

Peak Inspiratory Mouth Pressure in Healthy Subjects and in Patients With COPD*

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The validity of peak inspiratory mouth pressure (P.PImax) as a measure of inspiratory muscle strength was investigated by comparing it with sniff Pes in patients with COPD with respect to (1) learning effect, (2) reproducibility, and (3) measures of agreement. To assess the discriminating capacity of P.PImax, we compared the values in patients with COPD with those of healthy elderly subjects. Thirty-four patients (mean age, 62.5 years) with severe airways obstruction (FEV₁, 44% predicted; FEV₁/IVC, 37% predicted) and 149 healthy subjects (age \geq 55 years) were included. P.PImax was assessed during a maximal static inspiratory maneuver, while sniff Pes was assessed during a maximal sniff maneuver. Both maneuvers were performed from residual volume ten times on the same day. P.PImax showed no learning effect, while the sniff maneuver used seven attempts to obtain a maximal value. The intraindividual coefficients of variation of P.PImax and sniff Pes were

Conventionally, inspiratory muscle strength has been assessed by maximal inspiratory mouth pressure sustained for 1 s (PImax) during a maximal static maneuver against a closed shutter.¹⁻⁵ However, PImax is poorly reproducible with an average coefficient of variation of 25%.⁶ Furthermore, Smyth et al⁷ showed substantial and significant variations in reported normal values for PImax.

In the present study, we investigated whether instantaneous peak inspiratory mouth pressure during a maximal static maneuver (P.PImax) is a valid assessment of inspiratory muscle strength. Especially in patients with respiratory failure, only P.PImax can be measured during a maximal static maneuver, because these patients cannot sustain their pressure.^{8,9}

We compared P.PImax with the sniff maneuver, during which pressure can be measured at the mouth (Pmo),¹⁰ in the esophagus (Pes),¹⁰ and across the di-

aphragm (Pdi).^{11,12} Miller et al¹² showed that the sniff method was more reproducible than the static PImax. Because sniff Pes is an invasive method, Koulouris et al¹⁰ advocated the noninvasive sniff Pmo. They showed that sniff Pmo was comparable with sniff Pes in healthy subjects.¹⁰ However, sniff Pmo may underestimate sniff Pes in patients with altered lung mechanics due to increased airway resistance.

CV=coefficient of variation; IVC=inspiratory vital capacity; Pdi=pressure across diaphragm; Pes=pressure in esophagus; PImax=maximal inspiratory mouth pressure; Pmo=pressure at mouth; RV=residual volume; P.PImax=peak inspiratory mouth pressure

Key words: COPD; normal values; peak inspiratory mouth pressure; validity

The aim of our study was to investigate whether the noninvasive P.PImax is a valid assessment of inspiratory muscle strength by comparing it with sniff Pes in patients with COPD with respect to (1) learning effect (defined as the number of attempts needed to achieve the maximal value), (2) reproducibility, and (3) measures of agreement. Furthermore, to assess the discriminating capacity of peak inspiratory mouth pressure, we compared P.PImax in a group of patients with COPD with P.PImax in a group of healthy elderly subjects, comparable for age and gender. The latter group was aselectively drawn from a large population of healthy elderly subjects.

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METHODS

Patients With COPD

We studied 34 patients with known COPD, according to the American Thoracic Society criteria,¹³ at the start of a pulmonary

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rehabilitation program. All patients were in a clinical stable condition with optimal drug management. Entry criteria were (1) FEV₁ <60% predicted and (2) FEV₁/IVC (inspiratory vital capacity) <50% both after bronchodilation with two inhalations of 40 µg of ipratropium bromide. The study was approved by the medical ethics committee of the University Hospital of Groningen and all patients gave informed consent.

