Available online at www.sciencedirect.com

ScienceDirect

Journal of Otology 12 (2017) 80–85

www.journals.elsevier.com/journal-of-otology/

Value of section plane, MPR, and 3D-CTVR techniques in the fine differential diagnosis of ossicular chain in the case of conductive hearing loss with intact tympanic membrane

Yang Liu [a,*], Feng Yang [b], QiaoHui Lu [c], Danheng Zhao [a]

[a] *Center of Otolaryngology, PLA Navy General Hospital, Fucheng Road 6, Haidian District, Beijing, 100048, China*
[b] *Department of Otolaryngology, The Second Central Hospital, Baoding, Fanyang Road 57, Zhuozhou, Hebei, 072750, China*
[c] *Department of Radiology, PLA Navy General Hospital, Fucheng Road 6, Haidian District, Beijing, 100048, China*

Received 14 August 2016; revised 3 October 2016; accepted 7 December 2016

Abstract

Aim: To assess the quality of high-resolution CT section planes (HRCT), multi-planar reformation (MPR) and 3-dimensional volume rendered computer tomography (3D-CTVR) were here used in the fine differential diagnosis of ossicular chain in the case of conductive hearing loss with intact tympanic membrane.
Methods: Here, 17 cases of otosclerosis and 22 cases of ossicular chain deformity were selected. All patients had normal external ear canals, intact tympanic membranes, conductive hearing loss, type A tympanograms, and negative Gelle's tests. The respective radiological reports of the status of the ossicles via 3 protocols were compared to surgical findings. The quantitative assessments of the representation of different segments of the ossicular chain were based on a 3-point scoring system.
Results: MPR and CTVR imaging both showed the integrity of whole ossicular chain well. MPR and CTVR imaging were found to be superior to section planes with respect to showing the superstructure of the stapes and malformations ($P > 0.05$).
Conclusion: CTVR and MPR imaging were found to be better able to show the whole ossicular chain in the conductive hearing loss with normal tympanic membranes. Furthermore, the use of these techniques can have profound contributive value in the differential diagnosis of otosclerosis and ossicular chain absence or malformation.

Keywords: Ossicular chain; Conductive hearing loss; Volume rendered computer tomography; Multi-planar reformation; Section plane

1. Introduction

In some cases of conductive hearing loss, patients all have normal external ear canals, intact tympanic membranes, type A tympanograms, and negative Gelle's tests. This raises the question of how to assess the status of the ossicular chain, such as whether the condition is otosclerosis or whether the ossicular chain is absent or malformed. The 2 axial and coronal section planes of conventional HRCT do not allow otologists to clearly determine ossicle status, such as whether the chain in the middle ear is intact, absent, or damaged. For the last decade, the MPR technique, which can project multiple section planes of ossicles onto the same plane and show distinct 2D ossicle imaging, has enabled otologists to view the condition of the ossicular chain inside the middle ear cavity. The 3D-CTVR technique is another important method. The use of CTVR can indicate reveal the status of the ossicle distinctly and in 3D. The advantages and limitations of these 2 protocols have been reported and discussed by several authors

* Corresponding author.
E-mail address: liuyangdoc@sina.com (Y. Liu).
Peer review under responsibility of PLA General Hospital Department of Otolaryngology Head and Neck Surgery.

http://dx.doi.org/10.1016/j.joto.2016.12.004

(Zhang et al., 2011; Fatterpekar et al., 2006; Trojanowska et al., 2007). In the current study, both MPR and CTVR techniques were used to show the fine structures of the ossicular chain. A previous paper reported the important role that MPR and CTVR techniques play in the fine diagnosis of ossicular chains in the middle ear cholesteatoma (Liu et al., 2014). The quality of 3 protocols in the fine diagnosis of ossicular issues in conductive hearing loss with intact tympanic membrane was assessed using the same methods. The results collected here also indicate that these techniques might be used in combination in future clinical work.

2. Materials and methods

2.1. Cases

From March 2011 through August 2015, 39 cases approved by the ethics committee of our hospital were selected for this study. All these patients had conductive hearing loss (air-bone gap from 15 dB to 45 dB), normal external ear canals, intact tympanic membranes, type A tympanograms, and negative Gelle's tests. Of these 39 cases, 23 were female and 16 were male. They ranged in age from 7 through 68 (mean age: 33.7). All notes were taken during the first 3 days after the CT scan and tympanoplasty were performed. Both of these were carried out by the corresponding author along with written observations of the ossicle chain during and after each surgery.

