Alteration in transthoracic impedance following cardiac surgery

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Defibrillation; Resuscitation; Transthoracic impedance; Cardiac surgery

Summary
Introduction: Haemodynamically significant ventricular tachyarrhythmias are a frequent complication in the immediate post-operative period after cardiac surgery. Successful cardioversion depends on delivery of sufficient current, which in turn is dependent on transthoracic impedance (TTI). However, it is uncertain if there is a change in TTI immediately following cardiac surgery using cardiopulmonary bypass (CPB).

Methods: TTI was measured on 40 patients undergoing first time isolated cardiac surgery using CPB. TTI was recorded at 30 kHz using Bodystat® Multiscan 5000 equipment before operation (with and without a positive end-expiratory pressure (PEEP) of 5 cm of H2O) and then at 1, 4 and 24 h after the operation. Data was analyzed to determine the relationship between pre- and post-operative variables and TTI values.

Results: Mean pre-operative TTI was 54.5 ± 10.55 Ω without PEEP and 61.8 ± 15.4 Ω on a PEEP of 5 cm of H2O. TTI dropped significantly (p < 0.001) after the operation to 47.2 ± 10.6 Ω at 1 h, 42.6 ± 10.2 Ω at 4 h and 41.8 ± 10.4 Ω at 24 h. A positive correlation was noted between duration of operation and TTI change at 1 h (r = 0.38; p = 0.016). There was no significant correlation between the duration of bypass and change in TTI.

Conclusion: TTI decreases by more than 30% in the immediate post-operative period following cardiac surgery. This state may favour defibrillation at lower energy levels.

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Introduction

A cardiac arrest following cardiac surgery is not an uncommon event, with an incidence of approximately 0.5—2% in the immediate post-operative period.1—3 Electrical cardioversion is necessary to terminate ventricular fibrillation/pulse less ventricular tachycardia. Successful electrical cardioversion by transthoracic defibrillation is
dependent upon delivery of sufficient current through the heart to depolarize a critical mass of myocardium. While weak defibrillation shocks are likely to fail, sufficiently strong defibrillation shocks can cause temporary or permanent damage to the heart. Therefore, any factor affecting trans-myocardial current may have an adverse effect on the success of defibrillation. The current resuscitation guidelines from the European Resuscitation Council have increased the energy settings for defibrillation following cardiac surgery. According to these guidelines, the energy level for the first shock has been increased from 200 to 360 J monophasic shock (150–200 J biphasic).\textsuperscript{7}

Current flow during cardioversion is determined by the operator-selected electrical energy (J) and the impedance or resistance (Ω). Current is related to these two factors by the equation: \( I = \frac{E}{Z} \), where \( I \) is the peak discharge current; \( Z \) is the impedance and \( E \) the electrical energy selected.\textsuperscript{8} It is documented that transthoracic impedance (TTI) is an important factor determining trans-myocardial current.\textsuperscript{9,10} While high impedance alters monophasic defibrillation waveforms, impedance compensatory mechanisms have been incorporated in the newer biphasic defibrillators.\textsuperscript{11}

Cardiac surgery is routinely performed with cardiopulmonary bypass (CPB), which initiates an inflammatory response.\textsuperscript{12} It results in capillary fluid leak secondary to haemodilution, inflammation and hypothermia.\textsuperscript{13} There is evidence that increases in tissue blood volume contributes to a decline in TTI.\textsuperscript{14} However, it is not known whether CPB has any immediate impact on TTI. A previous study that compared pre-operative TTI to the values taken 3–5 days following median sternotomy showed a decline in TTI. They, however, did not perform TTI measurements within the first 24 h following cardiac surgery.\textsuperscript{15} We hypothesize that TTI will reduce within the first 24 h after cardiac surgery using CPB.