Healthy Subjects

We studied 248 subjects (121 male and 127 female subjects) aged ≥55 years. Subjects were randomly drawn from a sample of the general population of the province of Drenthe in the Netherlands, and they participated in a larger investigation regarding the health status of elderly subjects. A healthy subject was defined in our study according to the following functional criteria: FEV₁ (forced expiratory volume in 1 s) ≥ FEV₁, pred -1.64 SD and FEV₁/IVC ≥ FEV₁/IVC, pred -1.64 SD. Reference values are those of the European Community for Coal and Steel.¹⁴

In patients with COPD, lung function was assessed by static lung volumes, FEV₁, IVC, diffusion capacity, volume-pressure relationship, and static compliance. Inspiratory muscle strength was assessed by both P.PImax and maximal sniff esophageal pressure (sniff Pes). In healthy subjects, lung function was assessed by FEV₁ and IVC, while inspiratory muscle strength was assessed by peak inspiratory mouth pressure (P.PImax).

Static lung volumes were determined in a constant-volume whole-body plethysmograph (Jaeger, Würzburg, Germany). Spirometry was performed by a pneumotachograph (Jaeger) in patients with COPD, and by a water-sealed spirometer (Lode, Groningen, the Netherlands) in healthy subjects. Transfer factor for carbon monoxide (TLCO) was measured by the single breath method. Volume/pressure (V-P) diagrams of the lungs were recorded using an esophageal balloon. Static compliance was calculated from the V/P diagram.

P.PImax was measured by a pressure transducer (Hewlett Packard GmbH, 782018, Homburg, Germany). All patients were seated, wore a noseclip, and carried out their maximal inspiratory maneuvers from residual volume (RV). They performed against a closed shutter through an oval flanged mouthpiece with a leak of 2.0 mm diameter to prevent using the buccinator muscles.

Sniff Pes was assessed by using a 10-cm balloon, containing 0.5 mL of air and positioned in the middle of the esophagus, 40 cm from the anterior nares. The balloon was connected to a pressure transducer (Hewlett Packard GmbH, 782018, Homburg, Germany). All patients were seated and the esophageal pressure was measured during a maximal sniff (short sharp sniff as hard as possible) with the mouth closed from RV.¹²

Both P.PImax and sniff Pes were carried out ten times in patients with COPD, while P.PImax was assessed five times in healthy subjects. There was at least 20 to 30 s rest between each measurement and all assessments were recorded. In all sessions, the display in front of the patient provided visual feedback. None of the patients and healthy subjects had previously performed these inspiratory maneuvers. Before each measurement, the pressure transducer was calibrated with a reference instrument (Gambro KO7046, Gambro AB, Lund, Sweden) and ambient pressure was used as zero level.

Statistical Analysis

Learning effects of both P.PImax and sniff Pes were determined by measuring the mean difference between the values obtained in consecutive attempts in each method (MANOVA repeated measurements). Reproducibility of P.PImax and sniff Pes was assessed by the intraindividual variation coefficient, determined with analysis of variance (ANOVA) (with as dependent variables P.PImax and sniff Pes, and as independent variables

patient number and attempt number). The last four attempts of both P.PImax and sniff Pes were used for the calculation of this coefficient to exclude learning effects. The highest achievable P.PImax or sniff Pes was used for further comparative analyses.

Quantitative relationship between P.PImax and sniff Pes was assessed with measures of agreement described by Bland and Altman.¹⁵ The strength of the relation between P.PImax and sniff Pes was assessed by Pearson's correlation coefficient (r). The mean difference between P.PImax and sniff Pes in the patients with COPD was determined with the paired Student's *t* test. The mean difference between P.PImax in healthy subjects and P.PImax in patients with COPD was determined by the unpaired Student's *t* test. Significance level was set at 5%. Kolmogorov-Smirnov (K-S) test was used to investigate whether the variables showed a normal distribution.

RESULTS

All variables showed no deviation from a normal distribution.

Patients With COPD

Table 1 presents the characteristics of 34 patients with COPD. All had severe airflow limitation (mean FEV₁, 44% of predicted; mean FEV₁/VC, 37%). P.PImax and sniff Pes were 8.0 ± 2.5 kPa (mean ± SD) and 8.3 ± 1.9 kPa, respectively.

