RF Coil Designs for 7T Cardiac Imaging

J. T. Vaughan[1], C. J. Snyder[1], L. Delabarre[1], J. Tian[1], C. Akgun[1], G. Adriany[1], J. Strupp[1], P. Andersen[1], E. Auerbach[1], P-F. Van de Moortele[1], and K. Ugurbil[1]

[1]University of Minnesota-Center for Magnetic Resonance Research, Minneapolis, MN, United States

Objective: The objective of this study was to investigate three RF design approaches to cardiac imaging at 7T.

Background: Forty 7T systems are currently installed or are being installed worldwide. Most are used exclusively for head imaging. 7T whole body systems properly configured can be used for cardiac and other body imaging applications. (1-3) To successfully image the human heart at 7T however requires new approaches to RF coil design and application. Due to the dielectric constant of high water content tissues, the Larmor wavelength within the human body at 7T is nominally 12cm. The human trunk is about 3 x 6 λ in dimension. Consequential shortwave interference patterns result in severe B1 field non-uniformities in the body at 300MHz.(1) Additionally a conventional, highly reactive monolithic birdcage body coil becomes inefficient if indeed it could be built at all. To solve these problems, more efficient coil circuits are needed. And the coils must enable independent control of RF current phase and gain on multiple coil elements for RF field control (B1 shimming) to drive constructive field interference over the cardiac ROI. Pursuit of three RF coil design approaches incorporating these criteria follow.

Methods: In order to evaluate a spectrum of options in the new 7T cardiac imaging landscape, three RF coil approaches were taken and compared. Option 1 followed the conventional "clinical" body coil transmit and surface array receiver approach, albeit with a new coil design. Option 2 takes a newer approach employing a multi-channel transmit and receive, surface array. Option 3 is a hybrid of one and two, using a close fitting torso coil transmitter with a local receiver array. All three approaches are based on proven multi-channel TEM technology, using linear transmission line elements for the basic building blocks of each multi-element design.(4) In all three cases a sixteen channel parallel transceiver (5) was used to B1 shim, excite, and acquire 7T images from the heart. In all cases the forward and reverse powers are monitored for FDA guideline SAR compliance on the 16 transmit channels employed. In compliance with IRB approved protocols, 12 healthy normal volunteers have been included in this RF technology development project. Representative data is shown below.

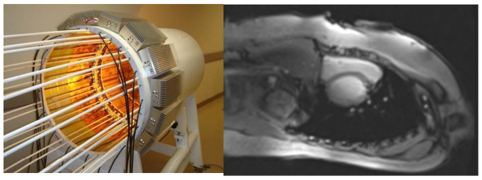

Figure 1. 16 channel TEM body coil (a.) used together with 16 channel receiver array to acquire (b.)

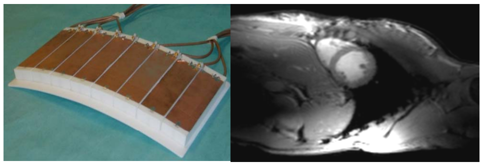

Figure 2. Two, eight channel TEM array panels (a.) above and below the chest were used to acquire (b.)

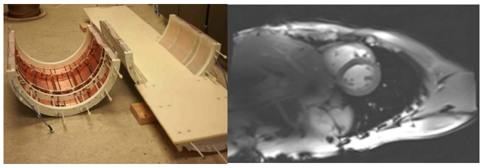

Figure 3. 12 channel TEM torso coil (a.) used together with 16 channel receiver array to acquire image (b.)

Body Coil : The 16-channel TEM body coil is shown in Figure 1a. Like commercial body coils for field strengths of 3T and lower, this 7T coil was built to fit into the extremely limited space between the system gradients and the MR system bore liner. The 60cm i.d. coil is comprised of 16 equally spaced, 32 cm coaxial transmit elements centered in the 1m long coil cavity. Elements were decoupled by balancing the mutual inductance with capacitance in the overlapping shield segments.(6) Each element was independently tuned and matched as evidenced by the 16 pairs of fiber-glass stems projecting from coil. Piezo-electric motor driven tuning and matching of these elements is being developed to facilitate eventual clinical utility of the coil.(7) Sixteen, channel dedicated 1kW power amplifier modules are also shown mounted on the end of the coil body demonstrating technology under development. Together with this 16 channel body coil a pair of eight loop receiver arrays was placed anterior and posterior to the subject's chest. After B1 shimming on the cardiac region, sixteen body coil transmit channels were used to excite a relatively uniform ROI. Thirty two channels (16 body coil plus 16 receiver array) were used to acquire the heart images in Figure 1b. This body coil option is the closest approach to current clinical imaging on 3T and 1.5T systems where a large body coil provides uniform excitation and local arrays increase sensitivity of reception.

