### Electrical conductivity measurement in Thiel-embalmed tissue model: relevance to radiofrequency ablation

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Electrical conductivity measurement in Thiel-embalmed tissue model: relevance to radiofrequency ablation


Thiel-embalmed human cadaveric specimens are used widely for biomedical scientific investigation. This letter reports electrical impedance measurements of Thiel-embalming solution from 1 Hz to 32 MHz. Compared to other solutions studied, Thiel solution has the lowest impedance throughout the test spectrum. The electrical conductivity of Thiel-embalmed liver sample exhibited a relatively flat frequency response from 100 to 500 kHz, which is the frequency range used for electro surgery and radiofrequency tumour ablation (RFA). It measured 5 Sm\(^{-1}\) compared to 0.22 Sm\(^{-1}\) obtained from ex-vivo fresh pig liver. Using finite element modelling and experimental evaluation, ablation zone obtained from the Thiel-embalmed liver sample was extremely small due to its much higher conductivity. Hence, we conclude that Thiel-embalmed tissue cannot be used as a reliable model for RFA evaluation.

\[ \text{Introduction: The standard post-mortem storage of human cadaveric specimens for biomechanical investigation is deep freezing at low temperatures (\(-20 \, ^\circ\text{C}\)). However, tissue banks of deep frozen human tissues is costly, of limited supply, requires defrosting before usage, and can act as a source of disease transmission during sample handling, unless safety handling precautions are in place. The use of Thiel embalming, recently popularised has overcome these problems as exemplified by the use of Thiel-embalmed heads for assessment of middle ear studies [1].} \]

Thiel embalming was first described by Thiel in 1992 [2], conserves texture, elasticity and colour in cadavers close to that of the living and is bactericidal. Unfortunately, Thiel embalming is not widely practised for a variety of reasons, including expertise needed, costs and time required for this soft embalming process. Hence, its availability is confined to a few centres worldwide [3,4]. Dundee University' Thiel-embalming facility, offers Thiel-embalmed cadavers for teaching, surgical skill training and research and development of medical devices [5]. There have been conflicting reports regarding the influence of Thiel preservation on tissue mechanics [6]. Although Thiel' embalmed tissue maintains soft tissue consistency and colour close to that of living tissue, Fessel et al. [7] reported that Thiel embalmed tendons do not exhibit the same biomechanical characteristics of fresh frozen tendons (from partial denaturation by boric acid in Thiel solution). There is little known in the reported literature on the electrical/dielectric properties of Thiel embalmed tissue. This report addresses this issue by providing data on electrical conductivity measurement. It also discusses the unsuitability of Thiel embalmed human tissue for studies and R & D in radiofrequency ablation (RFA).  

\[ \text{Thiel embalming solution and impedance measurement: Table 1 lists composition of our Thiel (tank) fluid, together with one moisturiser for impedance measurement comparison.} \]

\[ \text{Table 1: Composition of the Thiel tank solution.} \]

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<th>Moist</th>
<th>Tank fluid</th>
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<td>Hot tap water</td>
<td>20 L</td>
<td>20 L</td>
</tr>
<tr>
<td>Boric acid</td>
<td>600 g</td>
<td>720 g</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>-</td>
<td>2.4 kg</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>-</td>
<td>1.2 kg</td>
</tr>
<tr>
<td>Sodium sulphite</td>
<td>1000 g</td>
<td>1.68 kg</td>
</tr>
<tr>
<td>Propylene glycol</td>
<td>1 L</td>
<td>2.4 L</td>
</tr>
<tr>
<td>Stock II*</td>
<td>200 mL</td>
<td>-</td>
</tr>
<tr>
<td>Formalin (8.9 %)</td>
<td>-</td>
<td>2.04 L</td>
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* Stock II: 1 kg Chloroacetal in 10 litres of glycol.

Distilled water and aqueous KCl solution (11.5 g/L) were used as control samples. A sample cell consisted of two electrodes with 314.2 mm\(^2\) cross-section area and separated by a distance of 10 mm, yielding a sample fluid volume of 3142 mm\(^3\) (or 3.142 mL) [8]. A Solartron 1260 Frequency Response Analyzer was used to obtain impedance spectra of samples over a frequency range from 1 Hz to 32 MHz (Fig. 1). Impedance magnitude of the distilled water was extremely high (> 120 k\(\Omega\)) at low frequency up to 10 kHz, and was not included in Fig. 1a. Compared to all tested samples, Thiel solution (tank) has the lowest impedance magnitude throughout the whole test spectrum. For example at 10 kHz, impedances were 2.3 \(\Omega\), 4.0 \(\Omega\), 10.0 \(\Omega\) and 120.0 \(\Omega\) from tank, moist, KCl and water samples, respectively (Fig. 1a).

