The time taken for the regional distribution of ventilation to stabilise: an investigation using electrical impedance tomography

L. R. Caruana*, J. D. Paratz†, A. Chang‡, A. G. Barnett§, J. F. Fraser**

Summary
Electrical impedance tomography is a novel technology capable of quantifying ventilation distribution in the lung in real time during various therapeutic manoeuvres. The technique requires changes to the patient’s position to place the electrical impedance tomography electrodes circumferentially around the thorax. The impact of these position changes on the time taken to stabilise the regional distribution of ventilation determined by electrical impedance tomography is unknown. This study aimed to determine the time taken for the regional distribution of ventilation determined by electrical impedance tomography to stabilise after changing position. Eight healthy, male volunteers were connected to electrical impedance tomography and a pneumotachometer. After 30 minutes stabilisation supine, participants were moved into 60 degrees Fowler’s position and then returned to supine. Thirty minutes was spent in each position. Concurrent readings of ventilation distribution and tidal volumes were taken every five minutes. A mixed regression model with a random intercept was used to compare the positions and changes over time. The anterior-posterior distribution stabilised after ten minutes in Fowler’s position and ten minutes after returning to supine. Left-right stabilisation was achieved after 15 minutes in Fowler’s position and supine. A minimum of 15 minutes of stabilisation should be allowed for spontaneously breathing individuals when assessing ventilation distribution. This time allows stabilisation to occur in the anterior-posterior direction as well as the left-right direction.

Key Words: electrical impedance tomography, stabilisation, position change, regional ventilation, equilibration

Electrical impedance tomography (EIT) is a novel bedside imaging device which can provide real time information regarding ventilation without radiation1. Within the thorax, changes between inspiratory and expiratory lung volumes can be measured as the tidal variation in impedance1,2. The regional tidal variation of impedance has been used as a surrogate measure for the regional distribution of ventilation (RDV)2,3.

The time taken from moving a patient for the redistribution of ventilation to stabilise, as measured by EIT, is unknown. This information is important because changing a patient’s position is reported to redistribute ventilation4,5 and, to place EIT electrodes on a patient, it is necessary to change their position. A stabilisation time to account for the effects of changing a patient’s position on the RDV is necessary before attempting to assess the ventilation redistribution caused by any therapeutic intervention. The aim of this study is to determine the time taken for the RDV as determined by EIT to stabilise or return to baseline after positional change.

Materials and Methods
Eight healthy males aged 20 to 30 years consented to participate in this study. Ethical approvals from both The Prince Charles Hospital (EC2828) and University of Queensland (2008000916) were granted.

The Dräger Medical EIT Evaluation Kit 2 (Lubeck, Germany) was used to determine the tidal variation of impedance. The data were recorded as single two-minute files with the frame rate set at 10 Hz.

A pneumotachometer (Ventrak Model 1550 [Novametrix Medical Systems Inc., DRE, Wallingford, CT, USA]) measured tidal volumes (Vt) simultaneously via a Flow sensor (Model No 7222 [Novametrix Medical Systems Inc, DRE, Wallingford, CT, USA]). Actual Vt were compared to the maximum predicted Vt of 15 ml/kg of predicted body weight of males (50+0.91(height [cm]–152.4))6.

Height (m), weight (kg) and chest circumference (cm) were recorded.
Exclusion criteria
Participants were excluded for the following conditions: implantable cardiac devices, body mass index \( <18.5 \text{ kg/m}^2 \) or \( >30 \text{ kg/m}^2 \), smoking history, cardiorespiratory disease, diabetes mellitus, chronic fatigue syndrome, females, chest circumference \( <70 \text{ cm or } >150 \text{ cm (due to EIT belt limits)} \) and if they were unable to tolerate the mask (e.g. claustrophobia).

Data from a recording was excluded if the participant’s mean \( V_T \) exceeded the maximum \( V_T \) predicted for ideal body weight. Data that were considered erroneous or of poor quality were excluded.

An appropriate size electrode belt was positioned horizontally around the chest within the 4th to 6th intercostal space. The pneumotachometer was attached using a tight fitting mask.

