Three-dimensional Imaging of the Inner Ear by Volume-Rendered Reconstructions of Magnetic Resonance Data

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Objective: To evaluate 3-dimensional inner ear visualization by volume rendering of high-resolution magnetic resonance data in patients with clinically suspected inner ear abnormality.

Design: Prospective comparative study of different postprocessing techniques, based on blinded film readings.

Setting: Tertiary referral hospital.

Subjects: Fifty patients (17 females and 33 males) aged 1 to 77 years (average age, 42 years) with sensorineural hearing loss, vertigo, and/or tinnitus.

Intervention: Postprocessing of magnetic resonance data to inner ear reconstructions by the use of volume rendering as well as maximum-intensity projection; caloric testing by electronystagmography.

Main Outcome Measures: Film was read blindly by 4 radiologists using a 5-point parameter scale for image quality and diagnostic value. The assessibility of inner ear subsegments was evaluated. The specificity of volume-rendered reconstructions for detecting semicircular canal obliterations was assessed in a subgroup of 9 patients by caloric testing. The time required for data postprocessing as well as film reading was recorded by means of a stopwatch.

Results: Volume-rendered inner ear reconstructions were superior in image quality (P<.001), diagnostic value (P<.001), subsegment inner ear assessment (P<.001 to P<.001), and film reading time (P<.001) compared with maximum-intensity projections. The data postprocessing time was comparable for both techniques. Caloric weakness was noted in all patients assessed by electronystagmography.

Conclusion: Volume rendering is the postprocessing technique of choice for 3-dimensional inner ear visualization, performing better than maximum-intensity projections with respect to various parameters.


INNER EAR (IE) visualization requires high-resolution (HR) cross-sectional imaging, regardless of whether computed tomography or magnetic resonance (MR) imaging is performed. In cases where an abnormality of the membranous rather than of the bony labyrinth is clinically suspected, only MR imaging enables comprehensive IE assessment. Heavily T2-weighted HR sequences have become an indispensable part of IE imaging, whereas T1-weighted sequences may be necessary only when the patient’s history suggests a traumatic or acute inflammatory IE condition.

To cope with the huge number of cross-sectional slices provided by HR imaging, different postprocessing techniques have evolved. The most widely used technique, the maximum-intensity projection (MIP), yields about 8 to 12 two-dimensional projection images for each side. Data postprocessing to generate 3-dimensional (3-D) IE views by means of the volume rendering (VR) technique is a more recent postprocessing technique that has shown promising results in terms of image quality and reconstruction flexibility. To our knowledge, this is the first study assessing the VR technique in a large number of patients with clinical evidence of a pathologic IE condition.

RESULTS

The average time required for generating the MIP (3.4 minutes) and VR (3.1 minutes) images of one IE were comparable without statistically significant differences. The mean ± SD time required for assessing VR views amounted to 24.9±17.5 seconds vs 37.8±22.1 seconds for MIP images, resulting in a reduction of 34.1% for VR (P<.001, t test). The VR displays were assigned a higher score (P<.001,
PATIENTS AND METHODS

An experienced neuroradiologist (R.K.) assessed MR IE studies of 85 consecutive patients, referred by ear, nose, and throat physicians for HR IE imaging, for positive or questionable signs of IE disease. All patients (n=50; 33 males and 17 females, ranging in age from 1-77 years; average, 42 years) in whom IE disease could not be confidently ruled out on the basis of the primary, cross-sectional image data were included in the study. The majority of study patients had sensorineural hearing loss (n=24) followed by sensorineural hearing loss and vertigo and/or tinnitus (n=20). Vertigo and/or tinnitus were noted in 3 patients, and in another 3 patients conclusive clinical data were not available.

All patients underwent HR MR imaging in a 1.5-T scanner (Magnetom Vision; Siemens, Erlangen, Germany) with the use of a standard circular polarized head coil. A 3-D Fourier transformation–constructive interference in steady state sequence was applied, defined by the following variables: repetition time, 12.3 milliseconds; echo time, 5.9 milliseconds; slice thickness, 0.5 mm; flip angle, 70°; number of acquisitions, 1; time of acquisition, 13.5 minutes; matrix, 256 × 256; field of view, 130 mm. Subsequently, the study data were transferred via an internal network to a workstation consisting of a computer (Ultra 60; Sun Microsystems, Inc, Palo Alto, Calif) and a software package with a module for volume rendering (EASY VISION 4.1; Philips Medical Systems, Best, the Netherlands).

The VR postprocessing protocol was defined in a preliminary study using perspective views, threshold values, depth cuing, and other parameters. Figure 1 shows the impact of parameter variation on the image quality of VR views. In brief, a frontal 3-D shaded-surface view of the cochlea and vestibule was generated as well as a view of all 3 semicircular canals from a cranial-lateral angle (Figure 2A-B). The MIP reconstructions (Figure 2C), featuring 9 different projection images, were generated at the console of the MR imager. The postprocessing time was recorded by the use of a stopwatch. Subsequently, 4 radiologists (R.K., D.K., C.E., and R.L.) with varying degrees of neuroradiologic training (2 years, 1 year, 3 months, and 35 years, respectively) assessed the VR as well as the MIP reconstructions in a blinded manner on a 5-point parameter scale (1, insufficient; 2, poor; 3, sufficient; 4, good; 5, excellent) for image quality and diagnostic value. In addition, anatomic subsegments of the membranous labyrinth, defined as basal cochlea turn, middle and upper cochlea turn, vestibulum, and lateral, posterior, and superior semicircular canals, were selectively checked for their assessability.