Fig. 1 Impedance of selected solutions: (a) magnitude and (b) phase angle in the measurement frequency range.

\[ \text{Thiel embalmed cadaveric tissue conductivity in terms of suitability for use in radiofrequency ablation (RFA) studies: RFA has been widely used in minimally invasive ablative cancer therapy, particularly for liver cancer [9]. Hence Thiel embalmed liver samples were used in the study. A custom cylinder sample holder was designed with two removable (by screw action) electrodes (\(A = 113 \, \text{mm}^2\) cross-section area) separated by a distance L of 35 mm, yielding a sample fluid volume of 3955 mm\(^3\). Several sample holders were constructed and separately used for} \]
different types of tissue samples (e.g., human cadaver, ex-vivo porcine tissue or tissue-mimicking gel-phantom). An Agilent Impedance Analyzer (model 4395A), which has high frequency range up to 500 MHz, was used for tissue conductivity measurements. Since this study was specifically concerned with RFA application which normally uses frequencies only up to 500 kHz, we selected frequency points from 1 kHz to 1 MHz for the measurement of tissue electrical conductivity. 

Electrical conductivity of the measured liver sample (explanted Thiel-embalmed cadaveric liver, IRIS L-Liver_FEB-2011) had a relatively flat frequency response (Fig. 2) and was around 5 Sm⁻¹ from 100 kHz to 500 kHz (most used frequency range for electro-surgery and RFA). Although it was much lower than conductivities measured from Thiel-solutions (see Tank1 and Moist1, Fig. 2), Thiel-embalmed liver tissue still had 10 times higher electrical conductivity than that obtained from ex-vivo fresh pig liver (Table 2). Our measured conductivity of around 0.22 Sm⁻¹ for ex-vivo fresh pig liver aligns with values from literature, i.e., 0.23 Sm⁻¹ [10].

**Table 2:** Comparison of liver conductivity measurements at 500 kHz, average and standard deviation were deduced from n = 10 measurements.

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<th>Thiel-embalmed cadaveric liver</th>
<th>Ex-vivo fresh pig liver</th>
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<td>5.10 ± 0.56 Sm⁻¹</td>
<td>0.22 ± 0.08 Sm⁻¹</td>
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**RFA in FEM modelling and experimental evaluation:**

RFA probe (RTA Model 30) was used for both finite element method (FEM) analysis using COMSOL Multiphysics package and experimental evaluation together with an electrosurgical generator (DRE ASG-300) [11]. Ex-vivo pig liver samples were used for comparison (Fig. 3). We also measured thermal conductivities of Thiel-embalmed and fresh pig liver samples and found that there was no significant difference between them (p = 0.05). Our measured value of 0.501 Wm⁻¹K⁻¹ (n = 10, SD = 0.08) was used in our FEM modelling which is in agreement with [12]. Details of our thermal conductivity data will be published elsewhere.

**Fig. 3** FEM using ex-vivo pig liver model with (a,c) Thiel-embalmed and (b,d) fresh: FEM simulation and experiment evaluation.

Using ex-vivo fresh liver model, at an applied RF energy of 6 kJ (i.e., 20 W and 300 s), the maximal temperature at the ablation zone was kept just below 100 °C with the ablation volume shown as in iso-thermal surface plot of over 50 °C (Fig 3b) and tissue color changes (> 3 cm, Fig. 3d). However, due to much higher electrical conductivity for the Thiel-embalmed tissue, there was no obvious ablation zone in both FEM (Fig. 3a) and experiment (Fig. 3c), even with longer ablation time (900 s). For the Thiel-embalmed tissue, higher conductivity means lower resistivity resulting in lower resistive heating in RFA. Heating patterns would be more diffuse and tend to deliver less heating to the target zone. Finally, the RF generator outputs less power when the load (< 5 Ω, the Thiel-embalmed liver) is too low compared to the nominated output with load (> 150 Ω).

**Conclusion:** Electrical conductivities of Thiel-embalming solutions and embalmed liver samples were measured. On the basis of the present study, because of much higher electrical conductivities of Thiel-embalmed solutions and embalmed tissues, we conclude that Thiel-embalmed tissue is not a suitable model for RFA studies and R & D.

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**References**