Ultra High Resolution Imaging of Rodent Cochlea using a Composite Gradient System on a 3T Clinical MRI

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INTRODUCTION: High-resolution MRI is a valuable tool for the evaluation of inner ear pathology. However, the imaging resolution of the internal structure of the cochlea remains elusive given the limits of standard MRI systems[1-3]. On clinical 3T MRI, maximum spatial resolution for cochlear imaging reported in the literature has reached 0.3 mm voxel dimensions[4]. Ultra high resolution MRI capable of resolving the cochlear internal structures has been performed in small bore MRI scanners which have increased field strength and higher gradient performance. Steady-state imaging sequences, such as CISS, achieve excellent fluid anatomic detail of the cochlear chambers, but are susceptible to banding artifacts that increase with the long repetition times that are required for high resolution imaging. Recent studies of contrast enhanced MRI on guinea pigs (GP) have demonstrated that the separate cochlea chambers can be resolved using higher field (>4.7T) small bore MRI scanners with high performance gradient systems[5]. We hypothesize that improved images of the cochlear anatomy may also be obtained on high field human MRI scanners that have increased gradient performance. To test this hypothesis, experiments were performed using an insert gradient array simultaneously with the whole body gradients of our 3T clinical MRI scanner. The use of composite gradients will allow for higher spatial resolution cochlear imaging while maintaining acceptable signal to noise ratio (SNR) and scan duration and decreasing artifact. The purpose of this study is to demonstrate improved spatial resolution in 3T MRI of the cochlea using our composite gradient system at double gradient strength in an animal model.

METHOD: All MRI scans were performed on a Siemens 3 Tesla TIM Trio scanner, where the standard system was augmented with three additional gradient amplifiers and master/slave configured computers capable of controlling extra gradient channels[6]. A 15cm inner diameter insert gradient coil was interfaced to the slave gradient amplifiers[7]. Pulse sequences were implemented to control both gradient coils synchronously or separately. Three GPs were used for this work. Each GP's head was placed at the isocenter of the main magnet in a custom designed 4-channel phased array coil. A local birdcage RF coil was built for transmit only. Gd T1 contrast agent (0.5 mmole/ml; Omniscan; Nycomed) was administered with intratympanic injection. The uptake of the contrast agent in the cochlea chambers was monitored at 20 min intervals over a period of 250 min following the injection using a 3D FLASH sequence and composite gradients (with insert and body at the same strength). The scan time for each acquisition was 19:52 minutes. To evaluate the anatomic MRI, 3D CISS and 3D FLASH images were acquired using composite gradients at 12 hours delay from injection. The same acquisition was performed on the body gradients with adjustments of imaging parameters such as FOV, slice thickness and TE/TR to obtain the same resolution. The detailed scan parameters are summarized in Table 1. The body gradient operated at 40 mT/m strength and 200 T/m/s slew rate; the composite gradient was set at 80 mT/m and 400 T/m/s.

RESULTS: Figure 1 demonstrates multiplanar reformat (MPR) 3D FLASH images of the time sequence of Gd uptake using composite gradients. The scala vestibuli revealed substantial Gd uptake at 30 min post injection. Gd was detected in the cochlear apex within 70 min and the scala media showed little or no Gd uptake within 250 min. The scala vestibuli in the basal and 2nd turns of the cochlea revealed higher Gd uptake than the other chambers, suggesting that contrast preferentially enters the oval window. Figure 2 displays a comparison between 3D CISS and 3D FLASH images using the body (a,d) and composite gradients (b,c,e). Images using the composite gradients show the scala vestibuli and scala tympani spiral chambers of the cochlea(* in b). Hypointense lines seen in images coursing perpendicular through the scalar chambers (arrows in a, and c) represent banding artifact. Image (b) using the composite gradients was obtained in 41% less time and with mildly decreased banding artifact compared to the image obtained from body only (a). The 0.1 mm isotropic image (c) using the composite gradients demonstrates increased resolution and adequate SNR with same scan time for 0.15 mm resolution imaging acquisition using body only. 3D FLASH image using composite gradients (e) demonstrates the better definition of the scalar chambers than the image using body only (d) with 33% less scan time and better SNR.

Table 1 Imaging Parameters

3D FLASH	TE/TR (ms)	Scan Time (min)	Resolution (mm^3)
Body Only	5.39/20	19:39(1avg)	0.1x0.1x0.1
Composite	3.08/20	13:01(2avg)	0.1x0.1x0.1
Composite	3.08/20	19:52(3avg)	0.1x0.1x0.1
3D CISS	**TE/TR (ms)**	**Scan Time (min)**	**Resolution (mm^3)**
Body Only	8.23/16.48	10:11(1avg)	0.15x0.15x0.15
Composite	4.04/8.08	5:58(1avg)	0.15x0.15x0.15
Composite	5.5/10.9	16:21(2avg)	0.1x0.1x0.1

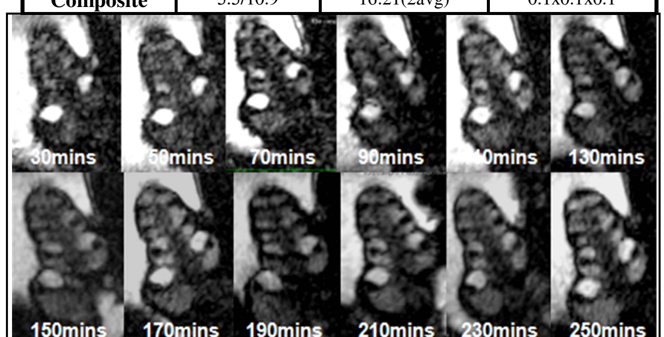

Fig1. Time sequence of 3D FLASH images obtained from composite gradients.

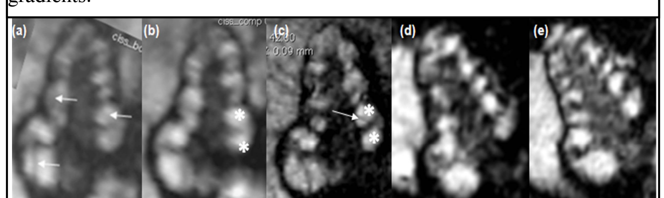

Fig2.3D CISS images obtained from body(a) composite(b,c) systems. 3D FLASH images obtained from body(d) and composite(e) systems.

DISCUSSION: One obvious limitation of clinical MRI is the restriction of gradient performance imposed by safety standards for human imaging. Results from this early work in guinea pigs are promising in that the improved quality in high resolution images seen with the composite gradient system not only demonstrates better visualization of the inner ear structures with less artifacts, but may actually allow for scan time reduction and increased time resolution. Our Gd uptake results presented in this work corroborate reports from studies performed on dedicated MRI systems with higher performance gradient systems and field strength than a clinical MRI[5]. The composite gradient MR system achieved ultra high resolution (0.1mm isotropic) contrast enhanced images with a 33% decreased scan time (because of the need for additional slices to cover the region of interest) and better SNR comparing to the regular gradient system (table 1). Equal spatial resolution was obtained with the composite gradient (0.15 mm isotropic CISS images) in 41% less scan time than the body gradient alone with no perceptible change in SNR and less banding artifact (Fig2). Our goal is to develop imaging protocols for human temporal bone studies using a high field (3T) human whole body scanner with a head neck insert gradient coil operating simultaneously in a composite mode. These early comparisons showing improved visualization of inner ear infrastructure in animals are evidence of the potential of this system to resolve the fine detail of the human inner ear and ultimately develop an objective test to diagnose inner ear pathology.

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