Differences between sniff mouth pressures and static maximal inspiratory mouth pressures

Y.F. Heijdra, P.N.R. Dekhuijzen, C.A. van Herwaarden, H.T.M. Folgering

ABSTRACT: Measurements of static maximal inspiratory mouth pressure (Pimax) and dynamic sniff mouth pressure (Psniff) are frequently used to assess inspiratory muscle strength. The aim of the present study was to examine, in 42 healthy subjects, the equivalence of Pimax and Psniff, the influence of body posture on Pimax and Psniff, and the effects of nasal patency and repeated manoeuvres on Psniff.

Pimax was significantly higher than Psniff, 11.05±0.42 versus 8.53±0.31 kPa. Because of the low agreement between Pimax and Psniff, the two measurement methods were not interchangeable. The limits of agreement were 2.56±3.92 kPa. Sitting Pimax was 11.05±0.42 kPa, and supine Pimax was 9.36±0.41 kPa. Sitting and supine Psniff were 8.53±0.31 kPa and 7.52±0.33 kPa, respectively. Psniff performed with one nostril open instead of two, was higher: 9.67±0.32 kPa left and 9.62±0.32 kPa right versus 8.53±0.31 kPa when both nostrils were open. After 20–28 sniff manoeuvres, Psniff fell from 8.43±0.31 kPa to 7.83±0.30 kPa, suggesting some mechanism of inspiratory muscle fatigue.

We conclude that measurement of sitting Pimax yields the highest values for inspiratory muscle strength. The two measurement methods, Psniff and Pimax, are not interchangeable. Measurement of Psniff is affected by nasal patency.

Measurement of maximal static inspiratory and expiratory pressures is an accepted clinical method for evaluating strength of the respiratory muscles [1–4]. Another method to assess respiratory muscle function is the dynamic sniff manoeuvre. The respiratory static and dynamic pressures can be measured at the mouth (mo), nasopharynx (np), oesophagus (oes) and transdiaphragmatic level (di). Koutouzis et al. [5] showed that Psniff mouth (Psniff) and Psniff nasopharynx (Psniff,np) were slightly lower than Psniff oesophagus (Psniff,oes) in normal subjects and in patients with inspiratory muscle weakness. In 10 patients, static maximal inspiratory mouth pressures (Pimax) were found to be in the same range as Psniff. Psniff in 10 healthy subjects was in the same range as Pimax reported by others. Laroché et al. [6] investigated 61 patients referred with suspected respiratory muscle dysfunction. Psniff,oes and Psniff,di were found to be higher than Pimax and maximal static transdiaphragmatic pressure (Ptmx,di). Miller et al. [7] compared oesophageal (Poes) and transdiaphragmatic pressures (Pdi) during both manoeuvres in healthy volunteers. These authors showed that Psniff was higher, had a narrower range of reference values, and was more reproducible than static Ptmx. Therefore, they concluded that maximal sniff is a natural manoeuvre, easily performed, and repeatable without fatiguing. In contrast, Wanke et al. [8] found Psniff at residual volume (RV) to be less negative than Ptmx reported by other authors [1–3]. To our knowledge, a comparison between Psniff and static Ptmx within the same healthy subject has not yet been studied.

Static Ptmx and Ptmx in sitting and semi-recumbent position have been studied in normal subjects by No and Stokes [9]. They demonstrated that body posture did not affect Ptmx and Ptmx. In contrast, Psniff,oes measured in supine position was found to be less negative than when measured in sitting and semi-recumbent position [10].

Accurate measurement of inspiratory muscle strength in patients with pulmonary diseases is important for assessing the causes of impending respiratory failure. Because of the discrepancies in the literature about the factors that may influence this measurement, the purpose of this study was to investigate: 1) whether measurement of Psniff is equivalent to static Ptmx at residual volume; 2) the effects of nasal patency on Psniff; 3) the effects of body position; and 4) whether signs of fatigue occurred after repeated sniff manoeuvres.
Methods

Pressure measurements

The apparatus and procedure to measure Pimax and Pmax were based on those used by Black and Hyatt [1]. A pliable flanged mouthpiece was connected to a closed, rigid, plastic tube with a small leak (ID 1.1 mm; length 40 mm), preventing buccal muscles from producing significant pressures and closing of the glottis. The pressure inside the tube was measured with a pressure transducer (range ±40 kPa) (Validyne DP15-34) and recorded on an ink-writing recorder (Kipp en Zonen BD 101, Delft, The Netherlands).