Participants lay supine for 30 minutes before a baseline recording was made. Participants moved into 60 degrees Fowler’s position (high-long sitting in bed) and recordings were repeated at 5, 10, 15, 20, 25 and 30 minutes. Participants returned to supine and measures were repeated after 5, 10, 15, 20, 25 and 30 minutes. Participants were blinded from both the EIT and the pneumotachometer displays. All recordings were made by the author (LC).

Data were stored in the EIT Evaluation Kit 2 and transferred to a distant computer for analysis using the Dräger Data Review Software (version 5.1), which automatically calculated results for the tidal variation of impedance both globally and regionally. Analysis of data were performed for the anterior-posterior direction, as well as the left-right direction.

Statistical methods
To account for the repeated results from the same participant, a mixed regression model was used. The model included a random intercept for each participant and a fixed effect of position-time. The estimated marginal means were compared to ascertain the time for stabilisation for Fowler’s position and return to supine from Fowler’s position. Fowler’s position and the return to supine from Fowler’s position were also compared to baseline supine. Statistical analyses were performed using SPSS 15 (IBM Corporation, Somers, NY, USA).

Results
Exclusions
Three recordings of two minutes were excluded, one for \( V_T \) greater than predicted, one for an error message and one for questionable signal quality.

Explanations
Because the regional tidal variation of impedance is a surrogate measure of the RDV, results are reported in terms of RDV.

The regional distribution of ventilation anterior (RDA) and posterior (RDP) add to give the global tidal variation in impedance, only the RDA is presented, as the RDP has the equal but opposite response to the RDA. Similarly, only the regional distribution of ventilation left (RDL) will be presented.

Fowler’s position compared to baseline
At all time-points, the RDA and RDL were significantly different to the baseline (\( p < 0.05 \)).

Table 1
Pair-wise comparisons based on estimated marginal means upon return to supine, compared to baseline for the regional distribution of ventilation expressed as a percentage of the global tidal variation of impedance

<table>
<thead>
<tr>
<th>Minutes after return to supine</th>
<th>RDA</th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean difference compared to baseline</td>
<td>( P )-value</td>
<td>95% CI for difference</td>
<td>Mean difference compared to baseline</td>
<td>( P )-value</td>
<td>95% CI for difference</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower bound</td>
<td>Upper bound</td>
<td></td>
<td>Lower bound</td>
<td>Upper bound</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5</td>
<td>-0.86</td>
<td>0.12</td>
<td>-1.93</td>
<td>0.21</td>
<td>-0.14</td>
<td>0.59</td>
<td>-0.65</td>
<td>0.37</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10</td>
<td>-0.93</td>
<td>0.09</td>
<td>-1.99</td>
<td>0.14</td>
<td>-0.79*</td>
<td>&lt;0.001</td>
<td>-1.03</td>
<td>-0.28</td>
<td></td>
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<tr>
<td>15</td>
<td>-0.77</td>
<td>0.16</td>
<td>-1.84</td>
<td>0.31</td>
<td>-0.55*</td>
<td>&lt;0.001</td>
<td>0.03</td>
<td>1.06</td>
<td></td>
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<tr>
<td>20</td>
<td>-1.84*</td>
<td>0.001</td>
<td>-2.95</td>
<td>-0.73</td>
<td>0.42</td>
<td>0.12</td>
<td>-0.11</td>
<td>0.95</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>-1.04</td>
<td>0.06</td>
<td>-2.12</td>
<td>0.04</td>
<td>0.88*</td>
<td>0.001</td>
<td>0.36</td>
<td>1.40</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>30</td>
<td>-1.99*</td>
<td>&lt;0.001</td>
<td>-3.08</td>
<td>-0.90</td>
<td>0.44</td>
<td>0.09</td>
<td>-0.08</td>
<td>0.96</td>
<td></td>
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</tbody>
</table>

*The mean difference is significant at the 0.05 level. RDA=regional distribution of ventilation anterior, RDL=regional distribution of ventilation left, CI=confidence interval.
Fowler’s position compared to non-baseline measures

