Surgical and Radiologic Anatomy (2019) 41:853–857
https://doi.org/10.1007/s00276-019-02225-8

ANATOMIC VARIATIONS

Anatomic variations of the round window niche: radiological study and related endoscopic anatomy

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Received: 2 October 2018 / Accepted: 15 March 2019 / Published online: 21 March 2019

Abstract

Purpose In the last decades, literature has shown an increasing interest in round windows (RW) anatomy due to its pivotal role in deafness surgery. The high variability of this anatomical region, with particular regard to the round windows niche (RWN), has been studied by several authors through different methods of investigation. The aim of the present research was to radiologically examine the morphological variability of the RWN and to link the imaging findings to the endoscopic view.

Methods High-resolution CT scans of 300 temporal bones without neuro-otological pathologies were retrospectively reviewed by 2 neuroradiologist and 1 ENT surgeon who independently evaluated the RWN morphological variations. To link the radiological to the endoscopic data, 45 cadaveric human temporal bones were submitted to a radiological evaluation and to an otoendoscopy conducted through a posterior tympanotomy approach.

Results Three variants of the RWN were detected on coronal CT scan reconstructions: 155 “cylindrical-type”, 97 “j-type” and 48 “truncated cone-type”. For each radiological type the endoscopic findings showed a specific endoscopic position of the RW chamber, which results in different degrees of RW membrane visibility when analysed through a posterior tympanotomy approach.

Conclusions To the best of our knowledge, this is the first description of the above-mentioned RWN radiological variations supported by endoscopic data. This study suggests an additional anatomical evaluation that could be useful to predict the RW membrane visibility through a posterior tympanotomy approach. Further studies are required to support the clinical implications of our observations.

Keywords Round window niche · Anatomic variation · Cochlear implant · Endoscopic anatomy · Radiological anatomy · Middle ear

Introduction

Antonio Scarpa was just 20 years old when, in 1772, he first described the human round window in the “De structura fenestrae rotundae auris, et de tympano secundario anatomicae observationes” [8]. Except for very few studies, only in the twentieth century the round window region regained the attention of medical researchers due to its clinical relevance. The tremendous advances of hearing bionic (e.g. cochlear implantation) for modern otology led to the rediscovering of the role of the round window region as a surgical route to hearing recovery. Curiously, a friendship bonded Antonio Scarpa to Alessandro Volta, professor of the University of Pavia, who first reported the electrical stimulation of the auditory system. More recently, Proctor et al. described the chamber of the round window as a well-defined cavity,

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located on the posterior surface of the promontory, of varying shape, size and direction, composed by four structures: the fundus, the tegmen, the anterior and the posterior postis [7]. The embryologic origin of the RWN seems to explain its high anatomic variability and its consequent pathological and surgical implications [10]. Moreover, between the 8th and 15th fetal week, the RW develops from the cartilage of the otic capsule, while the bony ossification starts from the 16th week [7, 10]. Tóth et al. suggested that the floor of the RWN arises entirely from a chondral ossification, while the walls derive both from membranous and chondral bones, which could explain a certain degree of anatomical variability [10]. In the last years, an increasing number of studies have investigated the anatomic variations of the RWN resorting to different exploring methods: histologic, otomicroscopic, endoscopic, radiologic, three-dimensional moulding or computerised techniques. The aim of the present work was to radiologically assess the morphological variations of the RWN, relating the imaging findings to their endoscopic anatomy.

Materials and methods

Radiological evaluation

A retrospective review of high-resolution CT scans was performed using the radiological databases of "IRCCS Policlinico San Matteo" and "Ospedale Santa Maria del Carmine". 150 head HR-CT scans, which contained temporal bone sequences without neuro-otological pathologies, were included in the study to describe the RWN region (totaling 300 petrous bones). The radiological exams were obtained by the multidetector brilliance CT 64 channel or the Toshiba Aquilon Prime, both with multi-slice spiral CT evaluations and with the following parameters of image acquisition/reconstruction: slice thickness 0.6 mm, pitch 0.3/0.5, kV 120 and mAs 150. The radiological evaluation of RWN morphology and the description of its anatomic variations were assessed by two neuroradiologists (neuroradiologist-1 and neuroradiologist-2) and one ENT surgeon, who independently examined each temporal bone to minimise the possibility of operator-dependent interpretation bias. Radiological assessment of the ear through the axial and coronal reconstructions was realised according to the current radiological practice [9].

