RF Power Optimization for 3D-MRCP Allows Breath Hold Acquistion at 3T

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Introduction: Three-dimensional fast-recovery fast spin echo (3D-FR-FSE) has been demonstrated in previous studies to enable high-resolution thin-slice MR Cholangiopancreatography (MRCP) with higher SNR and greater anatomic detail than comparable 2D single-shot fast spin echo (SSFSE) acquisitions [1]. While at 1.5T, the TR may be short enough to acquire a 3D dataset in a breath hold when coupled with parallel imaging, regulatory limits on SAR (specific absorption rate, a measure of patient RF heating) make this more challenging at 3T. We have developed a "SAR-burst" scan that more effectively takes advantages of the higher short-term (10-second-average) limit on SAR level while ensuring that the lower long-term (6-minute-average) limit is met as well. Additionally, the refocusing flip angle is automatically adjusted based on prescription parameters and patient weight to fully utilize available RF power while maintaining high SNR. These optimizations allow 3D-MRCP data to be acquired during a single breath hold at 3T.

Methods: SAR-burst mode for breath-hold 3D MRCP takes advantage of the fact that the short-term (10-second average) maximum SAR deposition allowed by the IEC is three times the six minute average[2]. For example, consider whole-body average SAR deposition limited to 3W/kg (first mode) averaged over 6 minutes. The maximum SAR deposition over the short term is then 9W/kg. However, to ensure patient comfort, a factor of 2 for the burst mode was selected. The burst scan is followed by a pre-calculated "cool-off" period such that the average SAR over the entire scan does not exceed the long-term FDA/IEC limit of 3W/kg. In addition, the RF amplifier heating limits were also allowed to exceed the normal mode value by a factor of 2.

To calculate the refocusing flip angle and cool-off period given a burst factor of 2, the following steps were performed.

- Step 1: Assuming some default refocusing flip angle $\theta_{default}$ (130° used here), the lower bound for TR (sequence repetition time) was calculated based on conventional long-term SAR, $TR_{long\text{-}term\ limit}$. This calculation is based on energy per RF pulse, echo train length, and patient absorption rate parameters such as weight and geometry.
- Step 2: A short-term lower-boundary on TR was calculated

$$TR_{short\text{-}term\ limit} = \frac{TR_{long\text{-}term\ limit}}{burst\_factor}$$

- Step 3: If the prescribed TR was less than the short term limit, the refocusing flip angle was reduced from the default value according to

$$\theta = \theta_{default} \times \sqrt{\frac{TR_{prescribed}}{TR_{short\text{-}term\ limit}}}$$

and the long-term TR limit was recomputed using this value.

- Step 4: If the prescribed TR is less than the (recomputed) long-term limit, impose a cool-down period after the scan is complete

$$T_{cool} = \left(\frac{TR_{long\text{-}term\ limit}}{TR_{prescribed}} - 1\right) T_{scan}$$

For example, if the short-term SAR is 4.8W/kg and the scan is 20s long, a cool-off time of 12s will assure that the average SAR over th entire scan (and consequently over a 6min window) is 3W/kg. In addition to the above burst mode modifications, other changes to the "standard" sequence included a new refocusing pulse of width 1.2ms (as opposed to a standard 3.2ms pulse) and additional relaxation time before data acquisition. These changes allow for a shorter echo spacing and better suppression of background tissue.

Patient Safety: In order to ensure patient safety, body skin temperatures were measured in the area around the small of the back before and after long scan sessions. Body skin temperature after scanning should not significantly exceed the mean core body temperature of about 37ºC.

RF System Safety: The major concern here is the long-term health of the RF amplifier for the burst mode. This is determined by a capability function defined as

$$F(t) = 0.75 \times (\text{total duty cycle of all pulses}) + 17 \times (\text{area under all pulses}).$$

The ratio of the capability function to TR should never exceed 1. A lower value indicates a safer operating mode.

Experiments: Volunteer imaging experiments were carried out on a GE 3T scanner equipped with the TRM gradient module operating in the whole body mode.

Results: A sample comparison between breath-hold scans obtained with the standard 3D FRFSE sequence and with the modifications given above is provided in Figure 1. The 10-sec average SAR deposited over the two cases was 2.7 W/kg and 3.5 W/kg, respectively (as measured by an external power monitor). The breath-hold times for the two cases were 31s and 25s long, respectively. The burst mode needed a cool-off time of 8sec after the breath-hold scan. For the standard mode, a TR of 1550ms was prescribed, the minimum allowed for a matrix size of 256×128. However, with burst mode, a larger matrix size of 256×160 could be prescribed while at the same time reducing the TR to 1200ms. (TRs less than 1200ms were found to be reduced in SNR due to incomplete T1 recovery at 3T.) The number of slices prescribed were 18 and 20 for the standard and burst mode sequence, respectively (constrained by reasonable breath-hold time for the standard case). Other parameters were the same for the two cases: Slice thickness=3mm, overlap=1.5mm, BW=41.7KHz, FOV=30, parallel imaging factor of 2. As can be seen from the images, burst mode scan provides better coverage and resolution in a shorter breath-hold time when compared with the standard 3D-FRFSE sequence.

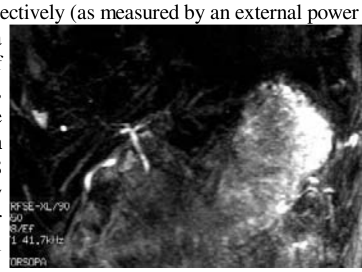

Figure 1(a): Standard 3D MRCP

Figure 1(b): Burst mode 3D MRCP

Patient Safety: Although a 3D-MRCP scan is typically completed in a single breath-hold, to test patient safety, eight volunteers were scanned for approximately 30 minutes using various protocols with the burst mode. The maximum body skin temperature in the small of the back recorded by an infrared thermometer post-scanning was 35.5ºC. The mean small of the back temperature increase was 1.8ºC. The maximum 10-sec average SAR deposited over the eight cases was 3.6W/kg while the average over the volunteers was (2.6±0.36)W/kg.

RF Amplifier Safety: The highest value for the capability ratio was 0.404 while the average was (0.325±0.05).

Discussion: We have designed and implemented a burst mode feature for breath-hold MRCP using the 3D-FRFSE sequence. Advantages include increased coverage and resolution in a shorter breath-hold. Patient safety issues have also been addressed. The maximum body temperature after burst mode scanning sessions remained well below core body temperature. RF amplifier operation was always in the safe zone as the maximum capability value was only 0.404 (<<1). The burst mode feature can therefore be safely used in a clinical environment.

References: [1] T. Matsui, M. Katayama et al. *Proc. ISMRM*, 2005, 1897. [2] IEC 60601-2-33, Second Edition, IEC, Geneva 20, Switzerland, 2002.