Surface Coil: The 16-channel surface coil transceiver is a pair of 15cm x 40cm arrays of independently driven TEM elements (2a). To image the heart with this coil, one surface coil of eight elements in located immediately beneath the upper torso, centered with the heart of the supine subject. Another eight element surface coil is place on the subject's chest, over the heart. After the B1 shimming is employed to maximize SNR and uniformity, and to minimize SAR over the cardiac ROI, the TEM surface coil is operated as a 16-channel transceiver to acquire the heart image (2b). High transmit efficiency and receive sensitivity are reasons for using closely fitted transceiver surface arrays for cardiac imaging. (2) These close coils however can limit VCG lead and receiver array placement near the heart.

Torso Coil: The 12-channel torso coil, (43cm id x 20cm element length) may offer a good compromise between the transmit efficiency and receive sensitivity of the surface array of Figure 2, and the uniform excitation, local reception, and space of the whole body coil approach in Figure 1. In Figure 3a, a 46cm id, 12 channel TEM torso coil is mounted on a patient table and split for easy access. This actively detuned transceiver coil was used together with a 16 channel receive array as described for the whole body coil. High signal, relatively uniform B1 shimmed cardiac images were acquired with 12 transceiver channels and 16 receive channels as with the body coil and receiver set above. While more efficient than a whole body coil, this arrangement provides more B1 field uniformity than the surface coil transceiver, and allows room for cardiac lead placement and additional local coils, including receiver arrays and multinuclear coils.(8)

Results: All images were acquired by retrogated FLASH cine' protocols with same or similar parameters: TR/TE = 40/3ms, Res = 2x2mm, thk = 6-7mm, FOV > 30x40cm, over 8-16 heartbeats, iPAT = 4. SAR in each example was kept under 5W (total sample) for these low flip, low power acquisitions. The respective efficiencies of the body, surface, and torso coils were measured as 4000, 1700, and 2000 μs block pulses required to turn a 90 degree flip. In all cases the heart was successfully B1 shimmed to produce efficient and uniform excitation field over the heart.(9) No intensity correction has bee applied to the images.

Conclusions: All three approaches using TEM body, surface array, and torso coils have produced successful 7T cardiac images in these preliminary studies. As expected, the body coil is less efficient than the smaller coils, due to its distance from the subject as well as space related inefficiencies. The body coil however is the most comfortable to the volunteer, and has more room for leads, devices, and other coils. The surface transceiver array is the most efficient option, but is the most constraining to the volunteer and allows no room for additional receiver coils, leads or devices. The torso coil does seem to offer a good compromise between the body and the surface coils, being nearly as efficient as the surface array, but allowing room for local receiver arrays and VCG leads. Arm placement is a temporary problem for the present execution. All three coil technologies offer different options and tradeoffs for cardiac imaging at 7T.

Acknowledgements

NIH NIBIB R01-EB000895, NIH NIBIB R01-EB006835, NIH NCRR P41-RR08079

References: 1.) Vaughan, et.al. Magn. Reson. Med. 61: 1, 244-248, (2009); 2.) Snyder, et.al Magn. Reson. Med. 61:517-524(2009); 3.) Metzger, et.al. Magn Reson Med 59:396-409 (2008); 4.) Vaughan, US Patent 6,633,161(2003) 5.) Vaughan et. al., Magn. Reson. Med. 56:1274-1282 (2006); 6.) Vaughan et. al. Proc. ISMRM 17, 392 (2009), 7.) Snyder et. al. Proc.ISMRM 2010; 8.) Snyder et. al., Proc. ISMRM 17, 4761 (2009); 9.) Van de Moortele, P-F, et. al., Proc. ISMRM 17 (2009)