Statistical analysis was performed by means of a Wilcoxon rank-sum test (paired samples) for the 5-point parameter scale, a McNemar test for the subsegmental labyrinth assessability, and t test for the results of stopwatch measurements for reconstruction and film reading time. The charts of all patients with evidence of lateral semicircular canal abnormality, as suggested by VR IE reconstructions (n=16), were reviewed for caloric test results; if these results were not available, the patients were asked to undergo caloric testing. In 9 of 16 patients, caloric testing could be performed by electronystagmography.

In total, 600 IE subsegments were selectively assessed for each postprocessing technique (VR and MIP). Figure 4 provides an overview of the imaging findings, based on VR reconstructions. The overall assessability of IE subsegments was significantly increased by the use of VR reconstructions as compared with MIP images (P<.001, McNemar test), showing a decrease in the significance level for judging the vestibulum (P<.01, McNemar test). Mono-

Figure 1. Impact of threshold value and depth cuing on image quality of volume-rendered reconstructions of the inner ear.

Wilcoxon test) for image quality (mean±SD, 4.1±1.1 vs 3.0±1.3) as well as diagnostic value (mean±SD, 4.4±1.1 vs 3.3±1.3) (Figure 3).

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COMMENT

Inner ear imaging with the use of unenhanced heavily T2-weighted, HR MR protocols has become an established visualization technique during the past decade. Most commonly a gradient-echo1,3 or a fast spin-
The statistically significant differences in parameter scores, subsegmental labyrinthine assessability, and image evaluation time between VR and MIP reconstructions in our study underline the superior performance of the VR technique. Image quality may not be as important in a grossly affected IE with extensive labyrinthitis ossificans. Yet, for complex abnormalities and/or syndromal diseases such as various IE dysplasias, the precise definition of the principal pathologic changes and associated IE lesions may be crucial for clinical management. The potential benefit and the specific procedure of a surgical intervention and reconstruction flexibility as compared with VR,7,14 Volume rendering, as the only technique that incorporates the entire data set into the 3-D image, has not been available for routine imaging purposes until recently because of limitations in hardware performances.14 A preceding study by our group showed that threshold-based direct VR, combined with user-defined postprocessing protocols and standardized IE views, allows for advanced 3-D IE visualization within about 5 to 6 minutes per ear.15 A further reduction of the postprocessing time for VR images, down to about 3 minutes per ear in the present study, was most probably due to increasing experience in handling the software and hardware tools. Volume rendering provides valuable tools for reducing image artifacts that severely compromise image quality in MIP reconstructions, such as those caused by fluid-retaining mastoid cells.5,15

Figure 2. Different postprocessing techniques for inner ear visualization, based on high-resolution magnetic resonance data: volume-rendered views of the cochlea (A) and semicircular canals (B) and maximum-intensity projection (C).

Figure 3. Results of blinded reading of hard-copy printouts of volume-rendered (VR) and maximum-intensity projection (MIP) labyrinth reconstructions by means of a 5-point scale.

Figure 4. Imaging findings, based on volume-rendered 3-dimensional reconstructions of the inner ear (IE).
such as cochlear implant, possible intraoperative complications, and implications for genetic counseling all are influenced by the type of dysplastic entity encountered. Moreover, precise IE assessment may have therapeutic implications not only in dysplastic but also in other pathologic conditions, such as a labyrinthitis. Although a T1-weighted, contrast-enhanced study is necessary in acute disease, a protracted course or chronic disease may lead to irregular obliterations of the labyrinthine fluid signal in T2-weighted HR MR studies. In our investigation, dysplastic and postinflammatory obliterations differed markedly in their appearance. Thus, the imaging protocol presented here may be especially beneficial in cases where anti-inflammatory treatment is considered as well as in patients where successful cochlear implant surgery depends on the timely recognition of labyrinthine obliterations before the occurrence of cochlear calcifications. Postoperative patients showing smoothly demarcated signal obliterations in our study could be reliably identified on the basis of their clinical history. Yet, not only the morphologic characteristics but the topography of IE lesions may help to differentiate between various causes of IE pathologic changes. Himi et al reported a preference of meningogenic IE lesions for the basal cochlear turn and semicircular canals as compared with tympanicogenous labyrinthitis. Both patients in our study whose clinical history suggested meningogenic labyrinthitis in childhood showed markedly affected basal cochlear turns and semicircular canals (Figures 5C and 6C).

A potential pitfall of 3-D postprocessing techniques is the choice of inappropriate rendering parameters, causing loss of relevant image information. As a reference method for detecting peripheral vestibular lesions as suggested by VR image reconstructions, caloric testing by using electronystagmography was chosen. Electronystagmography is widely recognized as a gold standard in terms of vestibular function tests. All patients with evidence of lateral semicircular canal fibrosis by VR reconstructions who agreed to undergo electronystagmographic testing showed caloric weakness, indicating a high specificity of the visualization protocol presented for detecting peripheral vestibular disease. The corresponding sensitivity of VR IE reconstructions, however, remains unclear, as caloric testing was not performed on a regular basis in all study patients.

Our results suggest that VR should be the method of choice for postprocessing HR IE images. Only direct VR allows for comprehensive IE assessment with a limited number of 3-D IE reconstructions and meets the need for rapid labyrinthine visualization in an easily appre-
ciable fashion. The image quality of 3-D VR views provides detailed information on morphologic features and topography of labyrinthine lesions, permitting differentiation of various kinds of IE disease in many cases.

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REFERENCES