2.2. CT scan and post-processing

The CT scanner used here was a 128-channel multi-detector row (Philips Brilliance iCT128). The area from the lower margin of the external auditory meatus to the top margin of the petrous bone was scanned with every subject in the supine position. The axial thin slice scanning was set at a collimation of 20 × 0.65 mm, with horizon (FOV) at 150 mm × 150 mm, pitch at 0.25 mm, matrix at 1024 × 1024, voltage at 120 kV and current at 350 mAs. The Y-sharp bone algorithm was used, with reconstruction set at overlapping 0.34 mm intervals and the results of a 128 to 140-layer image. Voxel dimensions were 0.1465 mm for X and Y, and 0.34 mm for Z. All data were then transmitted to the EBW4 workstation for reconstruction of 3 post-processing protocols including the conventional axial and coronal section planes of HRCT, the imaging of MPR and 3D-CTVR. The window level for the 3D imaging was set at 500 to −400 HU, and window width was set to 2000 HU.

2.3. Data analysis

All the CT images were analyzed by 2 independent and experienced radiologists. The standard observation planes and angle were as follows: 1) The planes of conventional HRCT: the epitympanum plane in the axial section (Fig. 1 A-1); the plane of the epitympanum and vestibular window in the coronal section (Fig. 1 A-2); 2). The planes of the MPR: the plane of the long axes of the incus and the reconstructed malleus paralleling the incudal long process (Fig. 1 A-3); and the plane of anterior and posterior crus of stapes (Fig. 1 A-4). 3) The reconstructed CTVR images were placed in a designed cube that could be magnified and rotated. Otologists are generally familiar with the 2 standard viewing fields of CTVR, namely from the posterior-inferior edge of tympanic membrane to the mesotympanum and epitympanum (Fig. 1 A-5) and from the antrum and epitympanum to the mesotympanum (Fig. 1 A-6).

2.4. Statistical analysis

All key segments of the ossicular chain were analyzed and are tabulated in Table 1. This table is similar to the one

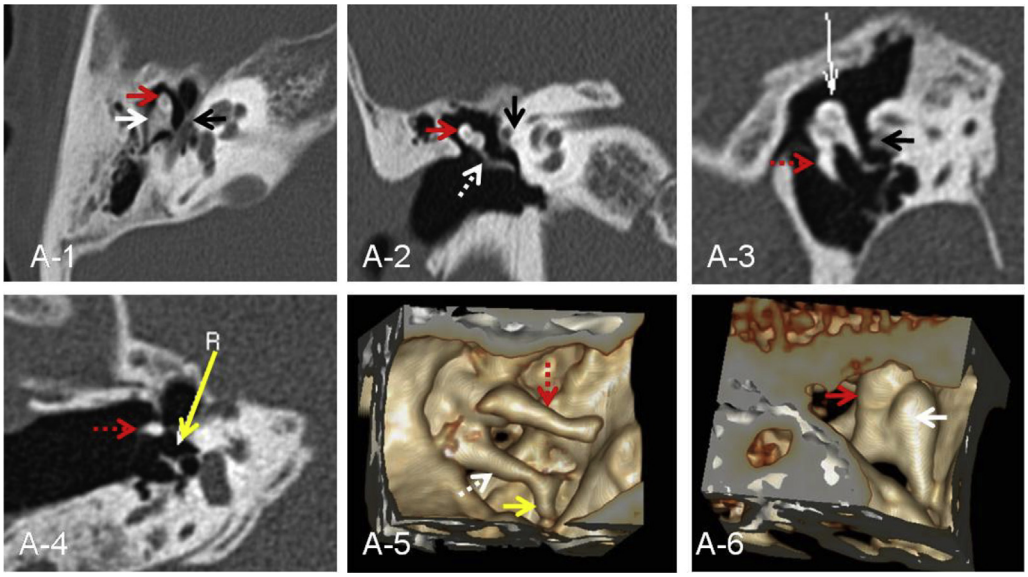

Fig. 1. **A**xial (A-1) and coronal section planes of conventional CT show the head of malleus (red arrow) and incus (white arrow). A-3 & A-4 are MPR images showing the whole intact ossicular chain. A-5 and A-6 are CTVR imaging. Red arrow—head of malleus; red dotted arrow—handle of malleus; white arrow—body of incus; white dotted arrow—long limb of incus; yellow arrow—normal stapes superstructure; black arrow—facial nerve.

