The threshold for sensing airflow resistance during tidal breathing rises in old age: implications for elderly patients with obstructive airways diseases

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Abstract

Objective: to determine whether the ability of elderly subjects to detect a rise in airflow resistance is attenuated in old age, and to measure the magnitude and variability of such a change.

Methods: we studied 124 healthy adults aged 20–86 years. Progressive external airflow resistance loading was used to measure the inspiratory and expiratory load detection thresholds (LDTs) during tidal breathing at rest.

Results: the mean inspiratory LDT rose from 4.00 (3.06 SD) kPa.s/L in the 20–39 age group to 6.51 (6.20) in the 40–64 age group (NS) and 29.10 (13.58) in the 65+ age group (P < 0.00001). The inspiratory LDT was significantly correlated with age, mainly due to the higher thresholds in people over the age of 65 (r = 0.7860, P < 0.00001), but did not correlate with age-corrected forced vital capacity or respiratory rate. Expiratory LDT values and correlations were very similar. Day-to-day variability in LDTs tended to be higher in older subjects.

Conclusion: the threshold for detecting external resistive loads during tidal breathing rises in old age. This appears to be a consequence of ageing processes rather than pathology, and might be a manifestation of a fall in proprioceptive acuity in elderly people. This finding has clinical implications for the self-management of asthma in old age. There is a need to conduct a similar study in patients with airways disease.

Keywords: airflow resistance sensing, age, asthma, respiratory proprioception, elderly

Introduction

Clinical experience suggests that elderly patients tend to be less aware of deterioration in their asthma or chronic obstructive pulmonary disease (COPD). An important contributing factor might be a reduction in the ability to detect a rise in airways resistance in old age. It has been postulated that the consequences of this could include a tendency to under ventilate in the face of rising airflow resistance and a failure to take timely therapeutic action or seek medical help, both of which could be detrimental to the well being of older people with airflow obstruction [1]. There is empirical evidence for this contention though almost all studies have been carried out in patients with asthma or COPD using progressive bronchoconstriction or under dynamic external airflow loading conditions [2–4]. In the case of induced bronchoconstriction, resistance rises in relatively large and unpredictable increments so it is not possible to determine the precise level of airways resistance at which a sensation of impaired airflow subjectively begins to be felt, so researchers have concentrated on comparing the magnitude of breathlessness with the changes in spirometry using visual analogue scales, thus inevitably overriding the early and subtle initial sensation of obstructed breathing. Similar limitations apply when external resistance loading is applied during exercise-induced ventilatory drive. It can be argued that such experimental conditions might not provide the best insight into the influence of ageing on one of the most pertinent issues, namely whether there is an inherent effect of age on the minimum amount of added airflow obstruction required for subjects to detect a change when breathing tidally at rest, a measure that can be referred to as the load detection threshold (LDT). In elderly people,
particularly those who are frail and have restricted mobility, it is reasonable to contend that it is the ability to detect a rise in airflow obstruction in the resting state that is most frequently of clinical importance. Detecting subjectively an increase in airflow resistance is the result of sensing that a change has occurred in the relation between inspiratory effort and the resulting tidal volume, an example of length-tension sensing [5–7]. The dynamic central monitoring of such breath-by-breath lung volume movements must depend on sensory information arising in thoracic mechano-receptors, including those located in the diaphragm, chest wall structures, airways and lung parenchyma. The deteriorative effects of old age on proprioception are well documented for a number of functions such as postural sway, gaze stability and point relocation [8–13]. If an analogous change occurs in the acuity and central interpretation of afferent mechano-receptor traffic from the diaphragm and chest wall, it can be hypothesized that the resting LDT would rise in old age and become more variable. It is not known whether such a change takes part as a normal consequence of ageing. Therefore, to explore the possible change of LDT with age, we measured the LDT in subjects with no known respiratory disease across the adult age range.

**Methods**

**Study design and subject selection**

We conducted a prospective open cross-sectional study. Subjects of the age of 18 years or more were invited to consent to participate. They consisted of hospital staff and members of the hospital volunteer workforce. Names were randomly selected from staff lists until there were at least 10 subjects in each 10-year age band who met the study criteria. The inclusion criteria were age >18 years, non-smoker (defined as never smoked or occasional experimentation), abbreviated mental test (AMT) [14] >7, willing to consent to take part in the study. The exclusion criteria were smoker, AMT <8, known to have a respiratory condition, positive answer to any question in the European Respiratory Society/International Union Against Tuberculosis (ERS/IUAT) bronchial symptom screening questionnaire [15], taking any medication that can alter respiratory sensory function (such as opioids or benzodiazepines), any known or apparent central or peripheral nervous system condition that might alter respiratory sensory function (such as stroke or peripheral neuropathy), diabetes mellitus, any condition that precluded performing spirometry (such as recent eye surgery).

