The maximal sniff in the assessment of diaphragm function in man

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Summary
1. We studied diaphragm function in a total of 64 normal subjects, who had no past or present respiratory or neuromuscular impairment.
2. We measured transdiaphragmatic pressure (Pdi) during maximal sniffs and compared these values with Pdi during maximal static inspiratory efforts (PImax).
3. The range of Pdi during maximal sniffs (82-204 cm H2O) had better defined lower limits than Pdi during PImax (16-164 cm H2O) and a higher mean value: mean ± SD for maximal sniffs was 137 ± 28 cm H2O and for PImax was 90 ± 37 cm H2O.
4. The reproducibility of sniff Pdi was assessed in eight randomly chosen subjects over 3 days: the mean coefficient of variation was 7.2%. By comparison the coefficient of variation of Pdi during PImax was 13.0% in seven subjects.
5. The maximal sniff is a spontaneous manoeuvre, easily performed, repeatable without tiring, and reproducible. Its measurement provides a more reliable quantitative method for assessment of diaphragm strength, which has potential in clinical practice.

Key words: diaphragm, maximal sniffs, maximal static inspiratory effort, transdiaphragmatic pressure.

Introduction
The measurement of the strength of the respiratory muscles provides the clinician with valuable information in the evaluation of patients with breathing difficulties [1]. The diaphragm is the major inspiratory muscle and assessment of its function is important, particularly since the diagnosis of complete or partial paralysis of the diaphragm can pose a major clinical difficulty [2].

Transdiaphragmatic pressure (Pdi) is believed to be the most accurate measure of the strength of diaphragm contraction [1,2]. The two respiratory manoeuvres commonly used to assess diaphragmatic function clinically have been a slow full inspiration and maximal static inspiratory efforts at various lung volumes [2-7]. But there are limitations to these tests, with a wide range among individuals making Pdi values open to misinterpretation [7]. We have tested the hypothesis that maximal sniffs might standardize the pattern of respiratory muscle contraction and provide a reliable quantitative assessment of diaphragm strength.

Methods
Techniques
Transdiaphragmatic pressure (Pdi) was measured with two commercially available 10 cm balloon catheters (P. K. Morgan) coupled to differential pressure transducers (Validyne MP45). One balloon, positioned in the middle third of the oesophagus and containing 0.5 ml of air, measured oesophageal pressure (Poes); the other, positioned in the stomach 65-70 cm balloon tip to nares and containing 1.5-2.0 ml of air, simultaneously measured gastric pressure (Pg) [8,9]. Pdi was obtained by electrical subtraction (Pdi = Pg - Poes) and Pdi at resting end-expiration (FRC) was used as a reference zero.

The data were displayed on an oscilloscope screen (Tektronix) and a paper recorder (Mingograf 800), and were simultaneously recorded on...
magnetic tape (Racal Store 7). Appropriate calibrations were made at the time of each test, by using water and mercury U-tube manometers as pressure standards. The frequency response of the equipment was assessed from the signal generated by a square wave input to the entire apparatus, which rose with a half-time of 6.3 ± 1.2 ms (mean ± SD), with no detectable phase or amplitude difference between oesophageal and gastric pressure responses.

**Subjects and protocol**

Sixty-four normal volunteers were studied, aged 22-75 years (mean age 35.1 years). The group was made up of 27 women, aged 22-53 years (mean age 31.2 years), and 37 men, aged 22-75 years (mean age 37.2 years). No subject had evidence of respiratory or neuromuscular disease. The balloon catheters were passed simultaneously through one nostril, after lubrication of the catheters (lignocaine gel, 2%) and topical anaesthesia of the nasal mucosa (xylocaine spray), and were swallowed by the subject with iced water.

Studies were made with the subject sitting facing an oscilloscope screen. All subjects followed the same protocol, which included a period of acclimatization to the apparatus. In each case subjects performed maximal sniffs followed by $P_{\text{Imax}}$ manoeuvres. The subjects were asked to perform single maximal sniffs (short sharp sniffs as hard as possible and such that peak $P_{\text{di}}$ was not sustained) at FRC, with at least two quiet breaths between each sniff. Body movement was not restricted. The sniffs were repeated until a plateau value of peak sniff $P_{\text{di}}$ was reached (usually within six sniffs) and a further eight to ten maximal sniffs were performed to ensure no further increase. The subjects were repeatedly encouraged to try as hard as possible and they could see their efforts, displayed as sniff $P_{\text{di}}$, on the oscilloscope screen, delayed by 1-2 s.