Psniff was measured with a flexible open-tipped catheter (ID 1.8 mm) [11, 12]. The tip of the catheter was positioned in the oral cavity, as close as possible to the posterior wall of the pharynx [5, 8]. Calibrations were made before each measurement with a water manometer. The 95% response time of the Fmo catheter system was 0.03 s. The subjects could see the recordings, and were encouraged to generate maximal deflections.

Subjects and protocol

Forty two healthy subjects (21 female, 21 male) participated in this study. The mean age was 42±2 yrs (range 23–68 yrs), height 1.74±0.02 m, weight 71±2 kg. Pimax was measured at RV, in sitting and supine position, in random order. Pmax was measured in sitting position at total lung capacity (TLC). The subjects were wearing a noseclip. Care was taken to maintain an identical posture and appropriate support for the arms, throughout the experiment in either position. The manoeuvre was repeated at least three times, until three reproducible measurements had been obtained, with a maximal variability of 10% [13]. Pressures had to be maintained for 2 s to be able to measure the plateau pressure. The highest pressure value was used for analysis.

The subjects were asked to perform maximal short sharp sniffs through the nose, from RV, with the mouth closed. Between the sniffs there was a pause of at least two quiet breaths, lasting 10 s. The sniffs were repeated until Psniff did not increase further. This was usually the case within eight sniffs. Subsequently, all subjects performed six sniffs from RV with both nostrils open, in a sitting (Psniff-begin) and a supine position, which was measured in random order in 35 of the 42 patients. Then the subjects performed six sniffs from RV with one nostril closed, followed by six sniffs with the other nostril closed. After that, they again performed six sniffs in a sitting position through the unoccluded nose, to test whether the sniff pressures changed (Psniff-end). Between the various sniff manoeuvres, a check was made that the catheter system was free of mucus. The highest Psniff values were selected for analysis.

Preceding all manoeuvres, the mouth pressure at the end of the expiration or inspiration was arbitrarily set at zero, for inspiratory and expiratory pressures respectively.

Data analysis

Results are expressed as mean±SEM. Differences were tested by means of the Wilcoxon signed rank test, corrected for multiple comparison by Bonferroni. A p-value of 0.01 was considered to be significant. The statistical method for assessing the agreement between Psniff and Pmax was performed according to Bland and Altman [14].

Results

The data for respiratory muscle strength of males and females are shown separately in table 1. In the rest of the results, the mean values for males and females were taken together. Static maximal mouth pressures were higher than dynamic sniff pressures performed with one as well as with two nostrils open. Pmax was 11.05±0.42 kPa and Psniff was 8.53±0.31 kPa (p<0.00005). Psniff with the left nostril open (Psniff-left) was 9.67±0.32 kPa (p=0.002), and Psniff with the right nostril open (Psniff-right) was 9.62±0.32 kPa (p=0.002).

Table 1. – Maximal respiratory mouth pressures during static and dynamic efforts

<table>
<thead>
<tr>
<th>Variable</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sitting</td>
<td>Supine</td>
</tr>
<tr>
<td>kPa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psniff</td>
<td>9.4±0.4</td>
<td>8.3±0.5</td>
</tr>
<tr>
<td>Psniff-begin</td>
<td>9.2±0.4</td>
<td>7.6±0.4</td>
</tr>
<tr>
<td>Psniff-end</td>
<td>8.5±0.4</td>
<td>7.1±0.4</td>
</tr>
<tr>
<td>Psniff-left</td>
<td>10.3±0.5</td>
<td>9.1±0.4</td>
</tr>
<tr>
<td>Psniff-right</td>
<td>10.6±0.4</td>
<td>8.6±0.4</td>
</tr>
<tr>
<td>Pmax</td>
<td>12.4±0.6</td>
<td>10.7±0.6</td>
</tr>
<tr>
<td>Pmax (pred)</td>
<td>9.8±0.2*</td>
<td>7.7±0.2*</td>
</tr>
<tr>
<td>Pmax</td>
<td>14.1±0.9</td>
<td>10.2±0.7</td>
</tr>
<tr>
<td>Pmax (pred)</td>
<td>14.3±0.3*</td>
<td>9.5±0.1*</td>
</tr>
</tbody>
</table>

Data are presented as mean±SEM. *: residual SEM after correction for sex, age and height. Psniff: highest dynamic sniff mouth pressure performed with open nose; Psniff-begin: Psniff at the beginning of a session; Psniff-end: Psniff at the end; Psniff-left: Psniff with left nostril open; Psniff-right: Psniff with right nostril open; Pmax: static maximal inspiratory mouth pressure; Pmmax: static maximal expiratory mouth pressure; Pmmax (pred) and Pmmax (pred): reference values according to Wilson et al. [2].

