A 13 channel 3 Tesla Shoulder Coil on a Domed Conformable Former

G. C. Wiggins[1], B. Zhang[1], C. Glaser[1], B. Stoeckel[2], M. P. Recht[1], and D. Sodickson[1]
[1]Radiology, NYU Medical Center, New York, NY, United States, [2]Siemens Medical Solutions, New York, NY, United States

Introduction: MRI provides an essential tool for musculoskeletal radiology. The highest quality images are obtained with anatomically specific RF coil designs, customized to the anatomy of interest. The shoulder presents a difficult target, however, because of wide variations in body habitus and the difficulty of arranging coil elements around the shoulder to optimize sensitivity. The most commonly available shoulder coils consist of a rigid concave housing on which 4 to 8 receive elements are arranged. These provide high sensitivity in the rotator cuff region, but the sensitivity drops off steeply towards deeper tissue such as the glenoid cartilage and the labro-ligamentous anatomy. Flexible designs have also been described to accommodate different body sizes [1]. In this work, we design, build and test a novel shoulder array aiming to achieve higher SNR in deep tissue and improving parallel imaging performance in a flexible coil housing which can conform to a variety of body types.

Methods: For a given object, the highest central SNR is obtained when the object is completely surrounded by coil elements [2]. Central SNR is also generally maximized if the overall coil structure conforms closely to the object. We have constructed a coil array on a flexible bowl-shaped housing which surrounds the shoulder joint and can be flexed to fit closely to subjects of varying body size. The coils are arranged in a soccer-ball geometry [3] incorporating 3 pentagonal centers of symmetry to form a quarter of a sphere, with 13 elements in total. The flexible former was constructed from 6mm thick closed cell polyethylene foam which was cut into a pattern of connected hexagons and pentagons 45mm on a side as shown in figure 1, left. When all the gaps were closed and joined together this formed a bowl shape with internal curvature approximately equal to a 200mm diameter circle (figure 1, center).

Circular surface coil elements with a track width of 5mm were cut with scissors from Pyralux flexible circuit board material (Dupont, Wilmington DE), individually optimized to follow the contours of the shell. Gaps were made in the copper for component placement by grinding the copper off with an abrasive disc on a Dremel tool. The coils placed over hexagonal and pentagonal tiles were approximately 100mm and 75mm inner diameter respectively (Figure 1, right). The shape and position of each coil element was adjusted to minimize inductive coupling with neighboring elements [4]. The coil elements were secured with duct tape to the flexible foam shell. Preamps (Siemens Healthcare, Erlangen Germany) were connected directly to each surface coil, and a detuning trap was formed around the match capacitor with a diode and hand-wound inductor. The preamps were connected to the scanner via two shielded cable bundles, each incorporating a common mode rejection trap, plugged into sockets in the patient table. The unloaded and loaded Q of the elements was determined by an S12 measurement with a double shielded probe lightly coupled to the coil element. Active detuning and preamp decoupling strength were characterized with the same double probe looking at the difference between the coil response with the preamp removed or with the coil actively detuned or with the powered preamp in place.

Coil performance was compared in volunteer measurements conducted in accordance with our institution's IRB to the small version of a commercially available 4 channel shoulder coil (Siemens Healthcare, Erlangen, Germany). SNR and g-factor were determined from 2D GRE acquisitions with TR/TE/Flip = 200mS/4.07mS/20deg, BW = 300 Hx/Pixel, 256 matrix, FoV = 220mm, slice = 3mm. SNR for Root Sum of Squares (SoS) and Optimum SNR combination were calculated according to the Kellman method [5]. High resolution anatomical images were obtained with a moderately T2-weighted Fat Saturated 2D TSE with TR = 3030mS, TE = 33 or 24 mS, BW = 217 Hz/Pixel, Flip = 150, Turbo Factor = 11 at various resolutions detailed below.