Table 1
Quantitative assessment (MV: score mean value; SD: standard deviation).

	Surgery			Section plane					P	MPR					P	CTVR					P
	2	1	0	2	1	0	mv	SD		2	1	0	mv	SD		2	1	0	mv	SD	
Head of malleus	39	0	0	39	0	0	2.00	0.00	–	39	0	0	2.00	0.00	–	39	0	0	2.00	0.00	–
Handle of malleus	39	0	0	39	0	0	2.00	0.00	–	39	0	0	2.00	0.00	–	39	0	0	2.00	0.00	–
Malleoincudal joint	38	0	1	39	0	0	2.00	0.00	0.37	37	1	1	1.92	0.35	0.65	38	1	0	1.97	0.16	0.65
Long limb of incus	28	3	8	25	11	3	1.56	0.64	0.77	28	4	7	1.54	0.79	0.89	26	2	10	1.44	0.88	0.67
Body of incus	38	1	0	38	1	0	1.97	0.16	1.00	38	1	0	1.97	0.16	1.00	39	0	0	2.00	0.00	0.42
Short limb of incus	38	0	1	38	1	0	1.97	0.16	0.59	–	–	–	–	–	–	39	0	0	2.00	0.00	0.28
Incudalstapes joint	28	1	10	14	14	11	1.08	0.81	0.06	26	2	11	1.38	0.91	0.70	26	1	12	1.36	0.93	0.61
Stapes superstructure	26	7	6	3	31	5	0.95	0.46	0.00	29	6	4	1.64	0.67	0.41	28	4	7	1.54	0.79	0.87
Malformed stapes superstructure	12	0	27	0	2	37	0.97	0.16	0.03	3	6	30	0.31	0.61	0.06	9	3	27	0.54	0.85	0.63

reported in a previous paper (Liu et al., 2014). During surgery, otologists are generally most concerned with the head of the malleus, the handle of the malleus, the body of the incus, the long limb of the incus, and the malleoincudal and incudostapedial joints. This is because when dealing with ossicular chain, otologists must first focus on the connection of the stapes and long limb of the incus. If the long limb of incus is present, the connection should be severed by cutting the incudostapedial joint in order to protect the inner ear. Because the attic is occupied by the head of malleus and body of the incus, reconstructing the ossicular chain usually requires removing the body of the incus. The handle of the malleus plays an important role in supporting the tympanic membrane and in the reconstruction of the ossicular chain. At the same time, segments of the ossicular chain, such as the lateral process of the malleus, the neck of malleus, and the lenticular process are not given due consideration. In all of the operations performed here, the anterior and posterior crus were replaced with the superstructure of the stapes. Because CTVR and MPR imaging only show the structure of the footplates and not their state (vibration or fixation), which is the chief concern, the footplates of the stapes were disregarded. All segment details, including comparisons of surgical findings for all 3 protocols are listed in a Table 1. SPSS software was used to complete the chi-square test. The quantitative assessments for the representation of different segments were based on a 3-point scoring system. A segment was scored 2 if it was intact, 1 if it was partial or eroded, and 0 if it was absent (see Table 1).