Endoscopic evaluation

To relate radiological to endoscopic data, 45 cadaveric human temporal bones with no known otologic diseases were submitted to HR-CT scan using the same parameters applied to "in vivo" evaluation and otoendoscopic study of the RWN through a posterior tympanotomy approach. Otoendoscopy was performed using Karl Storz HOPKINS® Straight-Forward Telescope 0° and Forward-Oblique 30° with diameter 2.7 mm and length 18 cm. In this phase of the study, the ENT surgeon and neuroradiologists worked together.

Statistical analysis

Quantitative variables were presented in the form of highest and lowest values (range), mean and standard deviation, while the qualitative variables were expressed as percentages and compared using the Chi-square test. Cohen's κ coefficient was used to evaluate "inter-rater agreement" between different raters. p values lower than 0.05 were considered statistically significant. All analyses were conducted using STATA (release 14, STATA Corp., College Station, TX, USA).

Results

HR-CT scans of 300 temporal bones were examined by neuroradiologist-1, neuroradiologist-2 and an ENT surgeon. Proceeding with the radiological evaluations, they were able to identify a significant variability which enabled them to describe three morphological types of RWN in the coronal reconstructions: "cylindrical-type", "j-type" and "truncated cone-type". According to the morphological findings, in the "cylindrical-type" the lateral entrance of the RWN is parallel to the RW membrane and the lateral walls are parallel to each other as well (Fig. 1a). This anatomic variation was recorded in 51.7% (155/300) of CT scans. The lateral walls of the "J-type" RWN are also parallel, but the entrance of the niche and the RW are located on different and not parallel planes, making the RWN resemble a "j" (Fig. 1b). The investigators observed a "j-type" RWN in 32.3% (97/300) of the examined cases. In the "truncated cone-type" RWN, the entrance of the niche is parallel to the RW, but the lateral walls gradually converge to the RW, forming a truncated cone shape (Fig. 1c). 16% (48/300) of CT scans showed a "truncated cone-type" RWN. In 266 out of 300 temporal bones (88.7%), the investigators agreed on the RWN morphology. The inter-rater reliability among different collectors was calculated and Cohen's κ coefficient proved an almost perfect agreement between different raters, Cohen's κ coefficient being 0.911 (95% IC 0.885–0.920) between neuroradiologist-1 and ENT surgeon, 0.877 (95% IC 0.870–0.898) between neuroradiologists-1 and neuroradiologists-2 and 0.811 (95% IC 0.778–0.825) between neuroradiologist-2 and ENT surgeon. By means of the Chi-square test, the presence of statistically significant differences of the RWN

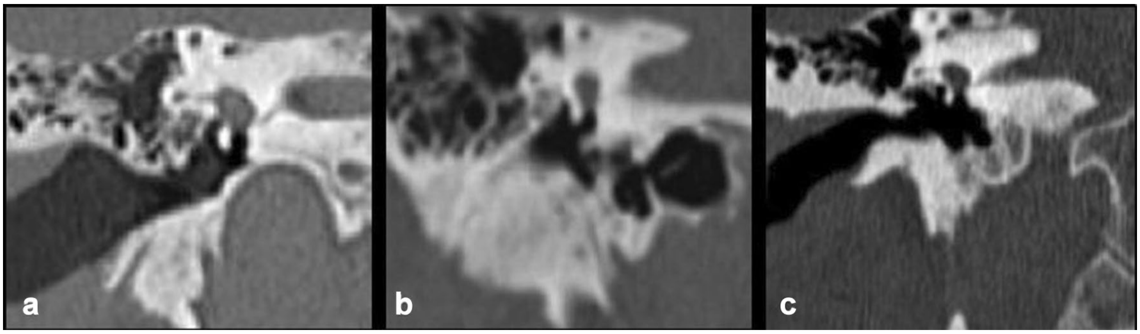

Fig. 1 Coronal CT scan reconstructions: **a** "cylindrical-type" RWN, **b** "j-type" RWN, **c** "truncated cone-type" RWN

Table 1 Intra-individual concordance between different RWN variations

Cylindrical–cylindrical	56	37.3%	Symmetric 67.3%
J–J	32	21.3%	
Truncated cone–truncated cone	13	8.7%	
Cylindrical–J	27	18%	Asymmetric 32.7%
Cylindrical–truncated cone	16	10.7%	
Truncated cone–J	6	4%	

morphology according to sex or according to side were also evaluated, resulting as follows:

- RWN type and temporal bone side: Chi-square test = 1.8; $p = 0.396$.
- RWN type and sex: Chi-square test = 3.4; $p = 0.183$ with a slightly higher prevalence of "cylindrical" and "truncated cone" types in female samples compared to male samples.