The relationship between Pmax and Psniff is shown in figure 1. A plot of the difference between the two methods against their mean is shown in figure 2. The mean difference (d) was 2.56±0.30 kPa. The limits of agreement were:

Upper limit: d±2sd, 2.56±(2 x 1.96) = 6.48 kPa
Lower limit: d±2sd, 2.56±(2 x 1.96) = -1.36 kPa

Thus, Psniff can be 6.48 kPa below or 1.36 kPa above Pmax.
SNIFF AND STATIC INSPIRATORY MOUTH PRESSURES

Fig. 1. — The relationship between static and dynamic mouth pressure of all subjects. The solid line represents the line of identity. □ : males; ■ : females. Pmax: static maximal inspiratory mouth pressure; Psniff: dynamic sniff mouth pressure.

The 95% confidence interval of the bias was:
\[
d \pm 2\text{SEM}, \quad 2.56 \pm (2 \times 0.30) = 3.16 \text{ kPa}
\]
and 
\[
2.56 - (2 \times 0.30) = 1.96 \text{ kPa}
\]

The SEM of the upper limit and lower limit was:
\[
\sqrt{3\text{sd}^2/n} = 0.53 \text{ kPa}
\]
The 95% confidence interval of the upper limit was:
\[
6.48 \pm 2\text{SEM}, \quad 6.48 + (2 \times 0.53) = 7.53 \text{ kPa}
\]
and 
\[
6.48 - (2 \times 0.53) = 5.42 \text{ kPa}
\]
The 95% confidence interval of the lower limit was:
\[
-1.36 \pm 2\text{SEM}, \quad -1.36 + (2 \times 0.53) = -0.30 \text{ kPa}
\]
and 
\[
-1.36 - (2 \times 0.53) = -2.42 \text{ kPa}
\]
The mean difference (d) between Pmax and Psniff-left was 1.38±0.32 kPa. A plot of the difference between Pmax and Psniff-left and their mean is shown in figure 3. The limits of agreement were:

Upper limit: d±2SD, 1.38+(2 × 2.07) = 5.52 kPa
Lower limit: d±2SD, 1.38-(2 × 2.07) = -2.76 kPa

Psniff-left can be 5.42 kPa below or 2.76 kPa above Pmax.
The 95% confidence interval of the bias was:
\[
d \pm 2\text{SEM}, \quad 1.38 \pm (2 \times 0.32) = 2.02 \text{ kPa}
\]
and 
\[
1.38 - (2 \times 0.32) = 0.74 \text{ kPa}
\]
The mean difference (d) between Pmax and Psniff-right was 1.43±0.31 kPa. A plot of the difference and their mean between Pmax and Psniff-right is shown in figure 4. The limits of agreement were:

Upper limit: d±2SD, 1.43+(2 × 2.01) = 5.45 kPa
Lower limit: d±2SD, 1.43-(2 × 2.01) = -2.59 kPa

Psniff-right can be 5.45 kPa below or 2.59 kPa above Pmax.
The 95% confidence interval of the bias was:
\[
d \pm 2\text{SEM}, \quad 1.43 \pm (2 \times 0.31) = 2.05 \text{ kPa}
\]
and 
\[
1.43 - (2 \times 0.31) = 0.81 \text{ kPa}
\]
Average inspiratory pressure by two methods kPa

Fig. 4. - The difference between Psniff-right and Pmax against mean for Pmax and Psniff-right. □: males; ■: females. Psniff-right: dynamic sniff mouth pressure with right nostril open; Pmax: static maximal inspiratory mouth pressure.

Fig. 5. - Comparison of different dynamic sniff manoeuvres of all subjects (means±SEM). Psniff: dynamic sniff mouth pressure performed with open nose; Psniff-begin: Psniff at the beginning of a session; Psniff-end: Psniff at the end; Psniff-left: Psniff with left nostril open; Psniff-right: Psniff with right nostril open.

