Improved high resolution imaging with 4-element liquid nitrogen phased array coil and VD-AUTO-SMASH at 1.5T

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Synopsis
We have recently developed liquid-nitrogen (LN2) cooled phased array RF coils that improve SNR significantly over similar room-temperature array coils and provide larger field-of-view coverage over single coils. In this study, we investigate the feasibility of combining LN2 phased array coils with parallel imaging that saves imaging time by several folds. We built a 4-coil element LN2 phased array and imaged using VD-AUTO-SMASH parallel imaging technique. Our phantom, animal and in vivo imaging tests show that the combined technique improves SNR and saves imaging time. The new technique may be useful for high-resolution imaging of human extremities and small animals.

Introduction
Liquid nitrogen (LN2) RF receiver coils can significantly increase SNR over room temperature RF coils [1]. However, since sample noise increases with resonance frequency and coil size, to keep sample noise significantly lower than coil noise at 1.5T or higher fields, coils are restricted to a few centimeters in size [1]. This limits the signal coverage and potential applications of LN2 cooled coils. Since phased array coils provide larger field-of-view (FOV) coverage while maintaining SNR, we have recently developed LN2 cooled phased array coils that increase SNR by 50-75% compared with their room temperature counterparts [2].

In the past few years, parallel MR imaging based on SMASH [3] or SENSE [4] techniques has drawn tremendous interest from the MR community since it reduces MR imaging time by several folds. Since parallel imaging uses redundant information obtained with phased array RF coil acquisition to reduce the number of phased encoding steps, it seems to be a good match with LN2 cooled phased array coils. Combining the two techniques may increase SNR and reduce imaging time. It is, therefore, the purpose of this study to investigate the feasibility of combining the two techniques.

Method
The study was conducted on a GE SIGNA 1.5T whole body MR scanner. Two identical linear phased array coils consisted of 4 coil elements were developed using our previous RF decoupling design [2]. They were separately tuned and matched at room temperature and LN2 temperature. Each coil element in the phased arrays was constructed from 14-gauge copper wire and formed into a rounded 3.3cm square. Each phased array was mounted on a fiberglass plate that does not deform at LN2 temperature, and placed inside a plastic container able to hold liquid nitrogen. A 2mm thick Styrofoam was used to provide thermal insulation for the scanned object. The separation between the phased arrays and the scanned object was about 1 cm. A gelatin phantom was imaged for quantitative evaluation of the phased arrays. To verify that the SNR gain measured with the LN2 coil was not caused by T1 shortening of the phantom at a lower temperature, the phantom was scanned twice using TRs of 500ms and 2000ms. In vivo imaging studies were conducted on 2 normal volunteers whose fingers were placed under the phased arrays during scans. A deceased adult rat was also imaged. Similar tests were conducted with the room temperature and with the LN2 cooled phased arrays consecutively under identical scanner's settings to enable quantitative comparison of the data. For parallel imaging, VD-AUTO-SMASH technique [5] was used in which full matrix images were reconstructed from partial phase encoding k-space data. An overall reduction factor of 2 was used in our study. The SMASH images were compared with the conventional FFT images reconstructed from full k-space data. Sum-of-square coil signal combination was used in both reconstruction techniques.

Results
In the phantom study, the SNR measurements are summarized in table 1. The ratio SNR(TR=2000)/SNR(TR=500) is the same for both the LN2 array and the room-temperature array indicating that the SNR gain in LN2 array is not due to a T1 change in the phantom. The rat and in vivo finger images show increased SNR in the LN2 cooled array, and their SMASH images resemble the regularly reconstructed images with only minor artifacts (Figs. 1 and 2).

Discussion
In this study, we developed a LN2 cooled phased array coil with 4 coil elements, and tested it for VD-AUTO-SMASH parallel imaging. Our results show that the parallel images resemble the conventionally reconstructed images with only minor artifacts. Compared with a similar room temperature phased array coil, the LN2 cooled array improves SNR by more than 60% in both the regular and the SMASH images. Using the VD-AUTO-SMASH technique, imaging time is reduced by 50% while the measured SNR increases due to higher sampling density in the central k-space than in the outer k-space. The imaging time can be further reduced using a larger number of coil elements in the phased array, which can be achieved on advanced MR scanners with more than 4 receiver channels. Future developments include designing a clinically compatible LN2 dewar and testing the LN2 array's compatibility with SENSE parallel imaging. Our new technique may be useful for clinical imaging of human extremities and biomedical imaging of small animals, which often demand high coil sensitivity and long imaging time.

Table 1. Relative SNR measurement in the gelatin phantom.

<table>
<thead>
<tr>
<th>Reconstruction</th>
<th>Room-temperature</th>
<th>LN2</th>
</tr>
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<tbody>
<tr>
<td>Regular</td>
<td>100</td>
<td>145</td>
</tr>
<tr>
<td>SMASH</td>
<td>145</td>
<td>232</td>
</tr>
</tbody>
</table>

Table 1: Relative SNR measurement in the gelatin phantom.

Reference

Figure 1. In vivo images of two fingers obtained with the LN2 array using (a) regular and (b) SMASH reconstruction. Imaging parameters are TR/TE = 500/14, FOV 16cm, 1 mm slice, 512x512 matrix and 4:24 scan time for the regular scan. The locations of the 4 individual coil elements are indicated with bars below.

Figure 2. Sagittal images of a deceased rat obtained with the LN2 array using (a) regular and (b) SMASH reconstruction and same imaging parameters as for the finger imaging. The coil element locations are indicated with bars.