Consequently, the intra-individual concordance rate was determined: in 101 out of 150 (67.3%) head HR-CT scans, the RWN of both sides presented the same radiological features. Specifically, in 56 (32.7%) it was cylindrical (Table 1).

In the second phase of the study, 45 temporal bone samples were submitted to HR-CT scan and a subsequent endoscopic evaluation of the RWN through a posterior tympanotomy approach was conducted. The investigators detected the following variations of RWN: 24 (53.3%) "cylindrical-type", 15 (33.3%) "j-type" and 6 (13.4%) "truncated cone-type" (Fig. 2a–f). No statistical difference was measured between these data compared with the percentages of the previous radiological findings on the 300 temporal bones. In the endoscopic findings of "cylindrical-type" RWN (Fig. 2a), the lateral entrance of the RWN was systematically oriented postero-inferiorly and positioned on a nearly horizontal plane, which allowed a direct visibility of the RW membrane. Also, the fustis pointed to the RW membrane. Endoscopy of the "j-type" RWN (Fig. 2b) always showed a lateral-inferior orientation of the lateral entrance, creating an obtuse angle. The RW membrane, concealed by the RWN walls, resulted in difficult visualisation. The fustis defined the anterior edge of the RW membrane. In the "truncated cone-type" RWN (Fig. 2c), the lateral entrance appeared constantly oriented postero-inferiorly and on a nearly vertical plane. The fustis pointed to the RW membrane, to which the lateral walls converged.

Discussion

We performed a radiological study conducted by 3 independent investigators (two neuroradiologists and one ENT surgeon) on 300 temporal bones with no known otologic diseases. Based on the coronal CT scan reconstructions, three anatomic variations of RWN were identified and described, with a significant agreement among the investigators: "cylindrical-type" (51.7%), "j-type" (32.3%) and "truncated cone-type" (16%). The different cranial–caudal developments of the RWN were subsequently related to the endoscopic findings on 45 cadaveric human temporal bones that showed 3 different spatial directions of the RWN. In particular, each radiological type of RWN showed a specific endoscopic position of the RW chamber and different degrees of RW membrane visibility when analysed through a posterior tympanotomy approach. To the best of our knowledge, this is the first description of the above-mentioned RWN radiological variations supported by endoscopic data. For many years, the RW chamber has been neglected in the literature due to its high anatomical complexity. The several anatomic variations of the RWN are still object of numerous studies, which differ for the applied technique of investigation, the analysed anatomic features, the spatial orientation of the anatomic samples and the employed "line-of-sight" mode [2–6].

Among relatively recent radiological studies, Cohen et al. focused on measurements of the depth, width and shape of the RWN [3]. Fujita et al. otomicroscopically examined the RWN of 50 temporal bones and compared