Learning Effects and Intraindividual Variation

The intraindividual variability of P.PImax and sniff Pes, expressed as coefficient of variation, in patients with COPD was 11.2% and 6.0%, respectively. Assessments of learning effects in P.PImax and sniff Pes are shown in Figure 1. There was a significant difference between the first and highest (ninth) attempt (average difference being 1.74 kPa, *p*<0.001) of the sniff Pes. From the seventh measurement onward, there was no significant difference (<5% increase, *p*>0.05). None of the attempts of P.PImax showed significant differences with the highest (fourth) attempt.

Table 1—Characteristics of the Study Population*

	COPD	Healthy
Sex, M/F	30/4	72/77
Age, yr	62.5 (5.1)	65.6 (7.7)
FEV ₁ b, L	1.2 (0.3)	2.6 (0.6)
FEV ₁ a, L	1.3 (0.4)	NA
FEV ₁ , %pred	44.3 (10.6)	99.1 (14.1)
IVC, L	3.6 (0.9)	3.4 (0.9)
FEV ₁ /IVC, %	37.8 (7.7)	77.3 (6.4)
TLC, %pred	116.0 (14.1)	NA
RV, %pred	166.5 (20.2)	NA
TLCO, %pred	74.1 (24.5)	NA
Cst, L/kPa	4.5 (3.1)	NA

*All values are expressed as mean (SD); NA=not assessed; FEV₁b=forced expiratory volume in 1 s before bronchodilation; FEV₁a=FEV₁ after bronchodilation; % pred=expressed as a percentage of the predicted value; RV=residual volume; TLC=total lung capacity; TLCO=transfer factor for carbon monoxide; Cst=static lung compliance.

Table 2—Peak Inspiratory Mouth Pressure in Healthy Subjects*

Age, yr, Range	Male		Female	
	No.	P.PImax	No.	P.PImax
55-64	38	11.0 (3.3)	38	8.8 (2.7)
65-74	22	8.7 (2.4)	25	8.2 (2.1)
75-94	12	7.9 (2.7)	14	5.4 (2.0)

*Values are mean (SD).

male groups (Table 2). P.PImax in female subjects aged ≥ 75 years was significantly lower ($p < 0.001$) compared with both younger female groups. The values in female subjects were about 80% of the values of the male subjects. In the male subjects as well as in the female subjects, there was a significant correlation between P.PImax and age: $r = -0.40$ ($p < 0.001$) and $r = -0.43$ ($p < 0.001$), respectively.

P.PImax in Patients With COPD and Healthy Subjects

P.PImax of male and female healthy subjects aged ≤ 65 years were used as a control group for the comparison with male and female patients with COPD. P.PImax was significantly ($p < 0.001$) lower in male patients with COPD compared with healthy male subjects: 8.2 (2.6) and 11.0 (3.3), respectively. Twenty-one male subjects had a P.PImax higher than 11.0 kPa (19 healthy subjects and 2 patients with COPD), while 22 male subjects had a P.PImax lower than 8.2 kPa (7 healthy subjects and 15 patients with COPD). P.PImax in female patients with COPD was significantly ($p < 0.05$) lower compared with healthy female subjects: 6.2 (1.4) and 8.8 (2.7), respectively.

DISCUSSION

This study shows that P.PImax had no learning effect, an acceptable intraindividual variation, and an acceptable agreement with sniff Pes in patients with COPD. Furthermore, the P.PImax in healthy subjects is significantly higher than P.PImax in patients with COPD of comparable age and gender.

As for the learning effect, patients with COPD needed only two attempts to achieve their maximal P.PImax, while seven attempts are needed for the sniff maneuver. This indicates that patients learn the P.PImax maneuver more easily than the sniff maneuver. The learning effect of P.PImax is in accordance with the observed three necessary attempts to obtain PImax in COPD in the study of Larson et al,¹⁶ who use also a flanged mouthpiece. In contrast with the latter study, it was shown that PImax in patients with COPD showed a plateau after nine attempts.¹⁷ However, a good comparison among the three studies is not possible, because we measured P.PImax while the other two studies measure PImax.^{16,17}

