Comparison of two different mouthpieces for the measurement of Pimax and PEmax in normal and weak subjects

N. Koulouris*, D.A. Mulvey*, C.M. Laroche*, M. Green*, J. Moxham**

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ABSTRACT: We investigated the effect of mouthpiece design on maximum static expiratory (PEmax) and inspiratory (Pimax) mouth pressures. We measured PEmax from total lung capacity (TLC) and Pimax from residual volume (RV) in 21 healthy volunteers, and in 40 patients referred for respiratory muscle testing. We compared two different mouthpieces, a semi-rigid plastic flanged type fitting inside the lips, and a 4 cm diameter rubber tube held against the lips. The tube mouthpiece gave significantly higher values for PEmax (p<0.02) in all subjects. Pimax was also significantly higher (p<0.005) with the tube mouthpiece in subjects who recorded normal pressures. We conclude that maximum pressures are obtained in all normal subjects with the rubber tube mouthpiece, and that differences in quoted normal ranges of maximum static respiratory pressures reflect in part the design of the mouthpiece and the way in which it was used.

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Respiratory muscle dysfunction is an uncommon but important cause of respiratory disability. The simplest and most widely applied technique for respiratory muscle strength assessment is the measurement of static mouth pressures [1]. A maximal effort is made against an occluded airway, with a small air leak to prevent glottic closure. Maximum inspiratory pressure (Pimax) is usually measured from residual volume (RV), and maximum expiratory pressure (PEmax) from total lung capacity (TLC). Mouth pressures can be a sensitive and specific index of global muscle weakness and are reduced before lung volumes [2].

Reference ranges [3–8] for the normal values of Pimax and PEmax have been reported by a number of authors (table 1), but important differences exist between these commonly quoted ranges. This variation may reflect differences in: a) the cohorts used to establish a normal range; b) the criteria of measurement; c) the design of the apparatus and the way it is used. It has even been suggested that the usefulness of static

<table>
<thead>
<tr>
<th>Table 1. – Reference normal ranges for PEmax and Pimax (kPa*, mean ±sd)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male</strong></td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>325</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>46</td>
</tr>
</tbody>
</table>

**Female**

| **No.** | **Pemax** | **Pimax** | **Source** | **Mouthpiece design** |
|---|
| 94 | 16.1±2.9 | 9.6±2.4 | Ringqvist [3] | Tube |
| 60 | 14.9±2.6 | 8.5±1.5 | Black and Hyatt [4] | Tube |
| 121 | 13.5±6.7 | 8.9±2.4 | Arora [5] | Tube |
| 480 | 9.2±3.2 | 7.0±2.6 | Luscher et al. [6] | Flanged |
| 87 | 9.1±1.6 | 7.2±2.1 | Wilson et al. [7] | Flanged |
| 60 | 8.7±2.3 | 6.9±2.3 | Vincken et al. [8] | Flanged |

* kPa=10.19 cm H2O. Pemax: maximum static expiratory pressure; Pimax: maximum static inspiratory pressure.
mouth pressures as a test of respiratory muscle strength "is obscured by the failure of a study population to reach the usually quoted standard values" [8]. The objective of this study was to assess the importance of mouthpiece design to the pressures obtained, as there has been no standardization of this variable in previous reports.

Methods

The study was approved by the local Ethical Committee and subjects gave informed consent. We studied two groups (table 2): a healthy volunteer group comprising six respiratory physiologists (RP) and fifteen naive subjects (NS), and a group of 40 patients referred for respiratory muscle testing. All of the volunteer group were non-smokers, and without respiratory disease. The patient cohort was divided into two subgroups using the normal ranges for P_{1max} reported by Black and Hyatt [4] for males and females. Those patients with a P_{1max} (measured with a rubber tube mouthpiece) less than 2 standard deviations from the mean for their sex were classified into a low-pressure patient group (LP). Those within these limits were classified as a normal-pressure patient group (NP).

<table>
<thead>
<tr>
<th>Sub-group</th>
<th>males</th>
<th>females</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>age range yrs</td>
<td>No.</td>
</tr>
<tr>
<td>RP (n=6)</td>
<td>4</td>
<td>32-44</td>
</tr>
<tr>
<td>NS (n=15)</td>
<td>7</td>
<td>23-34</td>
</tr>
<tr>
<td>NP (n=20)</td>
<td>9</td>
<td>21-74</td>
</tr>
<tr>
<td>LP (n=20)</td>
<td>13</td>
<td>17-71</td>
</tr>
</tbody>
</table>

We used two mouthpieces (fig. 1): one was a commercially available semi-rigid plastic flanged type (P.K. Morgan, Chatham, Kent). This type of mouthpiece is commonly used in pulmonary function laboratories. The other was a simple rubber tube of 4 cm internal diameter and 4.5 cm length, similar to that described by Black and Hyatt in their original paper [4].