3. Results

Table 1 summarizes the results of quantitative assessment of conventional section plane, MPR and CTVR for different ossicular segments. The long limb of the incus here served as an example: In surgery, 28 cases scored 2 points, 3 scored 1 point, and 8 scored 0 points. In the section plane, the 25 cases had a score of 2, 11 had a score of 1, and 0 had a score of 3, the mean value of score was 1.56, the standard deviation was 0.64, and the P value was 0.37 (>0.05) compared to pre-surgical values. The P value (0.37) indicated the imaging representation of the long limb of incus via the section was closely consistent with surgical findings. As shown in Table 1, most of the segments in 3 different protocol images had no significant differences from surgical findings ($P > 0.05$). However, the P values of the superstructure of the stapes ($P = 0.00$) and of malformed stapes ($P = 0.03$) in the section plane did show significant differences. This indicated that the representation of this segment via section plane did not match surgical findings closely. All the P values related to MPR and CTVR were greater than 0.05, which indicated that the representation of this segment via MPR and CTVR was consistent with surgical findings. Statistical data for the short limb of the incus in MPR were not included in Table 1 because it was blocked in the MPR imaging. The P values of the head and handle of the malleus were not counted because all 3 protocols produced the same results as surgery.

3.1. Case examples

3.1.1. Case A: otosclerosis

The patient was a woman of 40 years with a normal external ear canal, intact tympanic membrane, conductive hearing loss, type A tympanogram, and negative Gelle's test. During the operation, results showed the ossicular chain to be normal but the footplate fixed. Fig. 1 is the imaging preoperatively. In the section plane (Fig. 1 A-1 and A-2), not all of the ossicular chain was visible, especially the stapes superstructure, and the ossicles resembled an ice cream cone (Fig. 1 A-2). In the MPR images (Fig. 1 A-3 and A-4), the whole ossicular chain can be seen in the same plane and the stapes superstructure is also clearly visible (Fig. 1 A-4, yellow arrow). As shown in Fig. 1 A-5 and A-6, the ossicular chain can be observed directly and clearly under CTVR.

3.1.2. Case B: absent ossicular chain

The patient was a girl of 14 years who had had poor hearing since birth. The patient had a normal external ear canal, intact tympanic membrane, conductive hearing loss, type A tympanogram, and negative Gelle's test. In the section plane, Fig. 2 B-1 showed the head of malleus (red arrow) and body of incus (white arrow). Fig. 2 B-2 shows only a vague image of the

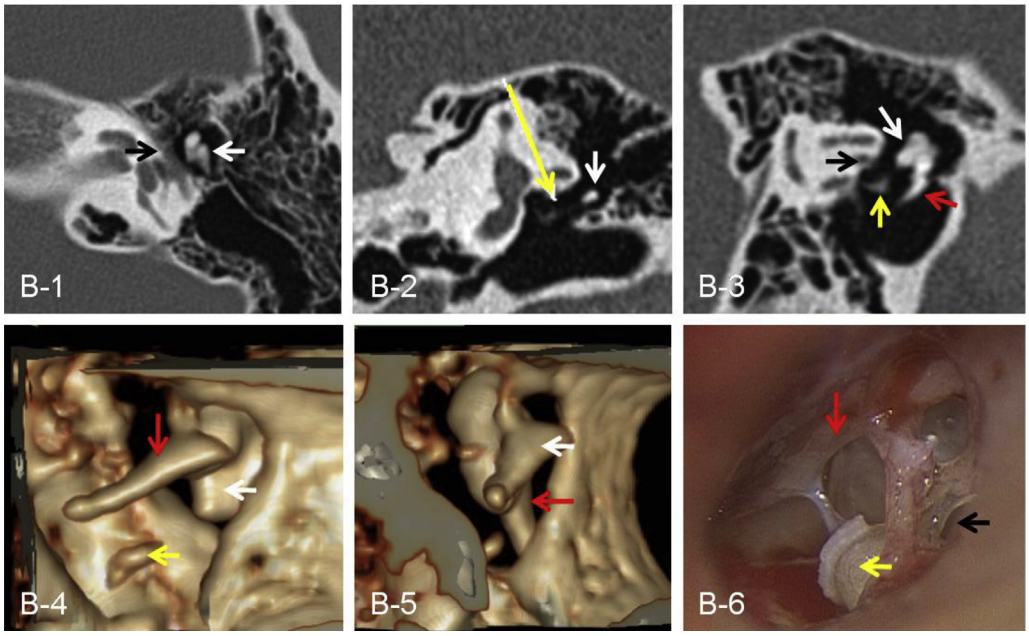

Fig. 2. B-1: axial section plane of CT; B-2 coronal section plane of conventional CT; B-3:MPR imaging; B-4 and B-5: CTVR imaging; B-6: Surgical image. Red arrow—hand of malleus; white arrow—body of incus; black arrow—facial nerve; yellow arrow—abnormal stapes superstructure.