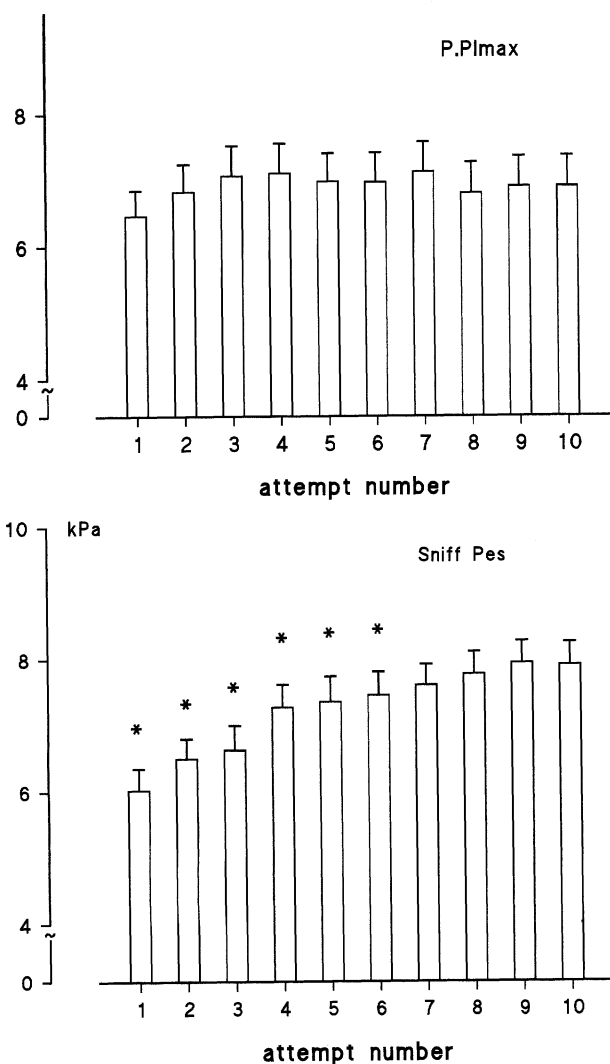


FIGURE 1. *Top*, Mean (\pm SEM) of the P.PImax by consecutive attempt number. *Bottom*, Mean (\pm SEM) of the sniff Pes by consecutive attempt number. Asterisk= $p < 0.05$ compared with the highest value.

Quantitative Relationship Between P.PImax and Sniff Pes

The mean difference between P.PImax and sniff Pes in patients with COPD was 0.29 kPa ($p = 0.49$), while the 95% confidence of the mean was -0.44 ; 1.04. The Pearson's correlation coefficient between P.PImax and sniff Pes was 0.57 ($p < 0.001$).

Healthy Subjects

We screened 248 subjects (121 male and 127 female subjects). Forty-nine male subjects (40%) and 50 female subjects (39%) were excluded because of low FEV₁ and/or FEV₁/IVC. Therefore, 72 male and 77 female healthy subjects (Table 1) took part in the assessment of reference values of P.PImax. P.PImax was significantly ($p < 0.01$) higher in the male subjects aged ≤ 64 years compared with both older

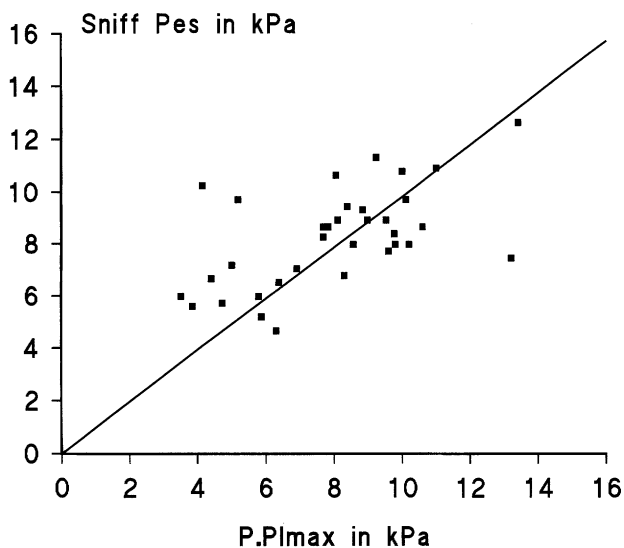


FIGURE 2. The relationship between P.PImax and sniff Pes.