Table 2. - Sex and age distribution of the 4 subgroups in this study

<table>
<thead>
<tr>
<th>Mouthpiece Design</th>
<th>P_{1max} kPa Flanged</th>
<th>P_{Emax} kPa Flanged</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP (n=6)</td>
<td>11.7±3.6</td>
<td>12.3±5.4</td>
</tr>
<tr>
<td>NS (n=15)</td>
<td>9.7±3.0</td>
<td>10.5±3.9</td>
</tr>
<tr>
<td>NP (n=20)</td>
<td>8.3±3.1</td>
<td>9.1±3.2</td>
</tr>
<tr>
<td>LP (n=20)</td>
<td>4.0±1.3</td>
<td>4.3±1.5</td>
</tr>
</tbody>
</table>

Each of the mouthpieces was fitted to a common stem incorporating a 3-way tap (fig. 1). The common stem was manufactured according to the design of Ringqvist [3]. The dimensions of the stem were length 27 cm, internal diameter 2.6 cm. A leak tube of length 3.7 cm and 2 mm internal diameter was incorporated into the stem 3 cm from the point of attachment to the mouthpiece. The 3-way tap was 7 cm from this point. The stem proximal to the 3-way tap was connected by a 70 cm fine polyethylene catheter to a Validyne MP45-1 differential pressure transducer (range ±35 kPa, Validyne Co, Northridge, C.A.). The transducer was calibrated before each study using a U-tube mercury manometer. Pressures were displayed on a Tektronix 5103N storage oscilloscope screen (Tektronix Inc, Oregon) and printed onto paper by a Mingograf 800 ink-jet recorder (Siemens-Elema, Sweden).

All studies were performed with a noseclip and with the subjects seated comfortably in a high-backed chair at 90° where they could see the oscilloscope screen.

Table 3. - Comparison of mouthpiece design in 4 sub-groups

<table>
<thead>
<tr>
<th>Mouthpiece</th>
<th>P_{1max} kPa Flanged</th>
<th>P_{1max} kPa Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP (n=6)</td>
<td>11.7±3.6</td>
<td>12.3±5.4</td>
</tr>
<tr>
<td>NS (n=15)</td>
<td>9.7±3.0</td>
<td>10.5±3.9</td>
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<td>NP (n=20)</td>
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<td>9.1±3.2</td>
</tr>
<tr>
<td>LP (n=20)</td>
<td>4.0±1.3</td>
<td>4.3±1.5</td>
</tr>
</tbody>
</table>

RP: respiratory physiologists; NS: naive subjects; NP: patients with normal static inspiratory pressures [4]; LP: patients with low static inspiratory pressure [4]; *: p<0.02; **: p<0.005 (paired t-test); P_{1max}: maximum static inspiratory pressure; P_{Emax}: maximum static expiratory pressure; mean ±SD.
flanged mouthpiece was held in the mouth behind the lips and gripped firmly by the teeth, the operator holding the stem. The subjects used their hands to hold the lips firmly onto the mouthpiece if a leak was noticed. Prior to a Pmax or Pimax effort the 3-way tap was closed by the operator with the subject at TLC or RV, respectively. When using the rubber tube mouthpiece, subjects held the stem with the 3-way tap already closed. When RV or TLC was reached, the subjects pressed the tube firmly against their face with the lips inside the tube. All subjects were given verbal encouragement and received uncalibrated visual feedback from the oscilloscope screen. A period of learning preceded the definitive measurements.

The mouthpieces were used in a randomized alternating order to minimize the effect of learning or fatigue on the definitive measurements. All measurements followed the criteria of RINQVIST [3] such that: i) no extra leakage occurred; ii) the three highest pressures recorded were similar (within 5%) and later attempts did not yield higher results; iii) the subjects felt that they had given a maximum effort. At least 1 min rest was allowed between efforts. Pressures maintained for less than one second were disregarded. The highest pressure generated by an individual for each mouthpiece was used for analysis.

Mean values for the four sub-groups studied were obtained and paired t-tests were used to detect statistically significant differences between pressures measured with the two mouthpieces.

**Results**

For Pmax mean values were significantly higher (p<0.02) for the tube mouthpiece in all four sub-groups (table 3). For Pimax the values were significantly higher (p<0.005) with the tube mouthpiece only in the subgroup of patients (NP) who could generate normal inspiratory mouth pressures (table 3). When all normal subjects and normal patients were compared as a group (RP, NS, and NP), the values were also significantly higher (p<0.005) with the tube mouthpiece for both Pmax and Pimax (table 4). The pressures achieved by the males and females in our volunteer group (RP, NS) are given in table 5.

**Discussion**

The results of the present study support the hypothesis that the choice of mouthpiece contributes to the differences between the normal ranges of static mouth pressures reported in the literature. When mouthpiece design is taken into account, the standard reference ranges (table 1) are remarkably similar although some variability remains. Our data is complementary to that of VINCKEN et al. [8] who concluded that such differences in the reference ranges were explained principally by the variation in the subject cohorts used.

COOK et al. [9] suggested that higher inspiratory pressures would be obtained with a “tube-type” mouthpiece simply because it prevented unwanted air-leaks. In the present study, the absence of extra leakage was one of the criteria for data acceptance. Therefore, this would not explain the differences obtained for Pmax with the two mouthpieces, and could not explain the differences in Pimax. An important factor must be the manner in which the mouthpieces are used and not simply the prevention of extra leakage.