### Measurement of transthoracic impedance

TTI was measured using Bodystat\textsuperscript{6} Multiscan 5000 impedance measuring equipment (Bodystat Ltd., Isle of Man, UK) as performed in previous studies.\textsuperscript{15,17} Measurement was averaged over a 5-s period using a low current sinusoidal wave at 30 kHz. Self-adhesive electrodes (Bodystat\textsuperscript{6}) were placed in the anterior-apical position, according to the current guidelines of the European Resuscitation Council.\textsuperscript{16} Anterior electrodes were placed to the right of the upper part of sternum, just below the right clavicle. The apical electrodes were placed over the left 5th intercostal space in the left midaxillary line, in a position corresponding to the cardiac apex. Measurement of TTI is imperceptible by the patient.

TTI was measured twice before the operation, first with the awake patient (at end-expiration while breath was held), and then on the ventilated patient with a positive end-expiratory pressure (PEEP) of 5 cm of H\textsubscript{2}O.

Three further measurements of TTI were obtained after the completion of the operation; first, 1 h after patient returned to the intensive care unit, second, 3 h later and then another one 24 h after the operation. All the measurements were performed at end-expiration.

The data from four patients could not be used due to inaccurate placements of electrodes and improper use of the impedance measuring device (in three) and concurrent pacing in one patient. Therefore, analysis was performed using data from 40 patients.

### Other recorded variables

Demographic and operative details were recorded for each patient. Along with each reading of TTI, some more variables were also recorded to account for any possible correlation with the change in TTI. These included temperature, fluid balance and total use of crystalloids and colloids. Post-operative body weight could not be recorded due to logistical issues and possible inaccuracy in measurements.

### Methods

#### Study patients

Following Local Research Ethics Committee approval, 44 patients undergoing first time cardiac surgery were recruited. The power of the study was calculated using the specialist sample size statistical software package nQuery Advisor\textsuperscript{8} Version 6.0. According to the power calculation, a sample size of 44 would have 90% power to detect difference of 0.5 S.D. or more in the change of TTI before and after bypass (assuming a simple paired t-test is used with the conventional 5% significance level). This relates to a difference of 3.5 Ω, using an estimate of S.D. of differences = 7 Ω, as used in a previous study.\textsuperscript{16} Written informed consent was obtained from all the patients. All patients had routine shaving of hairs from the chest before surgery. The anaesthetic and operative techniques, including the use of CPB was according to the already set standardized protocol. CPB was carried out with moderate haemodilution (haematocrit 22–25%) and either moderate hypothermia (30–32 °C) or normothermia, depending on surgeons’ preference. All patients were fully rewarmed before the end of the procedure.

#### Statistical analysis

Data were analyzed using SPSS v.11. Mean values ± S.D. were calculated at each time point. Means were compared using the Student’s paired t-test and repeated measures ANOVA. Pearson correlation analyses were used to determine the correlation between pre- and post-operative variables and TTI values. A p value of <0.05 was considered statistically significant.

#### Results

The data from 40 patients was included in the study. The demographic and operative data are as in Table 1.

TTI values showed a statistically significant drop from pre-operative to post-operative values (with or without PEEP) at all intervals (\( p < 0.001 \)). (Table 2).

The continuing linear downward trend in TTI from pre-operative to post-operative values was also of high significance (\( p < 0.001 \)) (repeated measures ANOVA) (Figure 1).
Table 1  Patient demographics and operative details

<table>
<thead>
<tr>
<th>Gender (male:female)</th>
<th>35:5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>63.0 ± 11.3a</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.68 ± 0.07a</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78.3 ± 12.2a</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>27.5 ± 3.5a</td>
</tr>
<tr>
<td>Diabetes</td>
<td>6/40 (15%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>24/40 (60%)</td>
</tr>
<tr>
<td>COPD</td>
<td>2/40 (5%)</td>
</tr>
<tr>
<td>Smoking</td>
<td>Non-smokers 15 (37.5%)</td>
</tr>
<tr>
<td></td>
<td>Current 5 (12.5%)</td>
</tr>
<tr>
<td></td>
<td>Ex-smokers 20 (50%)</td>
</tr>
<tr>
<td>CABG</td>
<td>26 (65%)</td>
</tr>
<tr>
<td>CABG + valve operation</td>
<td>3 (7.5%)</td>
</tr>
<tr>
<td>Use of LIMA</td>
<td>29 (72.5%)</td>
</tr>
<tr>
<td>Valve only</td>
<td>10 (25%)</td>
</tr>
<tr>
<td>PFO closure</td>
<td>1 (2.5%)</td>
</tr>
<tr>
<td>Operation time (min)</td>
<td>191.38 ± 43.53a</td>
</tr>
<tr>
<td>Bypass time (min)</td>
<td>92.15 ± 25.53a</td>
</tr>
</tbody>
</table>

