Eur Respir J 2001; 17: 688–695
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European Respiratory Journal
ISSN 0903-1936

Whistle mouth pressure as test of expiratory muscle strength

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Whistle mouth pressure as test of expiratory muscle strength. A. Chetta, M.L. Harris, R.A. Lyall, G.F. Rafferty, M.I. Polkey, D. Olivieri, J. Moxham. ©ERS Journals Ltd 2001.

ABSTRACT: Expiratory muscle strength is a determinant of cough function. Mouth pressures during a maximal static expiratory effort ($P_{E,max}$) are dependent on patient motivation and technique and low values are therefore difficult to interpret. This study hypothesized that a short, sharp and maximal expiration through a narrow aperture, a "whistle", might provide a complementary test of expiratory muscle strength.

To obtain a maximal whistle, subjects (27 healthy volunteers and 10 patients with amyotrophic lateral sclerosis) were asked to perform a short, sharp blow as hard as possible, from total lung capacity, through a reversed paediatric inhaler whistle, connected to a flange-type mouthpiece.

In both healthy subjects and patients, whistle mouth pressure ($P_{mo,W}$) was closely related to the pressure measured in the oesophagus and stomach during the same manoeuvre. In healthy subjects, $P_{mo,W}$ and $P_{E,max}$ correlated with wide limits of agreement, although $P_{mo,W}$ values were significantly higher than $P_{E,max}$ (131±31 cmH_2O *versus* 101±27 cmH_2O, $p<0.0001$). In patients, it was also found that $P_{mo,W}$ and $P_{E,max}$ values were strongly related ($r=0.937$, $p<0.0001$). In healthy subjects, the intraclass correlation coefficient and the variation coefficient for $P_{mo,W}$ repeated measurements were respectively 0.88 and 7.0%. However $P_{mo,W}$ and $P_{E,max}$ were always smaller than the gastric pressure generated by a maximal cough.

It is concluded that mouth whistle pressure, a noninvasive, reproducible and simple test, provides a reliable measure of expiratory muscle strength in healthy subjects that is acceptable to patients and can be used in a complementary fashion to maximal static expiratory effort.

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Keywords: Expiratory muscle strength
respiratory muscles
respiratory pressures
whistle mouth pressure test

Received: June 19 2000
Accepted after revision November 13 2000

Chest infection is a cause of serious morbidity and mortality in patients with respiratory and neuromuscular disease. Cough is considered to protect against chest infection and it has recently been shown that expiratory muscle strength is an important determinant of an effective cough [1]. Techniques to evaluate expiratory muscle strength are therefore of interest.

Mouth pressures during maximal static expiratory ($P_{E,max}$) efforts are widely used as a noninvasive test to assess expiratory muscle strength [2]. When high values are found, muscle weakness is excluded [3]. However, the normal range for $P_{E,max}$ is wide [2, 4], reflecting both the biological variability of respiratory muscle strength and also the difficulty some subjects have in performing the manoeuvre maximally. In the assessment of inspiratory muscle strength it has been shown that the use of a manoeuvre complementary to the static effort, such as the maximal sniff, can exclude inspiratory muscle weakness [5, 6]. Indeed sniffing is a natural manoeuvre which is more easily performed than static efforts, and by measuring the upper airway pressure during a maximal sniff, inspiratory muscle strength may now be accurately measured noninvasively [7] in a variety of clinical settings [8].

It was therefore reasoned that an additional test of expiratory muscle strength that was noninvasive, using a natural, uncomplicated manoeuvre, could be clinically useful. The main muscles of expiration are the abdominal muscles and one approach to measuring their strength is to record gastric pressure during a maximal cough [1] or following magnetic nerve stimulation posteriorly at the level of the 10th thoracic intervertebral space [9]. However, both these tests require passage of a gastric balloon catheter. The present authors hypothesized that a test using pressure measured at the mouth during a short, sharp and maximal expiration through a narrow aperture (a "whistle") would be a relatively natural manoeuvre that might be a useful additional noninvasive test of expiratory muscle strength. The main purpose of the study was to ascertain in healthy subjects, and in patients with respiratory muscle weakness, whether the measurement of mouth pressure during a whistle manoeuvre ($P_{mo,W}$) is reproducible, and whether mouth whistle was pressure closely reflects oesophageal and gastric pressures. In addition, the study aimed to compare mouth, oesophageal and gastric pressures during whistle and $P_{E,max}$ manoeuvres, as well as to compare whistle mouth pressure to gastric pressure, during a maximum cough.

