Target audience: Basic researchers and clinical scientists interested in MR safety aspects of scanning patients/volunteers equipped with intracoronary stents at ultrahigh fields (UHF).

Purpose: The sensitivity gain and signal-to-noise ratio (SNR) gain inherent to UHF MR (B ≥ 7T) holds the promise to enhance spatial and temporal resolution in MR imaging [1-2]. Such improvements could fuel a number of cardiovascular MR (CMR) applications. However, intracoronary stents commonly used in percutaneous interventions are currently considered to be contraindications for MR at B = 7T. The antenna effect due to the presence of an electrically conductive implant in combination with RF fields could induce local heating which exceeds the safety limits given by the IEC guidelines. For all these reasons this work examines RF induced heating of a copper tube and of a coronary stent. For this purpose numerical electro-magnetic field (EMF) simulations, RF heating experiments and MR thermometry (MRT) are performed at 7.0T.

Methods: EMF simulations were conducted to investigate E-field coupling with a copper tube and two non ferromagnetic coronary stent configurations (PRO-Kinetic Energy Cobalt Chromium Coronary Stent System, Biotronik, Bülach, CH; product #360553, l=40mm, d=4mm; product #360541, l=27mm, d=4mm). An in-vivo situation was simulated using a transceiver array tailored for cardiac MR at 7T [3] together with the human voxel model “Duke” of the virtual family [4]. For this setup SAR distribution was assessed w/wo a copper tube mimicking an intracoronary stent. For RF heating experiments an eight rung high pass birdcage RF coil was used [5]. MRT applying the proton resonance frequency method (PRF) was performed [6]. A fiber optics system (OpSens, Quebec, CA) was utilized to validate the MRTHe temperature maps. RF Heating was performed for 60 minutes using an input power of 198W. A cylindrical agarose phantom was used to emulate the electrical properties of human myocardium (ε=78, σ=1.2S/m).

Results: Our EMF simulations showed that a copper tube provides a reasonable approximation of a coronary stent since its antenna effect is similar to that of a coronary stent (Fig. 1 A-D). The weaving network structure of the stent induces minor peaks in the E-field for regions very close to the stent as demonstrated in Fig. 1E. However these local E-field peaks never exceeded $\frac{\left|E\right|_{\text{max}}}{\text{m}}$ 2560V/m (stent) at the tips, Fig. 1E. For the simulations using the human voxel model the copper tube was positioned at two locations which showed $\left|E\right|_{\text{max}}$ 310V/m for the 4 channel transceiver array (Fig. 1F-G). During the presence of the copper tube no increase in local SAR$_{\text{B1}}$, above the safety limits defined by the IEC guidelines [7] was found for arbitrary phase settings (Fig. 1 H-I) including a B1 optimized phase setting (Tab. I). For RF heating, the birdcage coil (Fig. 3A) was used to exceed the IEC SAR limits by a factor of ~3. For the reference phantom (Fig. 3B) a maximum temperature increase of $\Delta T = 27K$ was found in the absence of a conductive device. An extra temperature increase of $\Delta T = 32K$ was obtained for the presence of a copper tube in the agarose phantom. For a coronary stent the temperature difference maps are shown for a l=27mm stent (Fig. 3C) and a l=40mm stent (Fig. 3D). The extra temperature increase due to the presence of the stent was found to be $\Delta T = 32K$ for l=27mm and $\Delta T = 25K$ for l=40mm.

Discussion: The coronary stent examined here showed an RF heating behavior similar to that of a copper tube with the same geometry. Our results show an overall agreement between RF heating induced temperature changes derived from EMF simulations versus temperature maps deducted from MRT at 7.0T and the fiber optic system. Our results demonstrate that, the electric field distribution of the RF coil hardware used together with the position and orientation of the stent is of profound relevance for RF induced heating. The simulation results presented here, can be potentially utilized for safe multichannel transmission together with the use of virtual observation points [8-9].

Conclusion: Our EMF simulations and phantom studies suggest that if IEC guidelines for local SAR$_{\text{B1}}$ values are strictly followed, the extra RF heating, induced in myocardial tissue due to the presence of the stent, may not be significant versus the baseline heating induced by a cardiac optimized transmit RF coil at 7.0T. 