n = 40. COPD = chronic obstructive airways disease, CABG = coronary artery bypass grafting, LIMA = left internal mammary artery, PFO = patent foramen ovale.

Table 2  Pre- and post-operative TTI values (mean ± S.D.)

<table>
<thead>
<tr>
<th>Time of TTI measurement</th>
<th>Pre-operative no PEEP (Ω)</th>
<th>Pre-operative with PEEP (Ω)</th>
<th>Post-operative 1h (Ω)</th>
<th>Post-operative 4h (Ω)</th>
<th>Post-operative 24h (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (S.D.)</td>
<td>54.50 (10.56)</td>
<td>61.85 (15.42)</td>
<td>47.20 (10.60)</td>
<td>42.63 (10.20)</td>
<td>41.78 (10.37)</td>
</tr>
<tr>
<td>p Value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Figure 1  Graph showing mean (±1 S.D.) values of TTI, with a continuing linear downward trend from pre-operative to post-operative values.

Operation time was not significantly related to TTI at 1 h (p = 0.66), 4 h (p = 0.52) or 24 h post-operative (p = 0.81), but was significantly related to the drop in TTI. The correlation between operation time and the drop in TTI between pre-operative with peep and post-operative 1 h was r = 0.38; p = 0.016. A longer operation time was associated with a larger drop in TTI. There was also some evidence of a weak association between operation time and the drop in TTI between pre-operative with peep and post-operative 4 h and the drop in TTI between pre-operative with peep and post-operative 24 h (r = 0.26; p = 0.11 and r = 0.28; p = 0.08, respectively). There was no significant correlation with any other variables, including bypass time, fluid retention and the use of left internal mammary artery, with the change in TTI.

The numbers of patients included in the statistical analysis was slightly lower than that specified in the pre-study power calculation, however, although this had a minor effect on the power of the study, the actual effect sizes obtained were nonetheless statistically significant.

Discussion

Cardiac arrest following major cardiac surgery is relatively common with a reported incidence of 0.7% in the first 24 h.3 A successful defibrillation of the shockable rhythms needs delivery of an adequate defibrillation dose. While too low currents are likely to fail to defibrillate, too high currents can lead to cardiac damage.6 The new guidelines from the European Resuscitation Council have revised energy settings for defibrillation in patients following cardiac surgery.7 The recommended initial energy level for monophasic defibrillators has been increased to 360 J from 200 J (for biphasic defibrillators 150 J).

TTI is an important factor determining the trans-myocardial current for defibrillation.9 A high impedance can alter the monophasic defibrillation waveforms, by reducing current flow and prolonging the duration, thereby reducing effectiveness. However, current biphasic defibrillators can check and compensate for impedance, by adjusting the waveform and optimising current delivery.11,18 Our study demonstrates that TTI decreases significantly (up to 30% of its pre-operative value) within the first 24 h after cardiac surgery. There was a statistically highly significant drop (p < 0.0001) at all time points, when compared to the pre-operative values. Therefore, the amount of defibrillation current for a given energy dose at a given voltage from a monophasic defibrillator may be greater after cardiac surgery.