superstructure of the stapes (yellow arrow). In the MPR images (Fig. 2 B-3), the whole ossicular chain can be seen, showing the abnormal stapes superstructure (yellow arrow) and the lack of long limb of incus. In the CTVR image of the ossicular chain (Fig. 2 B-4) the abnormal ossicular chain can be observed directly and clearly. The long limb of incus is absent and the stapes superstructure was deformed (yellow arrow). During the operation (Fig. 2 B-6), the malleus was found to be normal, the long limb of incus was absent and the superstructure of the stapes was abnormal.

3.1.3. Case C: malformed ossicular chain

The patient was a man of 29 years who had had poor hearing for the previous 20 years. The patient also had a normal external ear canal, intact tympanic membrane, conductive hearing loss, type A tympanogram, and negative Gelle's test. In the section plane, Fig. 3 C-1 shows the normal long limb of incus (white arrow) and normal stapes superstructure (yellow arrow). However, the whole ossicular chain was visible in the MPR images (Fig. 3 C-2), showing abnormal stapes superstructure (Fig. 3 C-3 yellow arrow). In

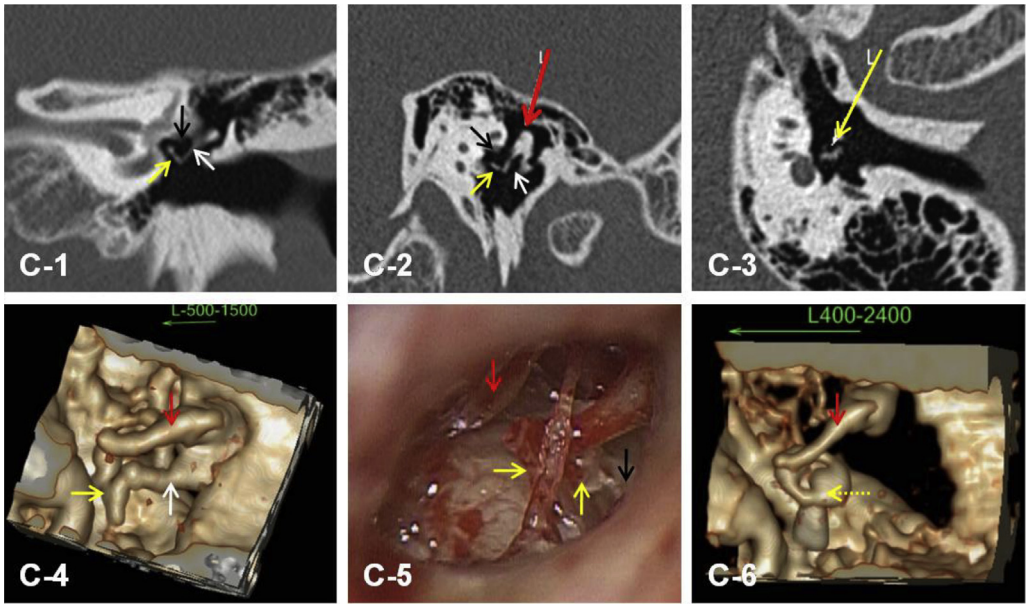

Fig. 3. C-2: Coronal section plane of conventional CT; C-3 and B-4: MPR imaging; C4 preoperative CTVR imaging; C-5: surgical image; C-6: post-operative CTVR imaging. Red arrow—hand of malleus; white arrow—long limb of incus; yellow arrow—abnormal stapes superstructure and PORP(C-6); black arrow—facial nerve.

the CTVR image of the ossicular chain shows the entire chain directly and clearly with malformed stapes superstructure (yellow arrow) (Fig. 3 C-4). Fig. 3 C-5 shows surgical findings and the abnormal stapes superstructure. Fig. 3 C-6 is a post-operative CTVR image showing the PORP (yellow arrow).