Psniff performed with two nostrils open (8.53±0.31 kPa) was lower than Psniff with one nostril open: left 9.67±0.32 kPa (p=0.00005); and right 9.62±0.32 kPa (p=0.00001) (fig. 5).

Static Pmax and Psniff were both significantly lower in the supine position. Sitting Pmax was 11.05±0.42 kPa, and supine Pmax was 9.36±0.41 kPa (p=0.000005). Sitting Psniff was 8.53±0.31 kPa, and supine Psniff was 7.52±0.33 kPa (p=0.00001) (fig. 6). The maximal expiratory mouth pressure (Pmax) in sitting position was 12.14±0.61 kPa.

Fig. 6. - Comparison of static and dynamic mouth pressures of all subjects, in sitting and supine position (means±SEM). Psniff-sup: Psniff in supine position; Pmax-sup: Pmax in supine position. For other abbreviations see legend to figure 1.

After 20–28 sniff manoeuvres, Psniff decreased from 8.43±0.31 kPa (Psniff-begin) to 7.83±0.30 kPa (Psniff-end (p=0.0007) (fig. 5).

Discussion

This study showed a low agreement between static Pmax and dynamic Psniff performed with one or two nostrils open; static Pmax was significantly higher than dynamic Psniff. Psniff with one occluded nostril was significantly higher and closer to Pmax, than with two open nostrils. Consequently, the results of Psniff measurements can be influenced by nasal congestion. Pressures in sitting position were higher than those in supine position, and Psniff decreased after 20–28 manoeuvres.

When comparing Pmax and Psniff, the 95% confidence intervals were wide, reflecting the wide variation of the differences between the two measurements. The two types of measurement were not interchangeable. When comparing Pmax and Psniff with only the left or right nostril open, the mean difference was smaller, but the limits of agreement did not improve, so that the different measurement methods were still not exchangeable.

Static Pmax was significantly higher than dynamic Psniff. An explanation for the observed difference may be the force-velocity and length-tension relationships of the respiratory muscles [15–19]. When performing static pressure manoeuvres, there is a minimal airflow through the leak, which may result in a higher pressure because of the force-velocity relationship. Also, the change in volume will be smaller, resulting in less decrease of...
diaphragmatic length and a higher pressure because of the length-tension relationship. Another mechanism that may explain these higher static pressures compared to the dynamic pressures, may be the topical anaesthesia used by others. When other investigators measured Pdi, simultaneous measurement of Pdi, Poes or Pp was achieved by inserting a catheter through the nose. Usually, topical anaesthesia was used [5, 7, 8]. In the present study the catheter was placed directly in the mouth. Thus, there was no need for local anaesthesia. It may be hypothesized that pain or nasal discomfort when performing multiple sniff manoeuvres, could result in submaximal efforts and lower pressures. Some subjects complained about a painful nose after many sniffs.

Sniff pressures were often reported to be higher than static pressures [6, 7], WANKE et al. [8] were the only authors who found lower Psniff values. However, none of these authors compared both procedures in the same subjects. WANKE et al. [8] also showed that sniff pressures were highest at RV. Because of this finding, we chose to measure Psniff from RV instead of the more conventional functional residual capacity (FRC) level. At levels below FRC, inspiratory muscle strength will be overestimated due to the elastic recoil pressure of the thorax [16, 20]. This, however, holds for the sniff pressures as well as the static maximal inspiratory pressures. HEITMANN et al. [21] found no difference between non-static peak maximal inspiratory mouth pressures and Psniff, in patients with acute respiratory failure. The correlation coefficient between these two measurements was 0.60. Similar correlations between static and dynamic pressures were found in patients with suspected respiratory muscle weakness [6]. However, the correlation coefficient measures the strength between the two pressure measurements, and not the agreement [14].

