Design of a Microendoscopic EIT Probe: A Simulation Study

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Abstract: We describe a simulation study evaluating different electrode configuration for a microendoscopic EIT probe intended to intraoperatively assess surgical margins during radical prostatectomy. In our simulation study, we analyze the performances of three probe designs with varying number of electrodes (8, 9, and 17) and configurations (dependent on number of electrodes).

1. Introduction

There is a significant clinical need to develop a technology to intraoperatively evaluate the pathological status of tissue margins during prostate surgery. Negative surgical margins lead to a significantly decreased rate of recurrence in men treated with radical prostatectomy (RP). We are developing endoscopically-introducible EIT probes to meet this need. Here we describe a microendoscopic EIT probe (Fig. 1) that will be paired with a high speed, high precision modular multi-channel EIT system [1].

Surgical constraints limit the maximum probe diameter to 12 mm (to enable the probe to fit within a laparoscopic port). This defines the design space used for evaluating the number and orientation of probe electrodes. Specifically, the probe was designed to fit as many electrodes as possible within a circular pattern to ensure 1) maximum coverage of the probe tip's active surface and 2) a uniform angular sensitivity. One mm diameter electrodes arranged in circular pattern were therefore chosen for the design. Based on the constraints, three cylindrical probes with 8, 9, and 17 electrodes were considered and evaluated.

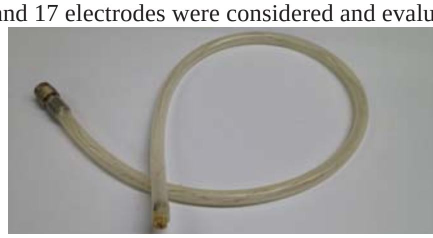

Figure 1: Image of a prototype probe.

2. Methods

Simulations were used to evaluate the 3 different probe geometries using a previously described 3-D EIT reconstruction algorithm [2]. Specifically, we were interested in evaluating which probe geometry identified the position and size of an inclusion most accurately. All possible tetrapolar drive patterns were used for the simulations.

2.1 Electrode Configuration

The 3 different electrodes geometries are shown in Fig 2. A 5 mm radius hemisphere represents the tissue being probed. A spherical inclusion of diameter 1mm and conductivity (σ) contrast of 10:1 ($\sigma_{inclusion}$:$\sigma_{background}$) was placed at 17 unique locations spanning the tissue volume. Results and analysis for one representative location are presented.

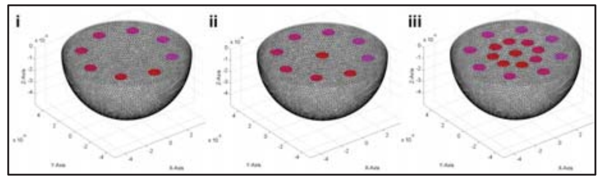

Figure 2: FEM meshes of 8 (i), 9 (ii), and 17(iii) electrode probe designs. The hemisphere represent the tissue volume being probed.

2.2 Simulation Results: Qualitative

For a spherical inclusion centered at (x,y,z) = (1.5mm, 0mm, -0.5mm), the 8 electrode configuration does not accurately identify the position and size, while 9 and 17 electrode configurations provide a more accurate representation (Fig. 3). The 17 electrode configuration provides a better size estimate than the 9 electrode probe.

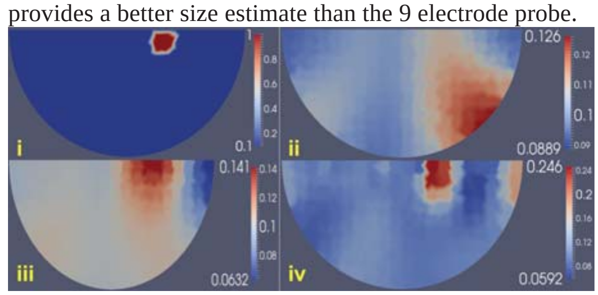

Figure 3. Comparison of 3D absolute reconstruction algorithm in the xz plane for 8, 9, and 17 electrode configuration presented in Fig. 3. ii, ii, iv respectively. An inclusion of diameter 1mm centered at [x,y,z] = [1.5mm,0mm,-0.5mm] is shown in Fig. 3.i.

2.3 Simulation Results: Quantitative

We define the Euclidian distance between the true center of inclusion and the center of the reconstructed volume as the position error (PE). For the inclusion as shown in Fig. 3 the PEs are listed in Table 1; the 8-electrode configuration performs worst while the 17-electrode configuration performs best.

Other quantitative analysis looked at i) the volume error (VE), which is defined as the difference between the true and reconstructed inclusion volume and, ii) noise analysis, in which PE and VE were compared in the presence of Gaussian noise (5 noise levels were explored). In all cases, the 17 electrode configuration performed the best and 8 electrode configuration performed the worst.

Table 1: Position Error in 'mm'

Configuration	8 electrode	9 electrode	17 electrode
Position Error	3.69 mm	0.87 mm	0.49 mm

3. Conclusion

Based on these simulations, a 17 electrode probe performs significantly better than the 8 and 9-electrode configurations. Moving forward, this configuration is being used to design our microendoscopic EIT probe for real-time monitoring of surgical margins.

References

[1] Khan S *et al* In *ICEBI* 2014

[2] Borsic A *et al* In *Phys. Meas.* **31** S1-1, 2010

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