Numerical Comparison of a Dedicated Paediatric Radiofrequency Array with Existing Adult Coil Designs

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Target audience: Engineers and physicists involved in coil selection and design for paediatric MRI through numerical evaluations using Finite-Element (FE).

Purpose: Paediatric body MRI is now part of routine clinical care, however, owing to the lack of dedicated coil designs for this patient group, many institutions use adult coils. SNR and B_1^- (receive) field measurements can be affected by the individual array elements' electronic and physical arrangement. The theory behind the numerical methods to extract these quantities has been previously documented¹ and simulations have been completed using FDTD software for various existing coils. In this study COMSOL Multiphysics® (Stockholm, Sweden) was used to compare existing adult designs commonly used for paediatric MRI with a 1.5T receive coil designed in cooperation with GE Healthcare and constructed in-house. The design prototype can be wrapped into two distinct configurations in order to achieve good body conformity with varying patient size. As an FE solver, COMSOL's tetrahedral mesh has potential advantages for simulation of anatomy-conforming array designs and code was developed for the comparative simulation with existing adult coil designs as part of this project.

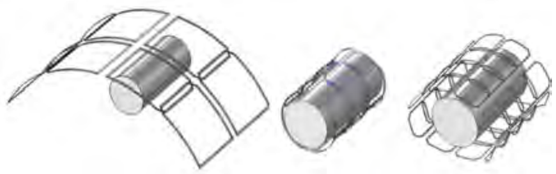

Figure 1: The existing cardiac, flexible array & new prototype designs around a cylindrical phantom.

Method: The coils included in the comparison were the adult cardiac array (8 channels), a small flexible extremity coil (16 channels) and the project prototype (32 channels). The latter can be arranged so one row of elements completely overlies another. Each element was tuned using lumped element capacitors (fine-tuned from an initial value) and the noise correlation matrix (Ψ) was then calculated to determine their cross-talk when loaded by either a cylindrical phantom or an in-house created infant tissue model. The power-normalised B_1^- field (sensitivity profile) for each element was then simulated for use in post-processing; two maps were calculated using Ψ and these results. First, the sensitivity of the array configuration under uniform noise conditions was investigated using the Uniform Noise Image (UNI) and a Sum of Squares (SOS) image was calculated to show the relative SNR performance of the designs at the start of the signal reception chain². These maps could be generated for any arbitrary plane through the load.

$$UNI(r) = \left| \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} B_{1\ i}^{-}(r)\Psi_{ij}B_{1\ j}^{+}(r)}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N} B_{1\ i}^{+}(r)\Psi_{ij}B_{1\ j}^{-}(r)}} \right| \qquad S(r) = \left| \sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N} B_{1\ i}^{-}(r)\Psi_{ij}B_{1\ j}^{+}(r)} \right| \qquad g_p = \sqrt{[(W^H \cdot \Psi^{-1} \cdot W)^{-1}]_{p,p}(W^H \cdot \Psi^{-1} \cdot W)^{-1}{}_{p,p}}$$

Calculation of the SENSE g-factor can be calculated for any pre-specified plane³. An alias diagram and its resultant inverse g-factor map were generated for slices through the phantom for each coil in order to compare the SNR performance for the arrangements under accelerated imaging conditions.

Results: The maximum SOS and UNI values are listed in Table 1 and a selection of plane maps through the baby model are shown in Figure 2. The overlaid configuration of the prototype coil was not simulated with the infant model owing to the fixed position of the arms and the adult cardiac array was too large to be effectively loaded by the cylindrical phantom. The inverse g-factor results for R = 2 in the -direction are shown (Figure 3) for the flexible and prototype designs.

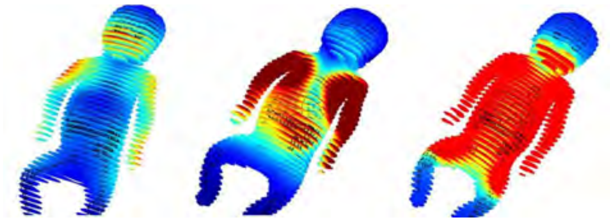

Figure 2: SOS Maps for (from left to right) the cardiac, flexible and project coil designs; the project coil shows the highest field uniformity. For reference, dark red shows a SOS value of 20.

Coil	Max SOS/UNI value		
	Phantom	Baby	Heart
Cardiac Array	-	5.5/5.5	1.5/3.0
Flexible Array	149.7/149.7	221.6/221.7	49.6/190.0
Prototype (loose wrap)	355.1/355.1	2933.4/2931.1	68.9/181.6
Prototype (Overlaid configuration)	388.6/412.9	-	-

Table 1: SOS and UNI maximum values for all the simulation configurations.

Discussion: The SOS and sensitivity maps for the prototype show increased B_1^- uniformity and better maximum values than for the existing coils in both phantom and infant models, despite the smaller element size. The phantom simulations also indicate that the overlaid configuration of the prototype still out performs the flexible design despite removing four elements. It was expected that the performance of the prototype when accelerated along the x/y axis would be better compared with the flexible design, however the simulation indicated all the coil designs had similar performance.

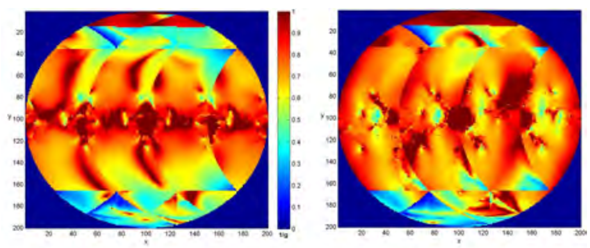

Figure 3: inverse g-factor map for Rx = 4 for (left) the flexible coil and (right) the project design. A 1/g value of 1 means no SNR loss at that point when accelerating the acquisition.

Conclusion: FE Simulations indicate that the proposed new coil design is likely to provide an SNR advantage over commercial cardiac and flexible coil designs currently used for paediatric MRI. Phantom studies also demonstrate this advantage is maintained even when in overlaid configuration (with 4 of 32 elements deactivated), allowing for a more tightly wrapped position for smaller infants. Although there is no improvement in acceleration potential in a phantom over the flexible design, the prototype design performs as well as the other designs and offers other advantages in flexibility, size adaptability and improved SNR.

References:

[1] A. Rotislav et al. 'A Numerical Postprocessing Procedure for Analysing Radio Frequency MRI Coils' Concepts in Magnetic Resonance 38A 133-147 (2011)

[2] P. Roemer et al. 'The NMR Phased Array' Magnetic Resonance in Medicine 16, 192-225 (1990)

[3] G. Chen et al. 'An optimisation method for designing SENSE imaging RF coil arrays' Journal of Magnetic Resonance 186, 273-281 (2007)