Oesophageal, gastric and transdiaphragmatic pressures were also obtained during repeated maximal inspiratory efforts performed against a closed valve, incorporating a small leak for comfort, at residual volume (RV). A conventional mouthpiece and noseclip were used. The subjects practised the manoeuvre, and were then asked to repeat the maximal inspiratory efforts, with suitable rests, until no greater decrease in oesophageal pressure was obtained (normally within four manoeuvres). Pressures sustained for 1 s were recorded. Delayed visual feedback was again provided, displayed as $P_{\text{oes}}$ to encourage the subject to make a maximal effort, and to sustain it for at least 1 s. In both instances the highest recorded value of $P_{\text{di}}$ was used for analysis.

To test the reproducibility of these manoeuvres, eight of the 64 subjects randomly chosen (five males and three females, aged 26-40 years) were studied in addition on 3 separate days over a period of 3-57 days. On each day, after an instruction and practice period, subjects were asked to perform maximal sniffs at FRC with two to three quiet breaths between each sniff, ten maximal sniffs being recorded at 0, 15 and 30 min.

Seven of the eight subjects also performed three maximal inspiratory efforts at RV at each of the three times, on the 3 days.

**Statistical methods**

Kolmogorov-Smirnov tests confirmed normal distribution of transdiaphragmatic pressure during maximal sniffs and maximal inspiratory efforts for the group as a whole, and for the male and female subjects as separate groups.

Statistically significant differences between sets of data were estimated by using Student's $t$-test (paired or unpaired as appropriate).

**Results**

**Maximal sniffs (Table 1a)**

The maximal sniff resulted in a sharp, transient and easily measured rise in transdiaphragmatic pressure (Fig. 1). The manoeuvre was readily mastered by all subjects and the study of any one subject was completed within an hour.

![Fig. 1. Maximal sniffs showing oesophageal pressure ($P_{\text{oes}}$), gastric pressure ($P_{\text{g}}$) and transdiaphragmatic pressure ($P_{\text{di}}$). Normal 31 year old male.](image-url)
Analysis of the time course of $P_{di}$ during maximal sniffs showed a variable slow rise followed by a rapid exponential rise of $P_{di}$. This fast component was assessed in several sniffs in four randomly chosen subjects and rose with a halftime of $36 \pm 8.8$ ms (mean $\pm$ SD).

The mean peak sniff $P_{di}$ for the group was $137 \pm 28$ cm H$_2$O (mean $\pm$ SD). The mean value for women (122 $\pm$ 25) was significantly lower than for men (148 $\pm$ 24) ($P < 0.001$). The lowest value for sniff $P_{di}$ was 112 cm H$_2$O in the men and 82 cm H$_2$O in the women. The contribution of oesophageal and gastric pressure to sniff $P_{di}$ was variable between subjects although in no instance was a negative value of $P_g$ obtained at peak $P_{di}$. The variation between subjects in sniff $P_{di}$ assessed from the coefficient of variation (CV) was 16% in the men and 21% in the women. The variation within a subject in sniff $P_{di}$, i.e. the reproducibility, was assessed from the CV for mean peak sniff $P_{di}$ repeated ten times on three occasions on 3 days ($n = 90$ sniffs) for each of eight individuals. This ranged from 4.9% to 13.8% in the eight subjects (mean 7.3%). Comparison of within-day and between-day variability of sniff $P_{di}$ showed no significant differences with no evidence of training, learning or other trend between days. The CV of the best one result of each group of ten maximal sniffs (‘best of ten’) over the 3 days was 5.0%. As respiratory function tests are often made in groups of three (rather than ten) the ‘best of three’ sniff $P_{di}$ was also analysed. The ‘best of three’ maximal sniff $P_{di}$ was found to be 96 $\pm$ 4.8% of the value of the ‘best of ten’.

