Safety of Human MRI at Static Fields Above the FDA 8T Guideline: Exposure to a 9.4T Static Magnetic Field Does Not Change Vital Signs and Cognitive Ability

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Introduction: Current FDA guidelines classify magnetic resonance (MR) diagnostic devices with a static magnetic field below 8 Telsa (T) as insignificant risk devices. Devices above 8T cannot be used for human experiments without FDA and IRB approval. Due to the limited number of MR devices having both a static field larger than 8 T and a bore large enough to accommodate human volunteers, there is very limited data available on the effect of human exposure to static magnetic fields larger than 8T. Human vital sign and cognitive ability measurements before and after exposure to a 9.4T MR scanner and a mock scanner with no magnetic field are compared using an FDA and IRB approved protocol.

Methods: The custom-built 9.4T 80 cm MR scanner described in [1] and a mock MR scanner with no magnetic field were used to assess the effect a 9.4T static magnetic field on human vital sign measurements and cognitive ability. The only portion of the 9.4T MR scanner that is outside the current FDA guidelines is the 9.4T static magnetic field. The FDA approved an investigational device exemption (IDE) to perform this study under IRB approval.

Informed consent was obtained from ten healthy, normal volunteers (6 male, 4 female) between the ages of 20 and 63 years. Neuropsychological testing was performed on each volunteer to assess working memory (letter number sequence (LNS) from Wechsler adult intelligence scale [3]), information processing speed (symbol digit modalities (SDM) test [4]), memory and learning (Hopkins verbal learning (HVL) test [5]), and level of fatigue (brief fatigue inventory (BFI) [6]). The 9.4T MR scanner and mock MR scanner procedures shown in Table 1 were then completed for each volunteer. For each "vital sign measurements" step, three consecutive measurements of heart rate, blood pressure, O_2 saturation, and skin temperature where made using an MR-compatible patient monitoring system (InVivo Research) while the volunteer lay supine. The order of exposure to the 9.4T MR scanner and the mock MR scanner was randomized and counter-balanced. Volunteers were moved through the magnetic field of the 9.4T scanner at a constant rate less than 4 cm/s. This has been found to minimize the gustatory, visual, and vestibular sensations associated with moving through a large static magnetic field.

9.4T MR Scanner Procedure
1. Vital sign measurements with volunteer outside magnet room (< 5 G field)
2. Vital sign measurements with volunteer's head 2.6 m from isocenter of the magnet (3000 G)
3. Vital sign measurements with volunteer's head at isocenter of the magnet (9.4T)
4. Up to 60 minutes of sodium imaging at 9.4T
5. Vital sign measurements with volunteer's head at isocenter of the magnet (9.4T)
6. Vital sign measurements with volunteer's head 2.6 m from isocenter of the magnet (3000 G)
7. Vital sign measurements with volunteer outside magnet room (< 5 G)
8. Neuropsychological testing
Mock MR Scanner Procedure
1. Vital sign measurements with volunteer's head 2.6 m from mock isocenter (0 G)
2. Vital sign measurements with volunteer's head at mock isocenter (0 G)
3. Up to 60 minutes of simulated sodium imaging
4. Vital sign measurements with volunteer's head at mock isocenter (0 G)
5. Vital sign measurements with volunteer's head 2.6 m from mock isocenter (0 G)
6. Neuropsychological testing

Table 1: Procedure overview

Sodium imaging at 9.4T was performed using a 26 cm diameter, custom-built, modified birdcage RF coil tuned to 105.92 MHz and a twisted projection imaging (TPI) acquisition [1]. FDA guidelines for SAR limits were not closely approached (<50%) during imaging. An audio recording of TPI acquisitions was played for the volunteer during the simulated imaging portion of the mock MR scanner procedure.

After completing both the 9.4T and mock scanner procedures, each volunteer was asked whether they experienced any discomforts including: temperature change, visual disturbances (magnetic phosphenes), metallic taste, nausea, vertigo, muscle twitching or tingling (peripheral nerve simulation), anxiety, sleepiness, or discomfort due to acoustic noise.

Vital sign data for each subject was tested for statistically significant changes using multivariate analysis of variance (ANOVA). A four-way ANOVA (9.4T/mock MR scanner, in/out bore, before/after imaging, magnetic field strength) with repeated measurements was used to test the null hypothesis that the static magnetic field of 9.4T does not cause a statistically significant change in human vital sign measurements. Each vital sign was tested at a 95% confidence level. An estimate of the effect of 9.4T static magnetic field on the measured vital signs of the volunteers was determined by fitting a linear regression line to the data collected for each vital sign for each volunteer [2]. The mean slope of all lines corresponding to a specific vital sign measurement gives an estimate of the overall effect of the magnetic field for that vital sign.

A two-way ANOVA (order of exposure to 9.4T and mock MR scanners, time) with repeated measurements was conducted to examine whether the order of exposure to the 9.4T MR scanner and mock MR scanner caused a statistically significant change in the neuropsychological functioning of the volunteers at a 95% confidence level.

Vital Sign	Effect Estimate
Pulse Rate	0.05 bpm /T
Systolic BP	- 0.04 mmHg/T
Diastolic BP	0.05 mmHg/T
O2 Sat.	- 0.00 %/T
Skin Temp.	0.01 °C/T

Table 2: Effect estimate of 9.4T static magnetic field

Results: Volunteers reported that during exposure to the 9.4T MR scanner they experienced: a temperature change (1), a metallic taste (2), a spinning sensation when moving through the magnetic field (6), muscle twitching or tingling (2, only 1 during imaging), anxiety (1), lightheadedness (1), and sleepiness (3). There were no reports of nausea, magnetic phosphenes, or discomfort due to acoustic noise. During exposure to the mock MR scanner the volunteers reported they experienced: a temperature change (1), anxiety (2), lightheadedness (1), sleepiness (8), and discomfort due to acoustic noise (1).

No statistically significant change due to the 9.4T static magnetic field was found for vital sign measurements of pulse (p=0.28), systolic blood pressure (p=0.99), diastolic blood pressure (p=0.40), O_2 saturation (p=0.15), or temperature (p=0.97). Table 2 shows the mean estimate of the effect of the 9.4T static magnetic field on each vital sign. These values are within the ranges reported by [2].

Analysis of the neuropsychological test data indicates that there were no statistically significant differences in neuropsychological test performance among the volunteers due to order of exposure to the 9.4T and mock MR scanners (LNS: p=0.53, written SDM: p=0.71, oral SDM: p=0.54, immediate memory HVL: p=0.12, delayed memory HVL: p=0.28, BFI: p=0.86) or across time (LNS: p=0.71, written SDM: p=0.09, oral SDM: p=0.14, immediate memory HVL: p=0.14, delayed memory HVL: p=0.42, BFI: p=0.78).

Conclusion: Exposure of human volunteers to a 9.4T static magnetic field did not cause a statistically significant change to vital sign measurements or cognitive ability. Volunteers reported only mild discomforts when exposed to the 9.4T static magnetic field. The most frequently reported discomfort was a spinning sensation when being moved through the magnetic field (6 of 10 volunteers).

References: **[1]** Damen *et al. ISMRM.* Abstract #3103, 2006. **[2]** Chakeres *et al. Journal of Magnetic Resonance Imaging.* 18:346-352, 2003. **[3]** The Psychological Corporation. 1997. **[4]** Benedict *et al. The Clinical Neuropychologist.* 12:43-55, 1998. **[5]** Western Psychological Services. 1991. **[6]** Mendoza *et al. Cancer.* 85:11-86-1196, 1991.