

Comparison of two different mouthpieces for the measurement of P_{imax} and P_{Emax} in normal and weak subjects

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

Comparison of two different mouthpieces for the measurement of P_{imax} and P_{Emax} in normal and weak subjects. N. Koulouris, D.A. Mulvey, C.M. Laroche, M.Green, J. Moxham.

ABSTRACT: We investigated the effect of mouthpiece design on maximum static expiratory (P_{Emax}) and inspiratory (P_{imax}) mouth pressures. We measured P_{Emax} from total lung capacity (TLC) and P_{imax} 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 P_{Emax} ($p < 0.02$) in all subjects. P_{imax} 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.

Eur Respir J., 1988, 1, 863-867.

* Respiratory Muscle Laboratory, Brompton Hospital, Fulham Rd, London SW3 6HP, UK.
** Dept of Thoracic Medicine, King's College Hospital, Denmark Hill, London SE5 8RX, UK.

Correspondence: Dr N. Koulouris, Brompton Hospital, Fulham Road, London SW3 6HP, UK.

Keywords: Maximal static respiratory pressures; methods; mouthpieces; normal subjects; respiratory muscle weakness.

Received: March, 1988; Accepted for publication August 2, 1988.

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 (P_{imax}) is usually measured from residual volume (RV), and maximum expiratory pressure (P_{Emax}) 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 P_{imax} and P_{Emax} 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 1. - Reference normal ranges for P_{Emax} and P_{imax} (kPa*, mean \pm SD)

No.	P _{Emax}	P _{imax}	Source	Mouthpiece design
Male				
106	23.4 \pm 4.5	12.7 \pm 3.1	RINGQVIST 1966, [3]	Tube
60	22.8 \pm 4.1	12.1 \pm 2.1	BLACK and HYATT 1969, [4]	Tube
80	21.2 \pm 4.4	12.4 \pm 2.7	ARORA 1983, [5]	Tube
325	15.1 \pm 8.0	11.1 \pm 3.5	LEECH <i>et al.</i> 1983, [6]	Flanged
80	14.5 \pm 3.3	10.4 \pm 3.0	WILSON <i>et al.</i> 1984, [7]	Flanged
46	13.7 \pm 3.7	10.3 \pm 2.5	VINCKEN <i>et al.</i> 1987, [8]	Flanged
Female				
94	16.1 \pm 2.9	9.6 \pm 2.4	RINGQVIST [3]	Tube
60	14.9 \pm 2.6	8.5 \pm 1.5	BLACK and HYATT [4]	Tube
121	13.5 \pm 6.7	8.9 \pm 2.4	ARORA [5]	Tube
480	9.2 \pm 3.2	7.0 \pm 2.6	LEECH <i>et al.</i> [6]	Flanged
87	9.1 \pm 1.6	7.2 \pm 2.1	WILSON <i>et al.</i> [7]	Flanged
60	8.7 \pm 2.3	6.9 \pm 2.3	VINCKEN <i>et al.</i> [8]	Flanged

* kPa=10.19 cm H₂O. P_{Emax}: maximum static expiratory pressure; P_{imax}: 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 sub-groups using the normal ranges for P_{imax} reported by BLACK and HYATT [4] for males and females. Those patients with a P_{imax} (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 2. - Sex and age distribution of the 4 subgroups in this study

Sub-group	males		females	
	No.	age range yrs	No.	age range yrs
RP (n=6)	4	32-44	2	32-40
NS (n=15)	7	23-34	8	19-32
NP (n=20)	9	21-74	11	25-50
LP (n=20)	13	17-71	7	19-80

RP: respiratory physiologists; NS: naive subjects; NP: patients with normal static inspiratory pressures; LP: patients with low static inspiratory pressures [4].

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].

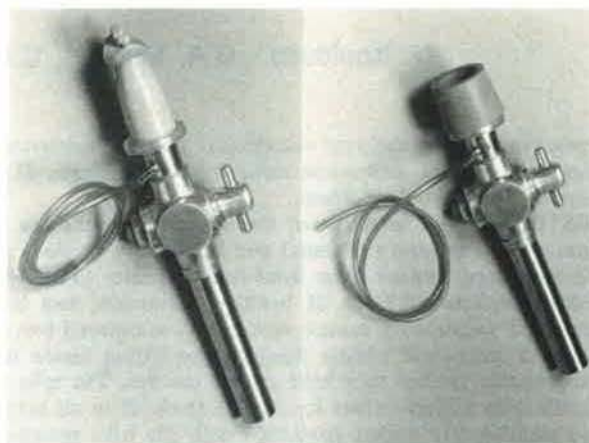


Fig. 1. - Detail of mouthpieces used in the present study: rubber tube (right), flanged (left) and the common stem.