Maximal static inspiratory efforts (Table 1b)

The mean value for $P_{di}$ during $P_{Imax}$. was $90 \pm 37$ cm H$_2$O (mean $\pm$ SD). The mean for women was $65 \pm 31$ cm H$_2$O and for men $108 \pm 30$ cm H$_2$O. The lowest value for $P_{di}$ during $P_{Imax}$. was 16 cm H$_2$O in the women and 52 cm H$_2$O in the men. The contribution of oesophageal and gastric pressure to $P_{di}$ during $P_{Imax}$. was very variable and negative values of $P_g$ were common. The variation between subjects in $P_{di}$ during $P_{Imax}$. was 48% in the women and 27% in the men. The variation within a subject in $P_{di}$ during $P_{Imax}$. was assessed from the CV for $P_{di}$ during $P_{Imax}$. repeated three times on three occasions on 3 days ($n = 27$) for each of seven individuals. This had a mean value of 13.0% (range 6.5-19.1%).

Comparison of sniff $P_{di}$ and $P_{di}$ during $P_{Imax}$.

In 59 of the 64 subjects sniff $P_{di}$ was higher than $P_{di}$ during $P_{Imax}$. There was a trend for high values of sniff $P_{di}$ to correspond to high values of $P_{di}$ during $P_{Imax}$. (Fig. 2). The mean value for sniff $P_{di}$ was higher than for $P_{di}$ during $P_{Imax}$ for the group as a whole and for the men and women as separate groups ($P < 0.001$ in all instances). The lowest value for sniff $P_{di}$ was 82 cm H$_2$O compared with 16 cm H$_2$O for $P_{di}$ during $P_{Imax}$. (Table 1). Multiple correlation analyses identified no significant relationship for male or female subjects between maximal sniff $P_{di}$ or $P_{di}$ during $P_{Imax}$ with age, height or weight ($r < 0.5$ in all instances). A comparison of the reproducibility of each manoeuvre repeated three times on three occasions on 3 days ($n = 27$) revealed that $P_{di}$ during $P_{Imax}$. was more variable (CV = 13.0%) than $P_{di}$ during sniffs (CV = 7.2%).

Discussion

We describe here the use of the sniff in the quantitative assessment of diaphragm strength in normal subjects. Previously the tests used have been a slow full inspiration and maximal static inspiratory efforts ($P_{Imax}$.) at various lung volumes. However, De Troyer & Estenne [7] clearly demonstrated in their study of 20 normal subjects that both the slow full inspiration and $P_{Imax}$ at FRC have limitations including wide between-subject variability and low,
TABLE 1. Respiratory pressures during maximal sniffs and maximal static inspiratory efforts

<table>
<thead>
<tr>
<th></th>
<th>Mean (cm H2O)</th>
<th>SD</th>
<th>CV (%)</th>
<th>Range (cm H2O)</th>
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</thead>
<tbody>
<tr>
<td>(a) Maximal sniffs</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>All subjects, n = 64</td>
<td>-99.8</td>
<td>24.61</td>
<td>20.2</td>
<td>-52 to -150</td>
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<tr>
<td>Poes</td>
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<td>25.54</td>
<td>16.3</td>
<td>-52 to -150</td>
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<td>Pg</td>
<td>42.6</td>
<td>31.89</td>
<td>74.9</td>
<td>0 - 134</td>
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<td>147.8</td>
<td>24.10</td>
<td>16.3</td>
<td>112 - 204</td>
</tr>
<tr>
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<td>21.55</td>
<td>20.8</td>
<td>-52 to -140</td>
</tr>
<tr>
<td>Poes</td>
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<td>27.90</td>
<td>28.4</td>
<td>-38 to -164</td>
</tr>
<tr>
<td>Pg</td>
<td>10.2</td>
<td>27.38</td>
<td>26.9</td>
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</tr>
<tr>
<td>Pdi</td>
<td>108.3</td>
<td>29.65</td>
<td>27.4</td>
<td>52 - 164</td>
</tr>
<tr>
<td>Women, n = 27</td>
<td>-62.4</td>
<td>23.73</td>
<td>38.1</td>
<td>-24 to -120</td>
</tr>
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<td>Poes</td>
<td>-64.7</td>
<td>30.85</td>
<td>47.7</td>
<td>16 - 140</td>
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</table>