Previous studies suggest that ischemic hearts may be more susceptible to a shock’s damaging effect than are non-ischemic hearts. Electrical shocks cause significant impairment in systolic and diastolic function in a dose-dependent fashion in ischemic hearts.19 The monophasic waveforms have been associated with greater myocardial damage than the biphasic waveforms.20 The mechanisms of myocardial damage include electroporation, formation of oxygen derived free radicals, and conformational dam-
age to ionic pumps or channels. However, only minor rise in troponin I was demonstrated following electrical cardioversion in a clinical setting. This study, however, excluded patients who had cardioversion following cardiac surgery. Cardiac operations using CPB leads to ischemia and reperfusion. It is not known if a heart after CPB becomes more prone to develop functional derangement after delivery of defibrillation shocks.

Since the incidence of cardiac arrests following heart operations is highest during the early post-operative period, we looked at the physiological mechanism governing current flow during this vulnerable period. As all our patients were ventilated within the first 4 h after the operation, therefore we measured TTI pre-operatively with and without ventilation. It therefore removed PEEP as a possible variable, which is known to increase the TTI. All the readings were obtained at end-expiration, as TTI is greater at end-inspiration than end-expiration. We used special impedance measuring electrodes from Bodystat Ltd. The electrodes were changed for each reading, in order to prevent the effect of drying, while positioning of the electrodes was carefully performed, avoiding breast tissue in the female patients.

It is known that an increase in tissue blood flow, blood volume, and tissue oedema reduce the TTI. CPB is a unique phenomenon where massive inflammatory response is initiated with several other physiological alterations. It results in capillary leak and oedema generation, which may be secondary to haemodilution, inflammation and hypothermia. It leads to an increase in total body water and extracellular fluids, with the effect lasting for up to 96 h. In a study on 17 patients, Kerber et al. have pointed out that hyperaemia, inflammation, tissue oedema and pleural effusions can account for the reduction in TTI following median sternotomy. They compared the pre-operative TTI with the values taken 3–5 days after operation. They, however, did not perform TTI measurements within the first 24 h following surgery. In another study, Gonzalez et al. demonstrated that bioelectrical impedance (BIA) detects fluid retention in patients undergoing CPB. It is therefore expected that the larger the fluid retention, the greater will be the drop in TTI. Perko et al. showed that alteration in body impedance closely follow changes in fluid balance in the peri-operative period. Our study did not show a significant correlation with the amount of fluid balance and the change in TTI at any time interval. However, we could not determine the extent to which inflammation in the chest wall, particularly sternum, contributed to the drop in TTI.

In this study, longer operation times were associated with a larger drop in TTI from pre-operative PEEP value to 1 h post-operative value. This was also the greatest drop in TTI encountered. Patients undergoing cardiac surgery experience a variety of pulmonary complications, including atelectasis, pleural effusions and pulmonary oedema. The atelectatic lung contains less air than normal lung, and pulmonary oedema and effusions in the pericardial and pleural spaces increase the extravascular water content of the chest. In theory, these changes explain the positive correlation between operation time and drop in TTI. A temporary post-operative paralysis of the diaphragm is also known to happen after cardiac surgery. This in turn could account for a reduction in lung volumes and alteration of TTI.

Conclusion

Our study confirms that TTI reduces significantly (up to 30%) in the immediate post-operative period after cardiac surgery. This state may favour defibrillation by lower energy shocks. However, further studies may be required to elaborate optimum energy settings for defibrillation after cardiac surgery.

Limitations of the study

This study failed to show any exact cause for a reduction in TTI following cardiac surgery. The inflammation associated with sternotomy and pericardium as well as the pulmonary changes may be the most probable causes for a reduced TTI. It may be that sample size was not sufficient to get any significant correlation with the fluid balance or other variables. Also, that in the short time period for the study, it was not possible to obtain sufficient numbers of off pump cardiac surgical cases as a comparison group. We also acknowledge the fact that modern biphasic defibrillators can circumvent the variation of TTI. Our findings are of more relevance to those cardiac surgical centres still using monophasic defibrillators.

Conflict of interest

None.

Acknowledgment

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References

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