Methods

Twenty-seven healthy volunteers (10 male) and 10 patients (all male) with amyotrophic lateral sclerosis (ALS) were studied. The severity of ALS was assessed by the Norris limb and bulbar scales [10] and by the ALS functional rate scale [11]. The study was approved by the hospital ethics committee and all subjects gave their informed consent.

Spirometry was measured by a horizontal bellows spirometer (Vitalograph Ltd, Buckingham, UK) and vital capacity (VC), forced expiratory volume in one second (FEV1) and FEV1/VC values were recorded. Predicted values of VC and FEV1 were obtained from regression equations by QUANJER *et al.* [12].

In order to obtain a maximal whistle, subjects were asked to perform a short, sharp blow as hard as possible from total lung capacity (TLC) through a reversed paediatric inhaler whistle (Astra Pharmaceuticals Ltd, Herts, UK) connected to a flange-type mouthpiece gripped between the teeth (fig. 1). Subjects performed whistles without a noseclip. Additionally, healthy subjects were asked to perform maximum whistles while holding their cheeks. Whistles suitable for analysis had to present pressure tracings showing a sharp peak and a duration of <500 ms. This was usually achieved after 3–6 whistle manoeuvres. Healthy subjects were also asked to perform whistles of varying intensities. Repeatability of whistle mouth pressure ($P_{mo,W}$) in healthy subjects was assessed by repeating measurements on two separate days. The whistle device had a linear relationship between resistance and flow across the range 10–100 $L \cdot min^{-1}$. The mean (range) value for peak flow through the device for healthy subjects was 92 $L \cdot min^{-1}$ (78–109 $L \cdot min^{-1}$). The resistance over this range was 29.3–44.4 $cmH_2O \cdot L^{-1} \cdot s$.

$P_{E,max}$ and maximal static inspiratory effort ($P_{I,max}$) were performed against a valve based on that used by BLACK and HYATT [4] which could be closed by turning a tap. A leak 3.7 cm in length and 0.2 cm in diameter was placed 3 cm from the mouthpiece to reduce discomfort and generation of high buccal pressures [13]. A conventional flanged mouthpiece and noseclip were used. $P_{E,max}$ was measured from TLC and $P_{I,max}$ from residual volume. The highest recorded pressures maintained for one second were used for analysis. Patients attempted to prevent perioral leak by holding their lips firmly around the mouthpiece with both hands. Day-to-day reproducibility of $P_{E,max}$ was assessed in the healthy subjects.

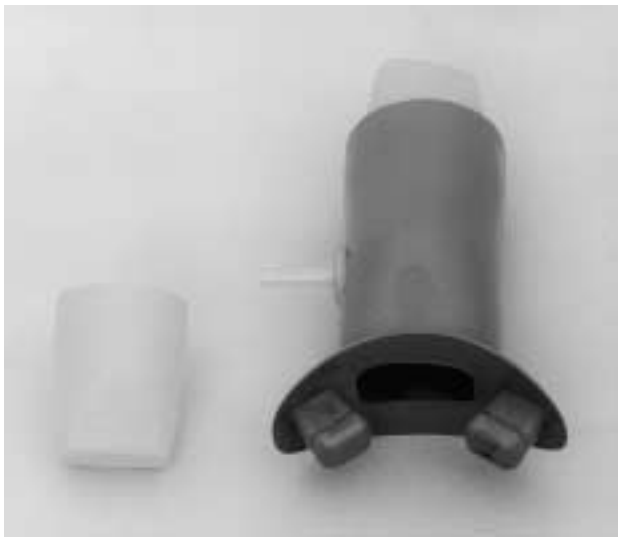

Fig. 1. – The whistle device consists of a reversed paediatric inhaler whistle connected to a conventional mouthpiece.

Gastric (P_{ga}), oesophageal (P_{oes}) and transdiaphragmatic (P_{di}) pressures were measured using a pair of commercially available latex balloon catheters (PK Morgan, Rainham, Kent, UK) 110 cm in length, passed through the nose and positioned in the stomach and oesophagus in the conventional manner [14]. The oesophageal balloon contained 0.5 mL air, the gastric balloon 2 mL.

P_{ga} during a maximum voluntary cough effort, was also measured in healthy subjects and patients. This manoeuvre was performed in a seated position without a noseclip. Invariably, subjects inhaled deeply before coughing, but no specific instructions were given regarding the magnitude of inspiration before cough. Repeated efforts were performed until no further increase in P_{ga} was obtained (usually achieved after 3–6 coughs).