When compared to Fowler’s position at 10 minutes, non-statistically significant differences occurred between the RDA measured at 10 minutes and measurements at 15 minutes (P=0.99), 20 minutes (P=0.22), 25 minutes (P=0.88) and 30 minutes (P=0.15), indicating that stabilisation of the RDA occurred at 10 minutes. Within the RDL, stabilisation occurred after 15 minutes in Fowler’s position with a non-statistically significant difference between 15 minutes and 20 minutes (P=0.16), 25 minutes (P=0.62) and 30 minutes (P=0.48).

Return to supine compared to baseline

When comparing the RDA to the baseline supine position (Table 1), the RDA was not significantly different to baseline occurring at 5 minutes (P=0.12), 10 minutes (P=0.09), 15 minutes (P=0.16) and 25 minutes (P=0.06). However, significant differences occurred at 20 minutes (P<0.01) and 30 minutes (P<0.01).

For RDL (Table 1), non-significant differences to baseline occurred at 5 minutes (P=0.59), 20 minutes (P=0.12) and 30 minutes (P=0.09). Significant differences to baseline were recorded at 10 minutes (P<0.01), 15 minutes (P=0.04) and 25 minutes (P<0.01) following return to supine.

Return to supine compared to non-baseline measures

Within the RDA, stabilisation occurred at 10 minutes. Non-significant differences occurred in supine at 10 minutes and 15 minutes (P=0.77), 20 minutes (P=0.11), 25 minutes (P=0.84) and 30 minutes (P=0.06).

Stabilisation upon returning to supine occurred in the RDL at 15 minutes with non-significant differences between 15 minutes and 20 minutes (P=0.64), 25 minutes (P=0.21) and 30 minutes (P=0.69).

Discussion

Limitations

This study only had a small number of spontaneously breathing, healthy subjects without the influence of inspiratory positive pressure in only two positions. This study does not look to correlate stability of the RDV with stability in other parameters such as blood gases or respiratory mechanics. However, the study has implications for those wishing to collect data on the RDV as assessed by EIT.

This is the first study to determine the stabilisation time of the RDV following a positional change. Stabilisation occurs after 10 minutes in Fowler’s position and in the supine position in the anterior-posterior direction. Left-right stabilisation occurs after 15 minutes in both positions. Therefore, a stabilisation time of 15 minutes should be allowed for spontaneously breathing, healthy individuals when assessing the RDV with EIT.

A stabilisation time is necessary because patients are moved in order to place EIT electrodes circumferentially around the patient’s thorax. Therefore, a proportion of measured variations occurring within 15 minutes of changing position may be due to lack of stabilisation rather than the effect of any intervention.

The stabilisation time in sick patients may vary from the 15 minutes seen in healthy 20- to 30-year-old males. Patients with pathology have been shown to require prolonged periods in a new position to gain benefit of positional changes. Large-scale clinical studies will be necessary to determine if stabilisation is affected by age or pathology.

Upon returning to supine, the RDV varied when compared to baseline. The RDA returned to baseline by five minutes but not at 20 and 30 minutes. Similarly, the RDL returned to baseline by five minutes but not at 10, 15 and 25 minutes. The contention that regional distribution of ventilation might be biologically variable in the same way that respiratory rate varies biologically may be the cause of the variance in the RDV when compared to baseline.

Changing position redistributes ventilation amongst other effects. This result confirms that changing position does redistribute ventilation because, when in Fowler’s position, the RDA and the RDL were always significantly different to the supine baseline.

It has been demonstrated that the primary cause of ventilation redistribution is due to lung tissue shift caused by gravity. It is possible that stabilisation might occur more quickly in the direction of gravity. This may explain why the anterior-posterior direction stabilised quicker than the left-right direction.

Conclusion

When assessing the RDV with EIT, a 15-minute stabilisation period should be allowed following any change in position before acquiring data. This time will allow for regional tidal variation of impedance to stabilise in both the anterior-posterior direction and the left-right direction.

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References


