Introduction

Acoustic noise in MRI scanners has long been a concern for patient comfort and, on occasion, for patient safety [1,2]. Acoustic noise interferes with communication between MRI physicians and operators. Acoustic noise also provides an unwanted stimulus and interference during fMRI studies.

We have studied acoustic noise in a 1.5 T cylindrical scanner equipped with epoxy-potted, shielded gradients. It has been widely assumed that acoustic noise comes overwhelmingly from vibrations of the gradient assembly. However, when vibration-isolated gradients are contained in an airtight enclosure, we have found that the primary sources of acoustic noise are eddy-current-induced vibrations of metal structures such as the magnet warm bore and the rf body coil. We have elucidated the relative strengths of source-pathways of acoustic noise and assembled a test scanner, including a vacuum enclosure of a vibrationally-isolated gradient assembly, a low-eddy-current rf coil and a non-conducting warm bore magnet that has reduced, by about 20 dBA, the acoustic noise levels in the patient bore to 85 dBA and below for several typical noisy pulse sequences.

Methods

Our goal is to reduce acoustic noise in the patient bore and in the vicinity of the magnet where operators or physicians may be present. Reduction of acoustic noise can be accomplished either by eliminating or reducing the sources of noise or by cutting off the pathways by which the noise is conveyed to the region of interest. To this effect we have investigated the source-pathways of noise.

In order to find the hierarchy of source-pathways, we tried many different configurations of a 1.5 T cylindrical scanner until changes were observed. Because of the logarithmic nature of sound perception and the long wavelength of audible sound, no difference is detected until one has an arrangement that affects the largest noise contribution. A loud noise masks a quieter one, so it is difficult to gauge the effect of changing a low-level noise source in the presence of a high-level source.

To assess the effect of changes on noise, we used a suite of noisy pulse sequences with varying slice directions (axial, sagittal, coronal) so that strong gradients would be applied along all three spatial directions. These pulse sequences were: SE, spin echo; FSPGR, fast spoiled grass; EPI-SE, echo-planar imaging, spin-echo; FSE, fast spin echo; FMFSPGR, fast multi-phase spoiled grass.

Some of the important scanner configuration changes included gradient assembly vibration isolation, a gradient assembly vacuum enclosure, a magnet with a non-conducting warm bore, passive non-conducting magnet shims, constrained-layer-damping on the gradient cryostat and patient bore and acoustic absorption and barrier material on the magnet cryostat and patient bore.

Results

Figure 1 shows the acoustic contributions of various source-pathways for the pulse sequences mentioned above.

Making MRI Quiet

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Acoustic noise levels were measured using two B&K Type 4155 preamplified condenser microphones and B&K Type 2639 preamplifiers. One microphone was placed at the magnet isocenter (to measure sound that would be heard by an imaging subject) and the second was positioned in the room at a height of about 1.8 m, 3 m from the front of the scanner and 2 m to the side of the magnet centerline.

The results of various combinations of scanner changes were combined to quantify the acoustic contribution of individual source-pathways.

The hierarchy of sound levels from Fig. 1 is approximately as follows. 1) Conducting magnet inner ("warm") bore (eddy-current-vibration source) via air. 2) Rf body coil (mounted on the patient bore, eddy-current-vibration source) via air. 3) Conducting warm bore via mechanical paths causing vibration of cryostat, patient tube etc. 4). Gradient assembly and vibrations of the non-conducting warm bore through the air. 5) Everything else (uncharacterized).

With an airtight enclosure and a vibration-isolation mount for the gradient coil assembly, it is interesting to note that the strongest sources of acoustic noise are the eddy-current-induced vibrations of the conducting warm bore of the magnet and our standard rf coil. The latter is a birdcage coil, with conductors made of 5-cm-wide copper strips, mounted on the outside of the patient bore tube. The rf coil is immediately inside the gradient coil and is therefore subject to very strong pulsed fields from the gradients. The magnet warm bore is within several nm of the outside of the gradient assembly and is subject to the leakage fields of the shielded gradient. The eddy currents thereby induced are evidently sufficient to cause substantial vibration of the magnet warm bore and consequently significant noise.

It is also noteworthy that the sound produced from the magnet warm bore is most strongly carried through air: when the gradient enclosure is evacuated, the sound from the warm bore excitation is substantially decreased.

Finally, we assembled an experimental "Quiet" scanner with many of the improvements discovered through this work. The resulting noise levels and comparison to the standard scanner are shown in Table 1.

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<th>Table 1. Experimental Quiet Scanner Noise Levels (dB)</th>
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<td>Patient bore</td>
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Discussion

The noise sources and pathways we have identified and alleviated point the way toward a significantly quieter MR scanner which would benefit patients, operators and physicians. The improvements we have described do not compromise MRI performance, i.e. by making the pulse sequences slower. 80 dB noise is at the level of loud conversation. It is desirable to continue this difficult process to uncover and remove the next layers of acoustic noise to make an even quieter scanner.

References