Imaging of the Inner Ear Using Inner Volume 3D-RARE

K. Cai, H. P. Fautz, K. Scheffler, J. Hennig
Sec. of MR Physics, University of Freiburg, D-79106 Freiburg, Germany

ABSTRACT
A fast inner volume 3D-RARE scheme is applied to inner ear imaging to get sub-millimeter spatial resolution and high contrast for the cochlea and the semicircular canals. A short TR using TR flip-back pulses and a small number of acquired matrix lines using an inner volume excitation allows for a scan time of about 1min. The MPR images had lower flow ghosts and magnetic susceptibility artifacts than 3D-CISS images. On the MIP images, the cochlea and the semicircular canals are clearly delineated.

INTRODUCTION
Heavily T2-weighted MR inner ear imaging has been used for the evaluation of various pathologic processes. Since the anatomy of the cochlea and semicircular canals and the facial and the superior vestibular nerve of the internal auditory canal are very small high resolution in all three dimensions is required. This necessitates high resolution 3D imaging techniques to provide a sufficiently high signal-to-noise ratio (SNR). Currently, the most commonly used techniques are conventional 3D fast spin echo sequences (FSE, TSE, ...), 3D gradient echo sequences (GRE), 3D fast asymmetric spin-echo (3D-FASE) sequences (1) and 3D constructive interference in the steady state (3D-CISS) sequences (2). However, conventional 3D SE or FSE sequences are limited by a very long scan time. 3D GRE acquisition lacks contrast and SNR. Even 3D FASE and 3D CISS acquisitions that have the shortest scan times still require nearly 5-7 minutes for an inner ear examination. In addition 3D CISS is basically a gradient-echo-based sequence that is sensitive for local magnetic field inhomogeneity (3). Recently an inner volume 3D-RARE technique that reduces measurement time by 1) shortening the TR using flip-back pulses 2) decreasing the number of acquired matrix lines due to an inner volume excitation has been proposed (4). The purpose of this study is to utilize a fast inner volume 3D-RARE acquisition pulse sequence for a high image quality and a high spatial resolution in the inner ear.

METHOD
All experiments were performed on a 1.5-T MR system (Siemens Magnetom Symphony) equipped with ultra-gradients (20 mT/m, 40 T/m/s rise time) using a quadrature head coil. In the clinical routine examination in our hospital a commonly used 3D-CISS sequence is used at TR/TE=12.25/5.9 ms and at a flip angle of 70°. Applying a field of view (FOV) of 120x120x46mm and a voxel size of 0.47x0.67x0.9 mm³ the scan time is 5min. The inner volume 3D-RARE sequence was applied with identical resolution. The echo train length (ETL) was 128 echoes (1.2s). The TE was varied between 120ms and 600ms using a centric phase encoding reordering scheme. TR and the FOV in both phase encoding directions was varied for optimization of SNR and image contrast and to evaluate the range of possible measurement times.
The inner volume 3D-RARE and the 3D-CISS technique were compared studying 8 healthy volunteers (mean age: 34; range 27-40; 3 male, 5 female). Inner volume 3D-RARE and 3D-CISS sequences were used to measure the inner ear at three locations: in a slice containing the root entry zone of the cochlear nerve, in one containing the cochlear aqueduct, and in one containing the semicircular canals. The image quality of the inner volume RARE and 3D-CISS images was assessed using the original source images. The three dimension reconstruction images were compared by multiplanar reformatted (MPR) images and maximum intensity projection (MIP) images.

RESULTS
As the inner ear is spatially distinguished from surrounding tissue the TE of the inner volume RARE sequence was optimized to a short TE of 122ms providing a high SNR but still suppressing the fat signal from temple bone. Fig.1 shows a comparison between inner volume RARE MIP images acquired in different scan times and a conventional 3D-CISS MIP image acquired in 5min. Although the SNR is clearly enhanced with the longer scan time in the RARE images of the same resolution (b and c) the cochlea and the semicircular canals are clearly delineated and the cochlea aqueduct show a high signal intensity in all images. Both RARE MIP images (b and c) with the same resolution than the 3D-CISS MIP image are comparable to the conventional MIP image. Even the image quality of the RARE MIP acquired in 1min is very close to the image quality of the 3D-CISS MIP.

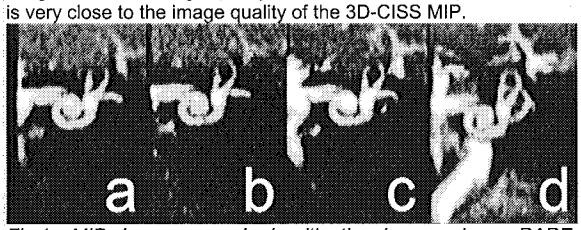

Fig.1: MIP images acquired with the inner volume RARE technique in different scan times (a-c) and with the conventional 3D CISS sequence (d). The image resolution for the MIPs (b-d) was 0.47x0.67x0.9 mm³ and 0.47x0.81x1.16 mm³ for the MIP (a). Using a TR/FOV of 3.2s/120x38x54mm³ (a,b) and 4.2s/120x45x64mm³ (c) for the RARE images the scan time was 1min (a), 1min24s (b) 2min37s (c) and 5min for the conventional 3D-CISS images (d).

In all eight volunteers the visibility scores for the facial nerve, superior vestibular nerve and trigeminal nerve were similar for both the inner volume 3D-RARE (scan time: 2min24s) and the 3D-CISS technique. In contrast to the inner volume 3D-RARE images in the 3D-CISS images the vertebrobasilar artery showed a variation in the signal intensity depending on its position in the slab and discontinuities of the semicircular canals due to susceptibility artifacts were seen in all subjects. Therefore the vertebrobasilar artery and the semicircular canals were better delineated in the 3D-RARE images. In the 3D-RARE images vessels around the inner ear are depicted dark so that overlaps between the vessels and the inner ear are avoided in the MIP images. In the 3D-CISS images the jugular vein has nearly equal signal intensity like the inner ear so that the inner ear and the jugular vein can not be distinguished in MIP images.

DISCUSSION AND CONCLUSIONS
The clinical utility of high-resolution MR studies of the inner ear has been reported for 3D-CISS and 3D-FASE sequences using scan times of 5-7min (3). The observed imaging properties like tissue contrast and sensitivity to susceptibility effects in the two compared sequences just reflect the well known differences between a CISS based and a RARE based technique. In this work, however, it was shown that even in a measurement time of 1min a sufficient image quality to describe the cochlea and the semicircular canals in MIP images can be achieved using a RARE based technique. The reduction in scan time may be used to obtain higher spatial resolution or simply to reduce the examination time.

REFERENCES
1. Eberhardt KE et al, Eur Radiol 1997;7:1485–1491
2. Lemmerling M et al, *Neuroradiology* 1999;41:292–299
3 Naganawa S et al, Am J Neruoradiol 22:1179-1185, 2001
4. Hennig J et al, Proc.8th Meeting ISMRM, p.682 (2000)