4. Discussion

The fine and objective diagnosis of the status of the ossicular chain in CT imaging is necessary to the restoration of hearing. However, the conventional coronal and axial section plane do not facilitate this. Modern CT technology has allowed data to be immediately transmitted to post-processing workstations for which 2D and 3D images of ossicular chains were created. These include MPR and CTVR imaging. In fact, the combination of these various techniques in the diagnosis of ossicular lesions is necessary, especially in the differential diagnosis of otosclerosis and malformed ossicular chains (Fujii et al., 2010).

4.1. Conventional section plane

The conventional section plane provides important information about the condition of the middle ear cavity (air or soft tissue) or structure (such as cochlea) (Tan and Goh, 2003). However, it has only a limited ability to show the whole ossicular chain or the superstructure of the stapes. Fuse T. performed a study using this method and they reported that the head of the malleus and the body and long limb of the incus was rendered visible in all cases, but the superstructure of the stapes were visible under high-resolution CT only in 60% of cases. This did not permit pre-operative diagnosis of partial defects of the stapes crus (Fuse et al., 1992). The results of the current work were consistent with this conclusion. The *P* values of stapes superstructure and malformed stapes superstructure both indicated that the assessment of these structures in axial and coronal section plane was very different from the surgical findings. In this way, results indicated that it was not possible to distinguish otosclerosis from the lack of an ossicular chain using the section plane.

4.2. MPR imaging

MPR imaging has been found to be superior to the section plane in showing different ossicular segments, especially the superstructure of the stapes. The major advantages of MPR are that it can show whole, fine ossicular chains within the same layer via multi-directional adjustment (Gong et al., 2004). Unlike conventional section plane imaging, MPR imaging preserves both resolution and contrasts. Fig. 1 A-3, 4 (otosclerosis) and Fig. 2 B-3 (ossicular chain absence) show examples of this: The image of the ossicular chain produced using MPR was much clearer than the one produced using conventional section plane imaging. Ulla M.B. also reported that the anatomic and pathological characterization of middle ear structure can be improved using the MPR technique (Blanco Ulla et al., 2009). Pandey A.K. reported that the assessments of the larger ossicular structure tend to be satisfactory and that the accuracy of assessments of the superstructure of the stapes were 76.97% for MPR but only 40% for section plane imaging (Pandey et al., 2009). This means that MPR can indicate anatomical features and pathologic conditions more precisely than section plane and can distinguish otosclerosis from absence of the ossicular chain more readily than other methods.

4.3. 3D-CTVR imaging

The current work focused on the CTVR technique. The post-procession technique and the viewing angle have already been described (Guo et al., 2013). This technique has shown considerable value in the fine diagnosis of the ossicular chain, both in the middle ear cholesteatoma and in the malformed vestibular window (Liu et al., 2014; Yang et al., 2015). The purpose of differential diagnosis of otosclerosis and absence of the ossicular chain is to assess the integrity of the overall ossicular chain. In the current study, clear and definite differences were indicated by CTVR, as shown in Figs. 1 A-5, 2 B-4, and 3 C-4. The largest advantage of CTVR technique is that by rotating the 3D images, the image of the middle ear structure can provide clear and direct views of the ossicular chain, as the otological microscopy. Another advantage of 3D images is that they are more accurate in the evaluation of partial erosion of segments, including the head of the malleus, long limb of the incus, and superstructure of the stapes. As shown in Table 1, most data regarding quantitative assessment in various segments of CTVR were superior to section plane. The *P* values of stapes superstructure and malformed stapes superstructure for CTVR were in this case greater than 0.05. These findings are consistent with those reported by Zhang LC et al (Zhang et al., 2011). In the overall analysis, the efficacy of CTVR in various segments was found to be superior to that of section plane. In CTVR imaging, the entire ossicular chain was clearly visible, as indicated by other authors (Calhoun et al., 1999; Jun et al., 2005).

5. Conclusion

CTVR and MPR were found to be better able to show the fine ossicular chain in the conductive hearing loss with normal tympanic membranes than conventional section plane. The use of CTVR and MPR techniques may make a profound contribution to the differential diagnosis of otosclerosis and absence or malformation of the ossicular chain.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Acknowledgment

We thank Prof. Jie Chen for generously providing his assistance in the statistical portion of our study. Prof. Chen:

Department of Statistics, Peking University People's Hospital, Beijing, China.