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<thead>
<tr>
<th>(b) Maximal static inspiratory efforts (PImax.)</th>
<th>Mean (cm H2O)</th>
<th>SD</th>
<th>CV (%)</th>
<th>Range (cm H2O)</th>
</tr>
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<tbody>
<tr>
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<td>31.52</td>
<td>38.0</td>
<td>-24 to -164</td>
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<tr>
<td>Poes</td>
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<td>27.90</td>
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<td>10.2</td>
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<td>-64.7</td>
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potentially misleading values in normal subjects. The PImax. would logically appear to be a better manoeuvre for maximal force generation by the diaphragm and therefore a better discriminator of diaphragm weakness, since it is known that the diaphragm has large reserve as a pressure generator and is capable of generating much greater pressures than are needed to achieve total lung capacity (TLC). Kreitzer et al. [5] studying patients with amyotrophic lateral sclerosis found Pdi at TLC near normal yet Pdi during PImax. at RV decreased to approximately one-half that seen in normal subjects. The alternative suggestion of Gibson et al. [10] of a modified PImax. manoeuvre, i.e. concentrating on moving the abdominal wall outwards during the maximal inspiration, may standardize the pattern of respiratory muscle contraction and avoid misleading low values of Pdi, but lacks simplicity and means more instructions for the patient to follow. This degree of co-operation may be difficult to achieve in the clinical setting.

The use of the sniff in the assessment of the diaphragm is not new. Hitzenberger in 1927 [11] described the sniff as a radiological test of diaphragm paralysis, since it is associated with crisp diaphragm descent in the normal subject. More recently Esau et al. [12] suggested that a short sharp sniff would approximate the diaphragm contraction elicited by a brief stimulation of the phrenic nerve. Our results in a large group of normal subjects demonstrated that peak Pdi generated during maximal sniffs has potential as a quantitative index of diaphragmatic strength in the clinical setting, with defined lower limits, little variability between or within normal subjects, simplicity and patient compliance. It has the advantage of being a manoeuvre familiar to all without the hindrance of noseclip or mouthpiece. Maximal volition is thus more likely. A mouthpiece can be difficult to manage for the elderly and for patients with weakness affecting facial muscles.

In contrast the results of Pdi achieved during PImax. at RV were very similar to the report by De Troyer & Estenne [7] of PImax. at FRC, including low values and wide between-subject variability. In our study transdiaphragmatic pressures achieved during PImax. manoeuvres were lower than those achieved during maximal sniffs. The converse might have been expected since the PImax. is a quasi-static manoeuvre whilst the maximal sniff is a dynamic manoeuvre, with presumed loss of force due to diaphragm shortening. It may be that there is greater diaphragm activation during maximal sniffs than during PImax., or it could be that during a PImax. there is antagonistic action of other respiratory muscle groups, not present or minimized during the sniff.

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Maximal sniffs and diaphragm function

The fall in $P_g$ below its resting end-expiratory level seen during $P_{Imax}$ in some subjects, but not during sniffs, may indicate strong recruitment of intercostal and accessory muscles with upward displacement of the diaphragm [7].

A direct comparison between the maximal sniff and maximal static inspiratory effort should also take into account the different lung volumes at which the manoeuvres were performed: the former at FRC and the latter close to RV. The inverse relationship between volume and maximal inspiratory muscle force by the measurement of minimal pleural pressures, found values in women to be 70-75% of male values. De Troyer & Yernault [18], assessing inspiratory muscle force by the measurement of minimal pleural pressures, found values in women to be 80-90% of male values. In our series maximal sniff $P_{di}$ in women was almost 80% of male values. This is also in agreement with other tests of lung function and muscle strength [14, 15]. A fall off in global inspiratory strength with advancing age has been found [16-18] but was not evident in this study, possibly because of the smaller numbers of older subjects. Leech et al. [19] found a significant positive correlation between inspiratory mouth pressures and body weight in both sexes in a large group of men and women aged less than 35 years. Contrastingly we found no correlation between diaphragm strength and body weight, so it is possible that diaphragm muscularity is only affected at extremes of weight. The absence of any correlation between height and inspiratory muscle strength confirms other studies [19].

Maximal sniff $P_{di}$ was greater than 80 cm H$_2$O in all our subjects and was highly reproducible within subjects. This could allow grades of diaphragm weakness to be detected and followed serially in the range between complete paralysis, with zero $P_{di}$, and normality. The maximal sniff $P_{di}$ may prove to be clinically useful in the assessment of patients where diaphragm weakness is suspected.

Acknowledgments

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References