**Method for measuring the LDT**

We constructed an apparatus using standard respiratory physiology equipment (Harvard Apparatus). It consisted of a flanged mouthpiece connected to a 1-way low resistance valve that was in turn connected to an airflow resistor by a 90 cm low resistance tube (Figure 1). The resistor could be positioned to either the inspiratory or expiratory direction of the valve. A disposable microbiological filter (Vitalograph) was placed between the mouthpiece and valve. The equipment dead space was <50 ml. In preliminary experiments, we determined that a lentiform resistor aperture gave the most consistent and near-linear calibration curve over the flow range encountered during tidal breathing. Calibration of the resistor through its full range of settings was performed in situ using pumped air at 5 l/min at room temperature (20–24° centigrade) and ambient humidity, with flow determined by a bobbin flow meter (rotameter) and pressure by a water manometer using standard laboratory methods.

LDT measurements were made in a quiet room with sources of distraction minimised. The researcher explained the test. The subject was seated comfortably and breathed through the LDT apparatus wearing a nose clip and a pulse oximetry finger probe (Criticare Systems). The need to breathe naturally and tidally was reinforced. The resistance sensation was not demonstrated to the subject because we had found in preliminary studies that such a manoeuvre tended to disrupt tidal breathing and did not improve the reproducibility of LDT measurements. A settling period of ~1 min was allowed and the respiratory rate was recorded after which the resistor was closed, silently and out of sight, in half millimetre increments every 4 or 5 breath cycles until the subject indicated by raising a hand that they had reached the point at which they could first feel definite resistance to breathing. The subject then disconnected and rested for about 2 min. The final aperture setting was recorded and later compared with the calibration curve to determine the measurement. For the main study, three measurements were taken in the inspiratory and expiratory modes in each subject, in random order. The means of the three readings were taken as the recorded inspiratory and expiratory LDTs, respectively. In individual subjects, the three readings showed little variability. For inspiratory LDT measurements in the main study 28/124 (23%) of the subjects had 3 identical aperture settings, in 54 (44%) the settings varied by 0.5 mm, in 40 (31%) by 1.0 mm and in 2 (2%) by 1.5 mm. The variability was proportionally greater for smaller aperture settings, though the mean within-subject within-test variability for the whole group was 6.4% and the greatest for an individual was 12.5%. The within-subject within-test variability for expiratory LDT measurements was very similar. No readings were discarded.
Day-to-day corrections for actual temperature, humidity and atmospheric pressure were not made because they were found to be too small to be of significance in this context.

**Measuring the within-subject variability of the LDT over time**

In addition to the main study, we obtained the consent of five subjects in each of the main age groups (20–39, 40–64, 65+) to take part in a study of the stability of the LDT over time. The method described above was used to take 20 LDT measurements in each subject, spread on 3 separate days 5–10 days apart.

**Spirometry**

Spirometry was performed on each subject using a Microlab 3300 portable spirometer. The ERS/ATS performance and interpretation standards [16] for forced spirometry were applied and recordings were made of peak expiratory flow rate (PEF), forced expiratory volume in 1 second (FEV1) and forced vital capacity (FVC). Subjects unable to have these indices measured to the required standard were not included in the data analysis. Height and age were recorded.

**Main study sequence**

In the main study, the sequence for each subject was as follows: invitation and information, check inclusion and exclusion criteria, consent, spirometry, LDT measurement.

**Statistical testing**

Continuous data were compared using the Mann–Whitney U test. Correlation coefficients were calculated by the Spearman rank correlation method using online software.

**Results**

In the main study, 124 subjects were included. The age range was 20–86 years. All subjects had PEF, FEV1 and FVC values that were >80% of predicted for age, height and sex and none had an FEV1/FVC percentage <70%. These spirometric data were taken to be additional confirmation of a lack of significant respiratory tract pathology. All had an oxygen saturation of 97% or more and none had a fall in oxygen saturation when having their LDTs measured.

Table 1 shows the mean inspiratory and expiratory LDT levels for three age groups. It can be seen that there was a small difference between young and middle-aged subjects, but a substantially higher mean value was found in elderly subjects. The ratio of males to females was similar in each age group. Figure 2a shows that the between-subject inspiratory LDT readings in the young and middle-aged subjects fell into a relatively narrow range, whereas those of the older subjects were spread wider. The distribution of expiratory LDT readings was very similar (Figure 2b). The overall correlation between age and LDT was highly significant (inspiratory LDT $r = 0.7860$, $P < 0.00001$, expiratory LDT $r = 0.7741$, $P < 0.00001$), mainly due to the rise in LDTs in subjects above the age of 65 years. A comparison of inspiratory and expiratory LDTs showed that there was a high degree of concordance between those indices in individuals, to the extent that in a plot of inspiratory against expiratory LDTs the line of regression through the points lies close to the line of identity between the x and y axes, indicating a lack of tidal phase bias towards either index. This shows that subjects detect inspiratory and expiratory loading with equal sensitivity during tidal breathing at rest.