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-Elcoma, 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. The

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

Mouthpiece	P_{imax} kPa		P_{Emax} kPa	
	Flanged	Tube	Flanged	Tube
RP (n=6)	11.7 \pm 3.6	12.3 \pm 4.8	13.8 \pm 5.5 *	17.5 \pm 6.14
NS (n=15)	9.7 \pm 3.0	10.5 \pm 3.9	14.0 \pm 3.8 **	16.2 \pm 3.9
NP (n=20)	8.3 \pm 3.1 **	9.1 \pm 3.2	11.5 \pm 4.2 **	13.9 \pm 4.6
LP (n=20)	4.0 \pm 1.3	4.3 \pm 1.5	8.2 \pm 3.5 *	9.3 \pm 3.7

RP: respiratory physiologists; NS: naive subjects; NP: patients with normal static inspiratory pressure [4]; LP: patients with low static inspiratory pressure [4]; *: $p < 0.02$; **: $p < 0.005$ (paired t-test); P_{Emax} : maximum static expiratory pressure; P_{imax} : maximum static inspiratory pressure; mean \pm s.d.

Table 4. – Comparison of mouthpiece design in all 41 subjects without weakness

Mouthpiece	P _{imax} kPa		P _{emax} kPa	
	Flanged	Tube	Flanged	Tube
	9.3±3.3	** 10.1±3.8	12.8±4.3	** 15.3±4.7

P_{EMAX}: maximum static expiratory pressure; P_{IMAX}: maximum static inspiratory pressure; ** p<0.005 (paired t-test); mean ±SD.

Table 5. – Pressures recorded by 21 normal volunteers analysed by sex

	P _{imax} kPa		P _{emax} kPa	
	Flanged	Tube	Flanged	Tube
Female (n=10)	8.4±2.4	8.8±2.5	11.5±3.1	14.2±4.3
Male (n=11)	12.0±3.1	13.1±4.4	16.2±3.8	18.7±3.6

P_{EMAX}: maximum static expiratory pressure; P_{IMAX}: maximum static inspiratory 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 P_{EMAX} or P_{IMAX} 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 RINGQVIST [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 P_{EMAX} mean values were significantly higher (p<0.02) for the tube mouthpiece in all four sub-groups (table 3). For P_{IMAX} the values were significantly higher (p<0.005) with the tube mouthpiece only in the sub-group of patients (NP) who could generate normal in-

spiratory 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 P_{IMAX} and P_{EMAX} (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 VINCEN *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 expiratory 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 P_{EMAX} with the two mouthpieces, and could not explain the differences in P_{IMAX}. 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

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

	P _{imax} kPa	P _{Emax} kPa
Male volunteers (n=23)	12.2±0.7	20.5±1.3
Male conscripts (n=33)	15.1±1.3	23.2±1.2

P_{Emax}: maximum static expiratory pressure; P_{imax}: maximum static inspiratory pressure. Mean ±SD.

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 ease 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 P_{imax} and P_{Emax} may be explained in part by the choice of mouthpiece and the way in which it was used.

References

- Green M. — Respiratory muscle testing. *Bull Eur Physiopathol Respir*, 1984, 20, 433–436.
- Moxham J. — Function and fatigue of the respiratory muscles. *In: Advanced medicine* 18, M. Sarnar ed., Pitman Medical, London, 1982, pp. 127–137.
- Ringqvist T. — The ventilatory capacity in healthy subjects: an analysis of causal factors with special reference to the respiratory forces. *Scand J Clin Invest*, 1966, 18 (Suppl. 88), 8–170.
- Black LF, Hyatt RE. — Maximal respiratory pressures: normal values and relationships to age and sex. *Am Rev Respir Dis*, 1969, 99, 696–702.
- Rochester DF, Arora NS. — Respiratory muscle failure. *Med Clin North Am*, 1983, 67 (3), 573–598.
- Leech JA, Ghezzi H, Stevens D, Bechlake MR. — Respiratory pressures and function in young adults. *Am Rev Respir Dis*, 1983, 128, 17–23.
- Wilson SH, Cooke NT, Edwards RHT, Spiro SG. — Predicted normal values for maximal respiratory pressures in caucasian adults and children. *Thorax*, 1984, 39, 535–538.
- Vincken W, Ghezzi H, Cosio MG. — Maximal static respiratory pressures in adults: normal values and their relationship to determinants of respiratory function. *Bull Eur Physiopathol Respir*, 1987, 23, 435–439.
- Cook CD, Mead J, Orzalesi MM. — Static volume pressure characteristics of the respiratory system during maximum efforts. *J Appl Physiol*, 1964, 19, 1016–1021.
- Laporta D, Grassino A. — Assessment of transdiaphragmatic pressure in humans. *J Appl Physiol*, 1985, 58, 1468–1476.
- Mead J, Milic-Emili J, Turner JM. — Factors limiting the depth of a maximal inspiration in human subjects. *J Appl Physiol*, 1963, 18, 295–296.

RÉSUMÉ: Nous avons investigué l'effet de la forme d'une pièce buccale sur les pressions buccales maximales statiques expiratoires (P_{Emax}) et inspiratoires (P_{imax}). Nous avons mesuré P_{Emax} à partir de la capacité pulmonaire totale et

P_{imax} 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 buccales 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 P_{emax} ($p < 0.02$) chez tous les sujets. P_{imax} est également sig-

nificativement plus élevée ($p < 0.005$) 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 buccale et la manière dont elle est utilisée.