty of round window membrane.

CT evaluation of facial nerve recess width and depth

Commonly used surgical approach in clinical round window area surgeries is a facial nerve recess pathway. Width and depth of facial nerve recess in this pathway is a key factor affecting exposures of round window niche, thus clear preoperative definition of width and depth of facial nerve recess is beneficial for surgery approach choices and smooth operations [15]. In cadaver dissection study, facial recess width is often determined by measuring distance from facial nerve mastoid segment to chorda tympani nerve, but it is very difficult to identify the chorda tympani nerve on CT. Some related studies showed that vertical distance (from outer edge of facial nerve mastoid segment of round window niche level to bony canal wall) is bigger than actual width of round window level facial recess for about 0.8 mm [14]. Therefore in this study, vertical distance (from outer edge of facial nerve mastoid segment of round window niche level to bony canal wall) was used to estimate width of round window level facial recess. Measured vertical distance (from outer edge of facial nerve mastoid segment of round window niche level to bony canal wall) in this study in adult group was (4.54±0.27) mm and children group (3.65±0.27) mm, and difference was significant. It is suggested that children's facial recess width is smaller than adults', so caution should be exercised during round window surgeries in children. Some studies showed no significant effect [16] on taste from transection side of chorda tympani nerve. Therefore if facial recess width is too small, sacrificing one side of chorda tympani nerve to increase facial recess width in order to facilitate round window niches exposure may be considered. He et al found that cone uplift height can indirectly reflect facial nerve crypt depth [12]. In this study, cone uplift height mean value in adults was (2.23±0.31) mm, children (2.03±0.35) mm, and there was no significant difference between the two age groups, indicating that facial nerve crypt depth of both men and women developed almost completely after birth and it is symmetrical on both sides, which is consistent with Norris's view [17].

Guidance value of CT measurement of the round window niche adjacent structure on positioning of the round window niche

The round window niche is adjacent to vital structures, with front-up adjacent to facial nerve tympanic segment, front next to cochlear base back, below adjacent to jugular vein ball cochlear, and rear adjacent to facial nerve mastoid segment. A clear definition of distances front adjacent structures to round window niche has an important guiding significance on round window niche positioning and niche wall removal orientation during surgeries. In this study, statistical analysis of relevant measurement data showed that vertical distances of round window niche to facial nerve tympanic segment, cochlear base back, jugular fossa ball and facial nerve mastoid segment had no significant differences between different ages, suggesting that basic distances between round window niche and adjacent structures were constant without influence of ages. Above measurement data helps intraoperative round window niche positioning. Vertical distance from trailing edge of round window niche anterior wall to cochlear base back was (0.89±0.31) mm in adults, (0.84±0.08) mm in children, and the difference between the two groups was not significant, indicating during grinding of leading edge bone of round window niche, it should not exceed 1.00 mm in adults and children, otherwise it will hurt inner ear. Vertical distance from lower edge of facial nerve tympanic segment to lower training edge of round window niche was (2.35±0.42) mm in adults, (2.12±3.208) mm in children, suggesting facial nerve tympanic segment is very close to upper edge of round window niche.

In this study, statistical analysis of relevant measurement data showed that vertical distances of round window niche to facial nerve tympanic segment, cochlear base back, jugular fossa ball and facial nerve mastoid segment had no significant differences between different ages, suggesting that basic distances between round window niche and adjacent structures were constant without influence of ages. During grinding of upper edge of round window niche, surgeons should be careful not to damage facial nerve tympanic segment. Results of this study showed that there was no correlation between vertical distance (from leading edge of facial nerve mastoid segment to midpoint of round window niche) and vertical distance (from lower training of round window niche to jugular fossa top), suggesting that when facial nerve mastoid is frontward, round window surgical area can be expanded downward, but caution should be taken to avoid damages to jugular bulb.

Disclosure of conflict of interest

None.