Furthermore, Fiz et al¹⁷ did not mention the type of mouthpiece they used, which may influence PImax values.

The intraindividual coefficient of variation (CV) of P.PImax (11.2%) was higher than sniff Pes (6.0%). Both CVs are comparable with two other studies investigating inspiratory muscle strength.^{2,12} Wilson et al² showed that the CV of PImax is 10.2%, assessed in five healthy subjects for 5 days. In the study of Miller et al,¹² the within-subject variation was assessed three times on three occasions for three consecutive days in eight healthy subjects. They found that the transdiaphragmatic pressure (Pdi) during a PImax method was more variable (CV=13%) than Pdi during a sniff (CV=7.2%). Since it may be expected that the CV in COPD is generally larger, we conclude that P.PImax has an acceptable intraindividual CV.

We found an acceptable agreement between P.PImax with sniff Pes (Fig 2). As far as we know, only Heritier et al⁸ assessed P.PImax in patients with respiratory failure and compared it with sniff Pmo. They showed that sniff Pmo underestimates inspiratory muscle strength compared with P.PImax. According to these authors, this may be due to the fact that sniff Pmo may underestimate inspiratory muscle strength due to impaired transmission of pleural pressure in the presence of airway obstruction.¹⁸ However, this lower sniff Pmo compared with the PImax maneuver was also shown in healthy subjects.¹⁹ Therefore, it is better to compare P.PImax with sniff Pes, because the latter provides a good reflection of inspiratory muscle strength.⁸ To our knowledge, our study is the first investigating both methods and showing an acceptable agreement be-

tween P.PImax and sniff Pes in patients with COPD.

Although no reference values of P.PImax are available, several studies have provided reference values of PImax.¹⁻⁵ These studies show the influence of age,¹⁻³ gender,¹⁻⁵ and type of mouthpiece used in the maneuver.²⁰ Assuming that these influences are also valid for P.PImax, we assessed P.PImax in healthy elderly subjects and stratified our patients for age and gender. We found that P.PImax is lower in female subjects compared with male subjects and that P.PImax decreases with age. This is in agreement with studies investigating PImax¹⁻⁵ instead of P.PImax.

Because of the influence of age and gender on P.PImax, we compared P.PImax in patients with COPD with P.PImax in healthy subjects of comparable age and gender. We found a significantly lower P.PImax in patients with COPD, being 73% of the control group, although there is a considerable overlap between healthy subjects and patients with COPD when P.PImax is below 11.0 kPa. A P.PImax higher than 11 kPa occurred in 19 healthy subjects and only 2 patients with COPD. We believe that a P.PImax of at least 11.0 kPa can be considered as normal inspiratory muscle strength, while a P.PImax lower than 11.0 kPa may indicate weak inspiratory muscle strength. Morrison et al²¹ found a significantly lower PImax in patients with COPD compared with healthy subjects of the same age, being 64% predicted. This is comparable with another study²² finding a PImax in patients with COPD of 56% predicted. The difference between our study and the other studies^{21,22} may be due to a lower degree of hyperinflation in our patients. Previous investigations showed that PImax decreases with higher TLC expressed as percent predicted.²² However, the less favorable position of the diaphragm in patients with COPD compared with healthy persons is not the only reason for an impaired inspiratory muscle strength in patients with COPD. Rochester and Braun²² showed that generalized muscle weakness in patients with COPD contributes to a low inspiratory muscle strength next to hyperinflation.

Our study shows that P.PImax is a valid method to assess inspiratory muscle strength. Moreover, P.PImax is a noninvasive method and it takes less time to obtain a maximum value compared with the sniff maneuver. These results support the clinical utility of P.PImax to assess inspiratory muscle strength in two different circumstances. On the one hand, P.PImax can be easily measured during routine follow-up of ambulant patients with COPD. On the other hand, P.PImax is a good method to assess inspiratory muscle strength in patients with respiratory failure who cannot undergo an invasive assessment of inspiratory muscle strength due to respiratory distress.

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