A Flexible Microstrip Transceiver Coil for Imaging Flexed Human Knee Joints at 7 Tesla

K. Subburaj[1], Y. Pang[1], S. Scott[1], B. Amirbekian[1], R. B. Souza[1,2], S. Majumdar[1], and X. Zhang[1]
[1]Department of Radiology and Biomedical Imaging, University of California San Francisco, San Francisco, California, United States, [2]Department of Physical Therapy and Rehabilitation Science, University of California San Francisco, San Francisco, California

INTRODUCTION: Recently, the number of studies on kinematics of the human knee joints using in-vivo MR images has increased with the advent of high magnetic fields (3T and 7T) and quantitative imaging techniques. Research has shown that flexed knee images provide superior visualization of several pathological conditions, especially anterior cruciate ligament (ACL) injury and meniscal tears [1]. Most knee TR coils are cylindrically designed for scanning knees in the extended position. These coils limit the maximum flexion angle while maintaining consistent space between the coil and the knee in addition to restriction imposed by bore diameter of the scanner. Although open magnets allow for greater freedom of movement in flexed knee studies, they suffer from low SNR at low magnetic field strength. Ultra-high magnetic fields (7T and beyond) are fundamentally advantageous due to inherently high SNR, and thus potentially high spatial and spectral resolution [2]. It would be useful to have a flexible coil for a 7T magnet that allows knees to flex to the maximum extent. Geometrically adjustable coils have also been shown to improve RF transmission efficiency and signal-to-noise ratio (SNR), providing better utilization of higher B_1 field closer to the coil surface and improved filling factor [3]. Microstrip transmission line (MTL) coils have better SNR than conventional surface coils in ultra-high fields [2, 4]. The objective was to design a proof of concept flexible MTL-based TR coil for ultra-high magnetic field (7T) that would provide high quality images for better diagnosis and biomechanical studies of the knee than the standard cylindrical coils.

MATERIALS AND METHODS: The physical layout of the single channel MTL-based TR coil is shown in Fig.1. The overall size of the coil is 300mm x 140mm. The functional elements were adhesive packed copper microstrip conductors (12 mm wide, 36 µm thick), ground plane (36 µm thick adhesive packed copper), a 12 mm thick dielectric substrate (Teflon) and four variable capacitors connected at the ends to the ground plane. There were two semi-oval shaped groves (8 mm wide) on the substrate to allow the coil to fold over the patient's knee. The segmented microstrip conductors were glued to the inner surface to create two rectangular loops (126 mm length and 90 mm width) and a sheet of thin copper foil (300 mm x 140 mm) was glued to the outer surface to create the ground plane (Fig.1). Variable matching and tuning capacitors (C_M and C_T) with a range of 1 to 25 pF were connected to the middle strip, which connect both loops, to adjust the resonance frequency of the coil according to the size of the patient's knee. Additionally four distributed capacitors (2.7 pF) were placed at the corners of each loop. A bench test was performed using a Agilent network analyzer. The primary resonant frequency was confirmed by measuring the reflection (S_{11}) and transmission (S_{21}) coefficients with a shielded 1.5-cm single loop sniffer (Fig.2.a). The S_{11} measurement was used to calculate the Q factors for both the unloaded and loaded conditions (Table 1). *In-vivo* experiments were performed on a full-body 7T MR scanner (GE, WI). The subject was positioned in supine, feet-first entry, and the coil was placed on top of the knee and strapped to maintain its position during scanning. A spoiled gradient echo (SPGR) sequence was used to acquire images of both the volunteer's knee and an oil phantom (standard head phantom). The imaging parameters were: TR/TE: 22/7.0 ms, flip angle 18, FOV: 14 cm, matrix: 256 x 256, thickness: 5 mm, BW: 31.25 kHz, NEX: 1.

RESULTS: The prototype microstrip RF coil (tuning range of 30 MHz) was built to operate at 298.2 MHz for imaging at 7T. A summary of the bench test results is given in table 1. At a 30^0 angle, the tuning frequency (f_t) range was 214-308 MHz (unloaded) and insignificant difference was observed in the loaded condition. At a 45^0 angle, the f_t range increased from 211-310 MHz (unloaded) to 212-304 MHz (loaded). The ratios of Q values measured (unloaded/loaded) were 2.99 (30^0) and 4.19 (45^0). Fig.2.b-d show the results from an oil phantom.