Results: The unloaded to loaded Q ratio was 6 or better for all coils. S12 coupling between neighboring coils ranged from -12 to -25 dB depending on the flexing of the foam substrate, measured as each new element was placed. In the completed array coupling as high as -8dB was observed, presumably due to screening by the subsequently added elements. Active detuning was -50dB and preamp decoupling was -30dB. The symmetrical coil arrangement and central attachment of the cable bundles allow the coil to be inverted for use on either shoulder. The former is large enough to fit patients up to at least 300 pounds, but can be squeezed flat to conform to thinner subjects. SNR maps for SoS combination for a 45kg volunteer are shown in Figure 3. SNR comparisons in specific ROIs are shown in Table 1. The SNR gain provided by the 13 channel coil ranges from 5% in the Deltoid muscle to 2-fold in the labrum and close to 3-fold in the anterior m. sub-scapularis. The use of Optimum SNR reconstruction offers gains of 10 – 50% in SNR in different regions, which is a result of the relatively high noise correlation observed for this coil. It is hoped that optimization of coil overlaps and improved preamp decoupling will reduce coupling and allow even higher SNR to be achieved with SoS combination. For the SNR data sets shown here the maximum g-factor at X3 varies between 1.09 and 1.56 for the 13 channel coil, and between 1.82 and 11.0 for the commercial coil, demonstrating a clear g-factor benefit for the 13 channel coil. The high SNR and low g-factor of the 13 channel coil allowed the resolution of the standard clinical T2 TSE to be increased from 0.62 × 0.62 × 3mm to 0.42 × 0.42 × 3mm, acquiring 30 slices in less than 2'42" and providing improved depiction of clinically significant details (Figure 4).

Conclusions: We have demonstrated a novel conformable shoulder array which offers significant SNR gains over the standard commercial coil. A 2-fold increase in SNR in the anterior and posterior labrum has the potential to impact the clinical MRI-based assessment of shoulder instability.

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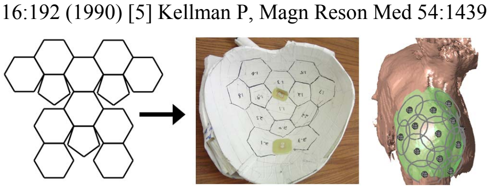

Fig. 1 Geometrical basis of the coil array

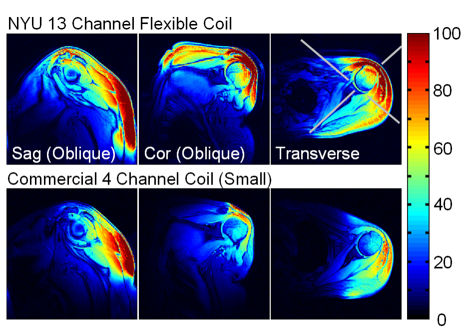

Fig. 3 Root Sum of Squares SNR

ROI	13 Ch SoS	13 Ch SNRopt	4 Ch SoS
Labrum	25	30	13
Sub-scapularis (inf. portion)	38.3	46.6	26.7
Sub-scapularis (ant. portion)	30.6	39.8	11.2
Clavicle	40.9	50.1	13.2
Supra-Spinatus	69.8	84.6	19.9
Infra-Spinatus	55.3	66.3	31.0
Deltoideus	70.7	96.6	67
Central Joint Cartilage	50	64	39

Table 1. SNR values for various regions of interest. Values are shown for Root Sum of Squares (SoS) and Optimal SNR (SNRopt) combination. Optimal combination promises even higher SNR from the 13 channel coil. It makes little difference to the 4 channel coil data due to the low noise correlation and hence is not shown

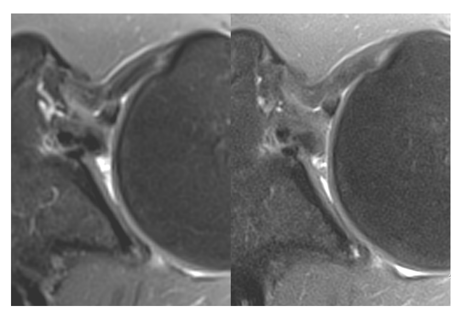

Fig. 5 Standard 3T Clinical Protocol 0.62 × 0.62 × 3mm) vs.High Res. (0.42 × 0.42 × 3mm) protocol with NYU coil. Note the much sharper anatomic depiction of cartilage, labrum and capsular-ligamentous structures in the anterior aspect of this shoulder joint and visibly improved contrast between different tissue types. There is posterior subluxation of the humerus.