References

Blanco Ulla, M., Váquez, F., Pumar, J.M., et al., 2009 Jul. Oblique multiplanar reformation in multislice temporal bone CT. Surg. Radiol. Anat. 31 (6), 475–479.

Calhoun, P.S., Kuszyk, B.S., Heath, D.G., Carley, J.C., Fishman, E.K., 1999 May-Jun. Three-dimensional volume rendering of spiral CT data: theory and method. Radiographics 19 (3), 745–764.

Fatterpekar, G.M., Doshi, A.H., Dugar, M., Delman, B.N., Naidich, T.P., Som, P.M., 2006 Oct. Role of 3D CT in the evaluation of the temporal bone. Radiographics 26 (Suppl 1), S117–S132. Review.

Fujii, N., Inui, Y., Katada, K., 2010 Nov. Temporal bone anatomy: correlation of multiplanar reconstruction sections and three-dimensional computed tomography images. Jpn. J. Radiol. 28 (9), 637–648.

Fuse, T., Aoyagi, M., Koike, Y., Sugai, Y., 1992. Diagnosis of the ossicular chain in the middle ear by high-resolution CT. ORL J. Otorhinolaryngol. Relat. Spec. 54 (5), 251–254.

Gong, R.Z., Chao, B.T., Liu, K., Fan, Z.M., Wang, H.B., Chen, Q.H., et al., 2004 May. CT multiplan reconstruction images of disorder of stapes. Zhonghua Er Bi Yan Hou Ke Za Zhi 39 (5), 265–268.

Guo, Y., Liu, Y., Lu, Q.H., et al., 2013. CT two-dimensional reformation versus three-dimensional volume rendering with regard to surgical findings in the preoperative assessment of the ossicular chain in chronic suppurative otitis media. Eur. J. Radiol. 82 (9), 1519–1524.

Jun, B.C., Song, S.W., Cho, J.E., Park, C.S., Lee, D.H., Chang, K.H., 2005 Sep. Three-dimensional reconstruction based on images from spiral high-resolution computed tomography of the temporal bone: anatomy and clinical application. J. Laryngol. Otol. 119 (9), 693–698.

Liu, Y., Sun, J., Guo, Y., et al., 2014. Quality assessment of 3D- CTVR, MPR and section plane techniques in ossicular chain reconstruction in middle ear cholesteatoma. Comput. Med. Imaging Graph 38 (8), 696–701.

Pandey, A.K., Bapuraj, J.R., Gupta, A.K., Gupta, A.K., Khandelwal, N., 2009. Is there a role for virtual otoscopy in the preoperative assessment of the ossicular chain in chronic suppurative otitis media? Comparison of HRCT and virtual otoscopy with surgical findings. Eur. Radiol. 19 (6), 1408–1416.

Tan, T.Y., Goh, J.P., 2003 Jul. Imaging of congenital middle ear deafness. Ann. Acad. Med. Singap. 32 (4), 495–499. Review.

Trojanowska, A., Trojanowski, P., Olszanski, W., Klatka, J., Drop, A., 2007 Mar. How to reliably evaluate middle ear diseases? Comparison of different methods of post-processing based on multislice computed tomography examination. Acta Otolaryngol. 127, 258–264.

Yang, F., Liu, Y., Sun, J.J., et al., 2015. Congenital malformation of the oval window: experience of radiologic diagnosis and surgical technique. Eur. Arch. Otorhinolaryngol. http://dx.doi.org/10.1007/s00405-015-3597-6.

Zhang, L.C., Sha, Y., Wang, Z.M., Luo, D.T., Huang, W.H., Dai, P.D., et al., 2011 May. 3D image of the middle ear ossicles: three protocols of post-processing based on multislice computed tomography. Eur. Arch. Otorhinolaryngol. 268 (5), 677–683.

Liu Yang, MD, Male, born in 1965, Professor of the center of Otorhinolaryngology of PLA, Navy general hospital, China. Committee member of WHO Collaborating Center for Prevention of Deafnes. Editor of Chinese Journal of Otorhinolaryngology & Head Neck Surgery and Chinese Journal of Otology. Professional direction is clinical otology and research of hearing loss, especially in the surgery treatment of middle ear chronic infectious disease, vertigo surgery, cochlear implantation, facial never surgery.