A weak negative correlation ($r = -0.2447$, $P < 0.01$) was found between LDT and FVC. To allow for the possibility that the observed age differences might be due to lung volume changes with age, the inspiratory LDT was plotted against lung volumes corrected to age 40, which showed no correlation ($r = 0.1031$, $P > 0.1$), thus indicating that age-related lung volume changes did not contribute substantially to the relationship between age and LDT. Similarly, there was no correlation with age corrected FEV1, or PEF, and no correlation with FEV1 or FVC expressed as percentages of those predicted for age and height. The resting respiratory rate at the start of the LDT procedure ranged from 10 to 22 per min between subjects, and varied <2 per min during the LDT procedure. There was no correlation between age or LDTs and starting or maximum respiratory rate.

The study of within-subject variability over time showed that the LDT values were highly reproducible. The mean coefficient of variation (for 20 measurements) of inspiratory LDT for subjects under the age of 65 years was 4.3%, and over 65 years 6.2%. Day-to-day variation in the mean LDT had a maximum range of 6.2% in the younger group and 10.7% in the older subjects.

**Discussion**

The study confirmed that elderly subjects usually have a reduced ability to detect an external resistance to airflow during tidal breathing at rest. This finding and the observed increase in LDT variability in older subjects are supportive of our hypothesis of age-related deterioration in the acuity of length-tension sensing by respiratory proprioceptive functions. This effect appears to occur in subjects without significant respiratory pathology. Although the mean LDT in old age was higher than in younger subjects by an approximate factor of seven, it must be emphasised that the detection

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**Table 1. Inspiratory and expiratory external respiratory load detection threshold (LDT) in different age groups**

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Inspiratory LDT (kPa s/L) mean (SD)</th>
<th>Expiratory LDT (kPa s/L) mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–39 (a = 25, 6 M; 19 F)</td>
<td>4.00 (3.06)</td>
<td>4.18 (3.20)</td>
</tr>
<tr>
<td>40–64 (a = 41, 8 M; 33 F)</td>
<td>6.51 (6.20)</td>
<td>6.67 (6.31)</td>
</tr>
<tr>
<td>65+ (a = 58,13 M; 45 F)</td>
<td>29.10 (13.58)**</td>
<td>28.97 (12.92)**</td>
</tr>
</tbody>
</table>

Compared to the 20–39 age group: **$P < 0.00001$,** *$P < 0.00001$.*
threshold in the majority of older subjects was still below the level that we found to be distressing or uncomfortable in young and middle-aged subjects who took part in our preliminary resistance ranging studies despite application of an external resistance that simulates a large fall in airway conductance. Therefore, in normal subjects the changes in LDTs with age would not be expected to cause symptoms under normal physiological conditions. There is debate as to whether external airflow resistance loading is a reliable surrogate for intrinsic airways resistance. Though some researchers have shown that there is poor concordance between the dyspnoea of external loading and that of broncho-constriction [17], there is evidence that both rely at least in part on sensory input from mechano-receptors. Further, the role of afferent sensory traffic from airway and lung parenchymal receptors [18] does not appear to be dominant and probably has a high degree of redundancy, indicated by the fact that lung transplant patients, who have denervated lungs but intact chest wall and diaphragmatic sensation, retain the ability to judge lung volumes and detect changes in external airflow resistance [19–21]. The findings of our study suggest that an age-related reduction in proprioceptive acuity could be at least partly responsible for the clinically observed reduction in the ability of elderly people to detect early the changes in airflow resistance that occur, for example, in a worsening of asthma. We have published the full hypothesis elsewhere [22]. It is now necessary to conduct research to determine whether the same changes occur in elderly asthmatic and COPD patients.

The clinical implications of our findings are 3-fold. Firstly, national guidelines [23] for the use of inhaled therapy for asthma that include the use of ‘rescue’ broncho-dilators when the patient feels an increase in chest tightness, or other dyspnoeic sensations, might not be suitable in old age because the patients could be too far into an attack before taking action. Further research is required to establish an evidence base for a variation in the guidelines for elderly asthematics. Secondly, it can be contended that elderly asthma or COPD patients with known proprioceptive impairment might be particularly susceptible to late detection of a rise in airflow resistance. At present, there is no empirical evidence to support that supposition, which needs to be the subject of further research. Finally, the reduced ability of an elderly person to feel a rising airflow resistance appears to be part of the recognized tendency for older people to present with less clear symptoms and signs, alongside the consequences of other factors such as hypoxia and dehydration. Therefore, the degree of reported breathlessness, if any, cannot be relied upon when assessing an elderly patient with asthma and COPD.

**Key points**

- The threshold for detection of an external resistive airflow load during tidal breathing at rest rises in old age
- This is a possible reason for the clinical observation that older patients often seem less aware of a deterioration in their asthma or COPD
- It can be argued that guidelines for the use of self-administered ‘rescue’ inhaled bronchodilator therapy should take into account the reduced awareness of rising airflow resistance in elderly patients.

**Conflicts of interest**

None

**Funding**

None

**Ethical approval**

Dorset REC.
References


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