To use a rubber tube mouthpiece as described by Black and Hyatt [4] requires the subject to press the apparatus firmly against the face with their arms. This requires the activation and co-ordination of muscle groups that are not recruited when using the flanged mouthpiece. Activation [10] and co-ordination [11] have been shown to be important determinants of maximal static respiratory pressures. If the flanged mouthpiece is
used in a similar fashion to the tube mouthpiece, i.e. pressed by the subject towards the oral cavity, discomfort inhibits the subject's effort and extra leakage occurs during an expiratory manoeuvre as the seal between the lips and mouthpiece is less effective. When the operator holds a tube mouthpiece for the subject, the seal between lips and mouthpiece is often inadequate and lower plateau pressures are recorded. Therefore, it is the manner in which the mouthpiece is used, as dictated by its design, that is the critical factor in the differences obtained in this study. Many patients with weak inspiratory muscles also have co-existing generalized muscle weakness. In these patients the recruitment of additional muscles when using the rubber tube mouthpiece may be less effective.

Our results are in contrast to those of Leech et al. [6], and Vincken et al. [8] who also compared a flanged mouthpiece with a mouthpiece fitted around the lips in order to prevent a leak, and were unable to show a difference between the pressures obtained. However, these authors do not give exact details of the manner in which the mouthpieces were used.

We had six patients whose data could not be included in the statistical analysis because they could not hold the common stem due to generalized neuromuscular disease, hand deformity, or quadriplegia. In these six patients, no pressures could be obtained with the rubber tube mouthpiece in the manner described by Black and Hyatt [4]. However, using the flanged mouthpiece and assisted by the operator, satisfactory mouth pressures could be recorded.

Other factors contributing to the variability in reference normal ranges must be considered. In the present study, pressures produced by the subjects were recorded onto paper to facilitate the case with which the 1 s plateau pressure could be identified. Previous studies [4, 5, 9] estimated the plateau by eye from a pressure dial. It is possible that this led to an overestimation of the plateau value. Ringqvist's data [3] for males include both military conscripts and naive volunteers. He compared the mean pressures produced by the conscripts to those of volunteers and showed that the former were significantly higher (table 6). Our normal male group was drawn from a similar population to Ringqvist's male volunteers, and record similar pressures (tables 5 and 6). Thus the subjects selected to construct a normal range must be representative of the population to which it will be applied. It may be preferable for a laboratory wishing to measure mouth pressures to choose one technique applicable to the study population and to establish a local reference range.

We conclude that in the clinical assessment of patients for global respiratory muscle strength, a flanged mouthpiece is more universally applicable. Although values obtained with a flanged mouthpiece are lower, this is not of clinical significance if the appropriate reference ranges are used [6-8]. However in normal subjects, maximal pressures are obtained with a rubber tube mouthpiece when it is used in the manner described by Black and Hyatt [4]. A rubber tube mouthpiece would seem appropriate in physiological studies when truly maximal pressures are needed. The differences reported in the literature for normal ranges of Pmax and Pimax may be explained in part by the choice of mouthpiece and the way in which it was used.

Table 6. - Data of Ringqvist [3] for male sub-groups, (tube mouthpiece)

<table>
<thead>
<tr>
<th></th>
<th>Pmax kPa</th>
<th>Pimax kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male volunteers (n=23)</td>
<td>12.2±0.7</td>
<td>20.5±1.3</td>
</tr>
<tr>
<td>Male conscripts (n=33)</td>
<td>15.1±1.3</td>
<td>23.2±1.2</td>
</tr>
</tbody>
</table>

Pmax: maximum static expiratory pressure; Pimax: maximum static inspiratory pressure. Mean ±sd.

References


RÉSUMÉ: Nous avons recherché l'effet de la forme d'une pièce buccale sur les pressions buccales maximales statiques expiratoires (Pmax) et inspiratoires (Pimax). Nous avons mesuré Pmax à partir de la capacité pulmonaire totale et
Pimax à partir du volume résiduel chez 21 volontaires bien portants, et chez 40 patients adressés pour tester leurs muscles respiratoires. Nous avons comparé deux pièces bucales différentes : l'une en plastique semi-rigide avec collet se plaçant à l'intérieur des lèvres, et l'autre, un tube en caoutchouc de 4 cm de diamètre placé contre les lèvres. Le tube en caoutchouc donne des valeurs significativement plus élevées pour Pemax (p<0.02) chez tous les sujets. Pimax est également significativement plus élevé (p<0.005) avec la pièce en tube chez les sujets qui ont des valeurs normales. Nous concluons donc que les pressions maximum sont obtenues chez tous les sujets normaux avec la pièce en tube de caoutchouc, et que les différences dans les limites considérées comme normales pour les pressions respiratoires statiques maximales reflètent partiellement la forme de la pièce bucale et la manière dont elle est utilisée.