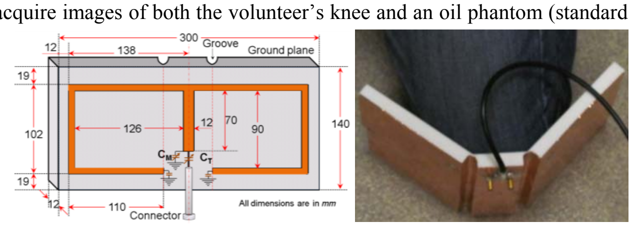

Fig.1: Schematic layout and physical prototype of the coil with load

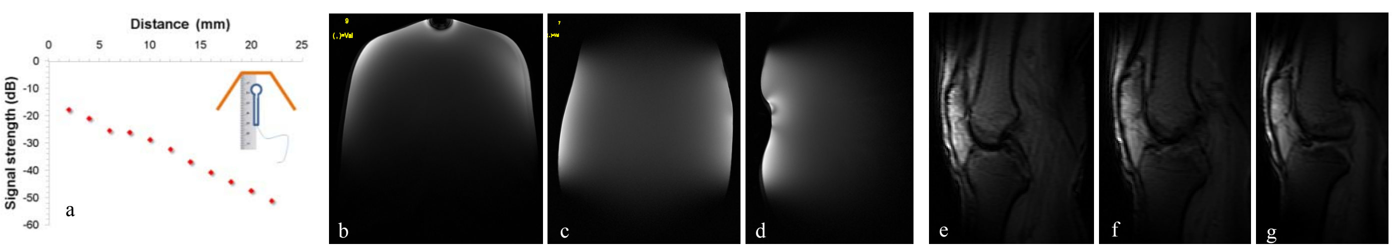

Fig.2: a: signal strength from center of the coil, (b) axial, (c) coronal, and (d) sagittal images of an oil phantom (e, f ,g) in-vivo knee images of a volunteer at 7T

Table 1:Experimental results

Angle	State	Frequency range (MHz)		at Resonant frequency (298.2 MHz)		Q factor	ΔQ factor (%)
		Min	Max	S_{11} (dB)	3 dB bandwidth (MHz)		
30^0	Unloaded	214.0	308.1	-32.6	3.5	170.38	2.99
	Loaded	211.0	308.9	-50.2	10.4	57.3	
45^0	Unloaded	211.8	310.9	-46.3	1.6	372.76	4.19
	Loaded	212.5	304.2	-48.3	6.7	89.02	

DISCUSSION: A flexible microstrip-based transmit-receive coil was designed, constructed, and tested on a human knee joint at 7T. The higher Q value at the 45^0 angle shows that the coil has a significant reduction of radiation losses when compared to 30^0. Oil phantom images clearly show B_1 field uniformity, coverage volume, and penetration (Fig. 2.b-d). The design of two rectangular loops design is shown effective in using the benefits of 2^{nd} harmonic resonance (reduce the constraint on size of the coil and resonant frequency) and gives a larger coverage volume [5]. As shown in figure 2.e, the region of knee closest to the coil shows superior SNR. This can be modified by introducing two additional slots on the substrate so that the coil can be wrapped closely around the knee. These results suggest that open-flexible coils would serve better for obese patients and accomplish equalized performance for different subjects independent of knee size. The prototype demonstrated the proof of concept design of flexible MTL-based TR coils have the potential to provide high quality images of flexed knee joints for biomechanical studies.

[1]. Niitsu, *Semin Musculoskelet Radiol* 2001, 5, 153-7. [2]. Zhang *et al.*, *Magn Reson Med* 2001, 46, 443-50. [3]. Adriany *et al.*, *Magn Reson Med* 2008, 59, 590-7. [4]. Mispelter *et al.*, *NMR probeheads for biophysics and biomedical experiments*. 2006. [5]. Zhang *et al.*, *Magn Reson Med* 2005, 53, 1234-9.