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References

[1] Rajan GP, Lampacher P, Ambett R, Dittrich G, Kuthubutheen J, Wood B, McArthur A and Marino R. Impact of floating mass transducer coupling and positioning in round window vibroplasty. Otol Neurotol 2011; 32: 271-277.
[2] Richard C, Fayad JN, Doherty J and Linthicum FH Jr. Round window versus cochleostomy technique in cochlear implantation: histologic findings. Otol Neurotol 2012; 33: 1181-1187.
[3] Erixon E, Kobler S and Rask-Andersen H. Cochlear implantation and hearing preservation: Results in 21 consecutively operated patients using the round window approach. Acta Otolaryngol 2012; 132: 923-931.
[4] Li ZH, Lv JY, Shen JM, Zhang GB, Wen X, Cai ZY and Lin YQ. Study of demonstrating main operative section of facial recess approach using double oblique multiplanar reconstruction on multislice CT. Chin J Radiol 2012; 46: 13-18.
[5] Johnson LA, Della Santina CC and Wang X. Temporal bone characterization and cochlear implant feasibility in the common marmoset (Callithrix jacchus). Hear Res 2012; 290: 37-44.
[6] Wu RG, Tang BH, Li LC, He YQ, Huang DC, Huang H and Wang ZC. [Measurement of anatomical relationships of facial nerve canal related to middle ear and mastoid surgery on multi-slice computed tomography-multiplanar reformation images]. Zhonghua Yi Xue Za Zhi 2010; 90: 1551-1555.
[7] Xing WW, Zhang LC, Chen HY and Gu JC. Three-dimensional quantitative measurements of multi-spiral CT images related to the sigmoid sinus. Chin J Otorhinolaryngol Head Neck Surg 2010; 45: 296-300.
[8] Li ZH, Lv JY, Tao BH, Shen JM, Zhang GB, Wen X and Cai ZY. Study of demonstrating main operative mark of transmastiod-epitympanum

approach of the facial nerve using double oblique multi-planar reconstruction in multi-slice CT. J Clin Otorhinolaryngol Head Neck Surg 2011; 25: 865-868.
[9] Zou TM, Guo MR, Zhang HZ, Shu F and Xie NP. Applied anatomy of scala tympani inlet related to cochlear implantation. J Souther Med Univ 2012; 32: 904-907.
[10] Zhu YJ, Tong BS, Xu SC, Liu YH and Duan ML. Applied anatomy of operation through posterior tympanum approach. Chin J Otorhinolaryngol Head Neck Surg 2008; 22: 867-870.
[11] Duan JJ, Luo HQ, Lu CJ, Wei JP, Li MZ and Xiong JP. Round window area temporal bone section versus CT. Chin J Otorhinolaryngol 2004; 39: 269-272.
[12] He LP, He F, Li YX and Zhao XT. An anatomy study of relate parameters of temple bone structure in the surgery of cochlear implantation. Chin Arch Otolaryngol Hea Neck Surg 2002; 9: 168-170.
[13] Alian WA, Majdalawieh OF, Van Wijhe RG, Ejnell H and Bance M. Prosthetic reconstruction from the tympanic membrane to the stapes head or to the stapes footplate? A laser doppler study. J Otolaryngol Head Neck Surg 2012; 41: 84-93.
[14] Zou ZF, Hua QQ, Cao YM, Liao H, Li W and Xie WQ. HRCT measurement of anatomyical structures related to the vibrant soundbridge to round window implant in children aged 1~6 years old. J Audiol Speech Pathol 2012; 20: 119-122.
[15] Song JJ, Park JH, Jang JH, Lee JH, Oh SH, Chang SO and Kim CS. Facial nerve aberrations encountered during cochlear implantation. Acta Otolaryngol 2012; 132: 788-794.
[16] Hu ZQ and Wang ZM. Study of otitis media with cholesteatoma chorda tympani nerve. Chin J Otorhinolaryngol 2001; 36: 123-125.
[17] Norris BK, Goodier AP and Eby TL. Assessment of air quality during mastoidectomy. Otolaryngol Head Neck Surg 2011; 144: 408-411.