Investigation of Relationship between Applied Current Amplitude and Measured Current Density Magnitude in a Live Pig

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INTRODUCTION: Current density imaging (CDI) is an MRI technique used to measure current density vectors produced by an externally applied source throughout a volume of tissue [1]. Human electro-muscular incapacitation (HEMI) devices, such as the TASER®, are becoming more commonly used by law enforcement and military. The ultimate goal of this work is to achieve a better understanding of the effects of HEMI devices on physiology such that the efficacy and safety of these devices may be enhanced. Specifically, this abstract reports on the relationship between applied current amplitude and measured current density magnitude. This relationship is expected to be linear over small ranges; however, it is not well understood for larger ranges. A small range of amplitudes is investigated in an in-vivo pig to establish a method for future work.

METHODS: The subjects are 4.0 kg anesthetized piglets injected with the muscle relaxant pavulon to reduce motion from muscle contractions caused by applied current pulses. Two 3 cm diameter flexible copper electrodes were positioned on the chest, as shown in fig. 1. A fast 3D gradient recalled echo sequence was modified to implement phase cycling and synchronization with a current pulse generator. Imaging parameters included: 1.5 T; body coil; flip angle: 15°; bandwidth: 31.25 kHz; FOV: 48 cm; encoding steps: 128 x 128; slice thickness: 3.8 mm; and number of slices: 64. Applied current pulses were 20, 30 and 40 mA with a pulse width of 4.7 ms. MRI phase datasets were processed to yield current density vectors.

RESULTS: Current density vector plots for 40 mA are shown in fig. 1 as blue coloured arrows for one plane near the chest. Some of the possible 3D streamlines were computed between the two electrodes and are displayed as red coloured curves in fig. 1. The same streamlines are shown in fig. 1(a) and 1(b). The streamlines of fig. 1(b) show the current pathways penetrating deep into the chest. Fig. 2 shows the measured relationship between applied current amplitude and current density magnitude and compares this with a theoretical linear relationship (red dashed line).

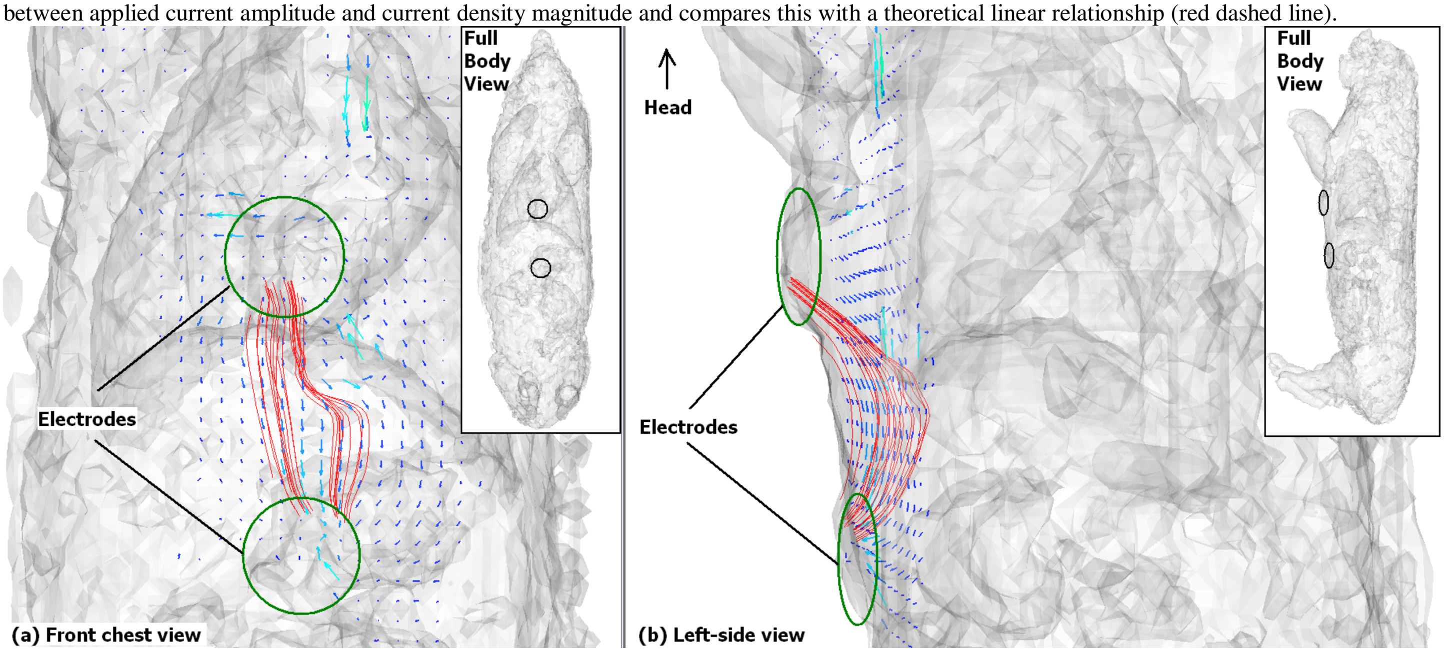

Fig. 1: CDI results for 40 mA. Vector plot in one plane (blue arrows) and streamlines (red curves) for current density vectors. (a) Chest view; and (b) side view.

DISCUSSION: The results of three acquisitions (i.e. 20, 30 and 40 mA) demonstrate a nearly linear relationship between applied current amplitude and current density magnitude. The current density magnitude was averaged over a group of 1839 voxels; selected by quality. The red dashed line in fig. 2 shows a theoretical linear relationship and the blue solid line shows the experimental measurements. The theoretical straight line is matched to the 30 mA experiment. The 20 mA experiment deviates by 7.2% and the 40 mA experiment deviates by 0.6%. These errors are likely attributed to measurement error, but may also indicate a nonlinear relationship over a broader range of current amplitudes. One observed physiological effect of the different current amplitudes was visibly more intense muscle contractions at 40 mA compared with 20 mA. Different states of muscular contraction may be a cause of a nonlinear relationship. A broader range of current amplitudes needs to be investigated in future work.

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REFERENCES: [1] G. C. Scott et al. Measurement of nonuniform current density by magnetic resonance. *IEEE Trans. Med. Imag,* Vol. 10, No. 3, pp. 362-374, 1991

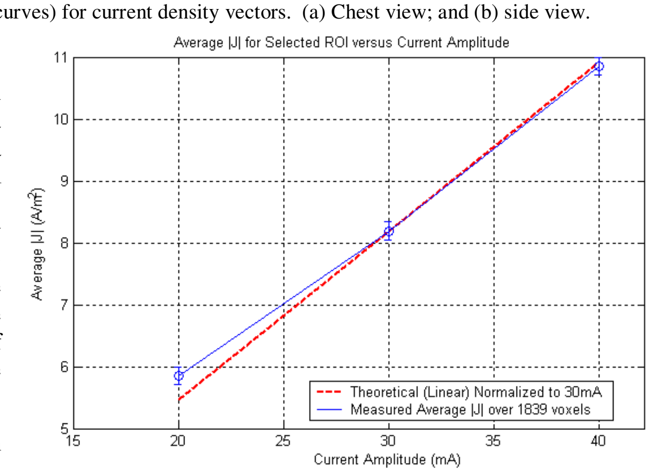

Fig. 2: Plot of relationship between applied current amplitude and current density magnitude. Dashed (red) line shows theoretical linear relationship and blue line shows actual measurements.