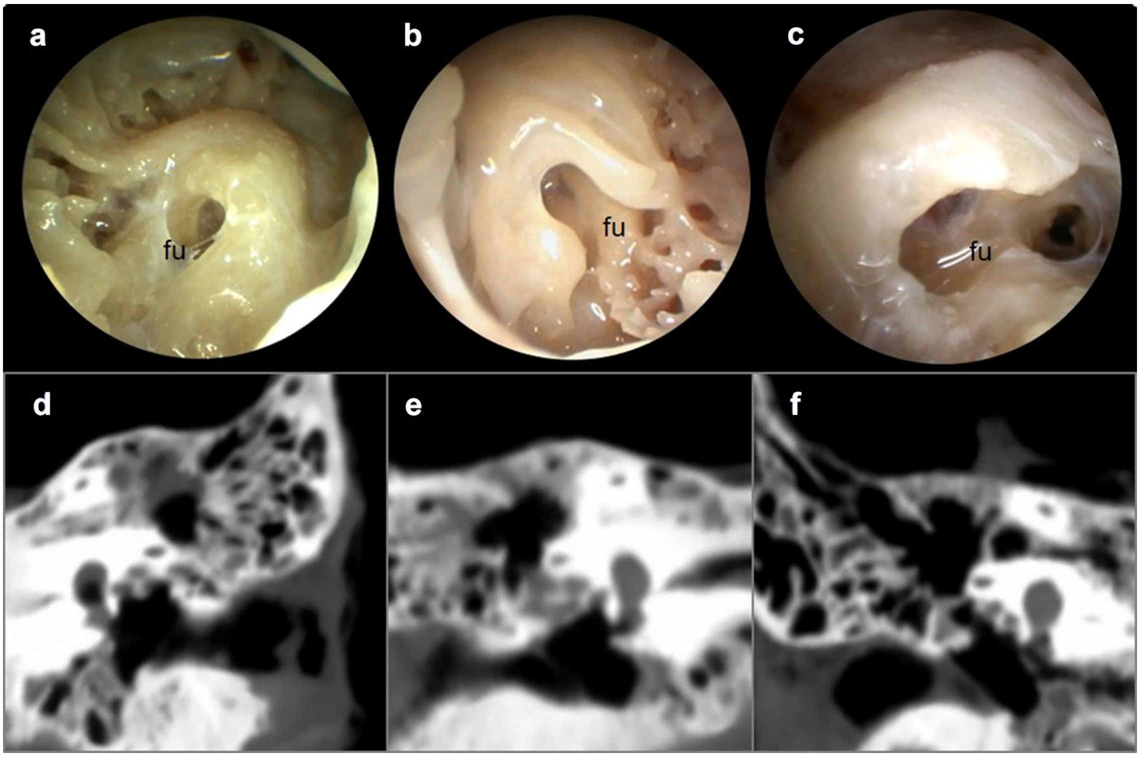

Fig. 2 Endoscopic anatomy and relating coronal CT scan reconstructions in temporal bone samples **a** "cylindrical-type" RWN endoscopy, **b** "j-type" RWN endoscopy, **c** "truncated cone-type" RWN endoscopy, **d** "cylindrical-type" RWN radiology, **e** "j-type" RWN radiology, **f** "truncated cone-type" RWN radiology. *fu* fustis

the range of angles necessary to perpendicularly reach the RW membrane through a transcanalar approach with CT scans measurements [4]. Even though a comparison with previous works is quite difficult due to the dissimilar methods of study, our findings appear in agreement with the possible different spatial directions of the RWN reported by Proctor et al. in a microscopic study of 1989 [6]. According to Cohen et al., no statistically significant differences of the RWN-types were detected according to sex or temporal bone side [3]. Two different orientations of the fustis were endoscopically observed in the three types of RWN. The type A fustis classified by Marchioni et al. was detected in the "cylindrical-type" and "truncated cone-type" RWN with an overall frequency of 67.7% of cases. This result appears quite similar to the percentage of type A fustis found by Marchioni (71.4%) [5]. The "j-type" RWN was characterised by a type B fustis, occurring in 32.3% of ears.

Many fascinating aspects define the RWN, which is characterised by a multitude of anatomic variations regarding its size, shape and direction, leading to the numerous different ways to study the same structure. Future studies should consider all these parameters together, resorting to more holistic methods of investigation (e.g. 3D additive manufacturing [1]).

Conclusions

The importance of the CT scan to predict RW visibility is widely reported in the literature, which greatly describes the anatomic factors that may limit or enhance the viewable portion of the RW when examined through a posterior tympanotomy approach. Taking into account the anatomic variations of the RWN on coronal reconstructions, our work suggests an additional anatomic element that may be useful to predict RW membrane visibility through a posterior tympanotomy approach. Our research was based on imaging projections that are employed in daily radiological and surgical practices, to avoid mathematical or geometrical formulas unsuitable for routinely practice. Further studies are required to support the clinical implications of our observations.

Author contributions PC: Project development, data analysis, manuscript writing. IA: data analysis, manuscript writing. MM: data analysis. AS: data collection, data analysis. MM: data analysis, manuscript editing. ER: data collection, data analysis. CT: data analysis. MN: data collection, data analysis. MAB: project development. MB: project development.

Funding All the authors certify that they receive no financial support or funding for this work.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent For this type of study, formal consent is not required (retrospective study).

Human/animal rights statement This article does not contain any studies with animal participants performed by any of the authors.

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