There is a very wide range of Pimax and Pemax values in several studies. The most comprehensive studies were performed by RINGQVIST [3], BLACK and HYATT [1], and WILSON et al. [2]. The mean Pimax values were 13.0±0.3 kPa, 12.4±0.3 kPa and 10.6±0.5 kPa, respectively. The mean Pmax values were 23.7±0.6 kPa, 23.3±0.6 kPa and 14.8±0.5 kPa, respectively. We used the prediction values according to WILSON et al. [2], because these authors used a flanged mouthpiece. The fact that our inspiratory values, measured with a flanged mouthpiece, are close to the reference values of BLACK and HYATT [1], which were measured with a tubed mouthpiece, suggests that the shape of the mouthpiece is of less importance [22]. The expiratory pressures were in the same range as measured by WILSON et al. [2]. The subjects in the study by RINGQVIST [3] were pushed so hard that they suffered from spontaneous nose bleeds and conjunctival haemorrhages as a result of their efforts. Normal values for Psniff are not available. The population of the studies in which Psniff was measured was very small. WANKE et al. [8] found a Psniff of 7.5±0.3 kPa in six normal subjects. KOULOURIS et al. [5] measured a Psniff of 11.4±0.7 kPa in 10 normal subjects.

Sniff pressures performed with one instead of two open nostrils were higher in 40 of the 42 subjects. PERTUZE et al. [23] showed that the sum of separate flow-volume curves through the left and right nasal passages was similar to the total inspiratory nasal flow. Unilateral occlusion did not lead to an immediate dilatation of the contralateral nasal airway. Nasal inspiratory flow depends on the nasal resistance, and changes proportionately to the degree of mucosal congestion [24-26]. Therefore, force-velocity and force-length relationships, as discussed before, might be responsible for the pressure differences found. A second explanation could be that the collapse of the nasal valve occurs at a lower transnasal pressure gradient when one nostril is used during a sniff manoeuvre [24]. The assessment of inspiratory muscle strength by the sniff procedure could possibly improve by using one instead of two nostrils.

Activation, co-ordination and recruitment of diaphragm and other respiratory muscles are not maximal in the supine position [10]. In the upright posture, there is generally more phasic and tonic activity in the scalene, sternocleidomastoid and parasternal intercostal muscles. The diaphragm shows more phasic activity, while the abdominal oblique muscles show more tonic activity. This results in an increased rib cage motion [27, 28]. Also, the compliance of the rib cage increases, and the compliance of the diaphragm-abdomen compartment decreases, in the upright position [29]. All of these factors appear to compensate for the longer costal and crural segments of the diaphragm and the higher velocity of contraction in the supine position in normal subjects [30], since the inspiratory mouth pressures measured supinely were significantly lower than those when sitting upright.

After 20–28 sniff manoeuvres, Psniff was significantly lower than Psniff at the beginning of the session, when a plateau had been reached. "Fatigue", defined as a condition in which there is a loss in capacity for developing force, resulting from muscle activity under load, which is reversible by rest [31], might be an explanation. Although the time tension index (TTI) was far below the fatigue threshold (TTI <0.15) [32] considering the contraction time to be less than 500 ms and the pause being 10 s, "fatigue" occurred. The reasons for the "fatigue" found in this study remain unclear. Measurements of motivation, relaxation rate [33], or power spectrum of the respiratory muscle electromogram [34], might yield some more insight. MILLER et al. [7] stated, in their original study, that the manoeuvre was not tiring. Their subjects performed approximately 16 sniffs. Possibly the larger number of sniff manoeuvres in our study is responsible for the difference. The time between the sniff manoeuvres was the same as in the study by MILLER et al. [7]. In studies published later, the time between two sniffs was increased from two normal breaths to 10-45 s [6, 8]. Fiz et al. [35] showed that chronic obstructive pulmonary disease (COPD) patients could make 20 subsequent static Pimax manoeuvres without decline in pressure. They did not investigate when Pimax declined, so that we do not know after how many static manoeuvres "fatigue" will appear.

From the data of this study we conclude that: 1) Pmax is significantly higher than Psniff; 2) the agreement between Psniff and Pmax, as well as the agreement between Psniff with one nostril open and Pmax, is low,
so that the two types of measurement are not interchangeable; 3) Psniff performed with one open nostril is significantly higher than with two nostrils open, consequently, nasal congestion will influence the measurement of Psniff; 4) both Pmax and Psniff in supine position are significantly lower than in sitting position; and 5) a decline in Psniff occurs after 20–28 sniff manoeuvres, possibly due to some kind of "fatigue".

When assessment of maximal inspiratory muscle strength is needed, it is important to realize that the results of respiratory muscle strength measurements are influenced by the type of measurement, body position and the number of efforts.

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References