The whistle device, the mouth piece and the balloon catheters were connected to differential pressure transducers (Validyne MP45-1, Validyne, Northridge, CA, USA), carrier amplifiers (PK Morgan), a 12 bit NB-MIO-16 analogue-digital board (National Instruments, Austin, TX, USA) and a Macintosh Quadra Centris 650 personal computer (Apple Computer Inc., Cupertino, CA, USA) running Labview™ software (National Instruments). P_{di} was obtained on-line, by subtraction of P_{oes} from P_{ga}. A minimum sampling frequency of 100 Hz was used. Peak pressures were taken as those measured from the baseline at relaxed end-expiratory lung volume, at the peak pressure, obtained.

Healthy subjects and patients were studied in the seated position and pressures were displayed on a computer screen in front of the subject to provide visual feedback [15]. Subjects were strongly encouraged to make maximal efforts.

Data are presented as mean±SD. VC and FEV1 values were expressed as per cent of predicted value, FEV1/VC is expressed as per cent. Differences in numerical data were examined by means of paired t-tests. The agreement between measures was assessed by the method of differences against the means according to BLAND and ALTMAN [16]. The relationship between measures was assessed by Pearson′s correlation coefficient (r) and linear regression analysis. The repeatability of measures was expressed as intraclass correlation coefficient (rI) [17] and assessed by calculating the coefficient of variation. A p-value <0.05 was considered statistically significant.

Results

Healthy subjects

Personal details were: age, 32±6 yrs; height, 170±10 cm; weight, 68±13 kg; and body mass index, 24±4

$kg \cdot m^{-2}$. Spirometric values were: VC, 104±13% pred; FEV_1, 104±14% pred; FEV_1/VC, 83±7%.

In the 27 healthy subjects, $P_{mo,W}$ and $P_{E,max}$ values were 131±31 cmH_2O (range 77–202 cmH_2O) and 101±27 cmH_2O (range 44–155 cmH_2O), respectively ($p<0.0001$). The 95% confidence intervals of the mean were 119–143 cmH_2O for $P_{mo,W}$ and 90–111 cmH_2O for $P_{E,max}$. In the same group of subjects, $P_{mo,W}$ did not differ from $P_{mo,W}$ obtained while holding cheeks (139±35 cmH_2O, range 72–217 cmH_2O). The ratio $P_{mo,W}/P_{E,max}$ was 1.3 (range 0.9–2.1) and in 24 out of 27 subjects, was >1. There was a significant correlation between $P_{mo,W}$ and $P_{E,max}$ ($r=0.674$, $p=0.0001$) (fig. 2). The bias between $P_{mo,W}$ and $P_{E,max}$ was 30 cmH_2O, with $P_{mo,W}$ tending to be numerically greater than $P_{E,max}$. The limits of agreement ranged from -17–77 cmH_2O (fig. 2). The rI and the variation coefficient for $P_{mo,W}$ repeated measurements were 0.888 and 7.0%, respectively. In the same group of subjects, rI and variation coefficient for $P_{E,max}$ were 0.790 and 10.2%, respectively.

In the 12 subjects in whom P_{oes}, P_{ga} and P_{di} were measured during both the whistle and $P_{E,max}$ manoeuvres, values were respectively: $P_{mo,W}$ 139±27 cmH_2O and $P_{E,max}$ 109±27 cmH_2O ($p<0.02$), $P_{oes,W}$ 129±20 cmH_2O and $P_{oes,PE,max}$ 109±24 cmH_2O ($p<0.05$), $P_{ga,W}$ 163±36 cmH_2O and $P_{ga,PE,max}$ 160±60 cmH_2O, and $P_{di,W}$ 34±29 cmH_2O and $P_{di,PE,max}$ 50±51 cmH_2O. The ratios of $P_{mo,W}/P_{oes,W}$ and $P_{mo,W}/P_{ga,W}$ were 1.1 (range 0.95–1.23) and 0.88 (0.54–1.1), respectively. Biases between $P_{mo,W}$ and $P_{oes,W}$ (the mean of the difference between these two variables) and between $P_{mo,W}$ and $P_{ga,W}$ were 9 cmH_2O and -26 cmH_2O and limits of agreement (bias±2SD) ranged from -17–35 cmH_2O and from -83–31 cmH_2O (fig. 3).

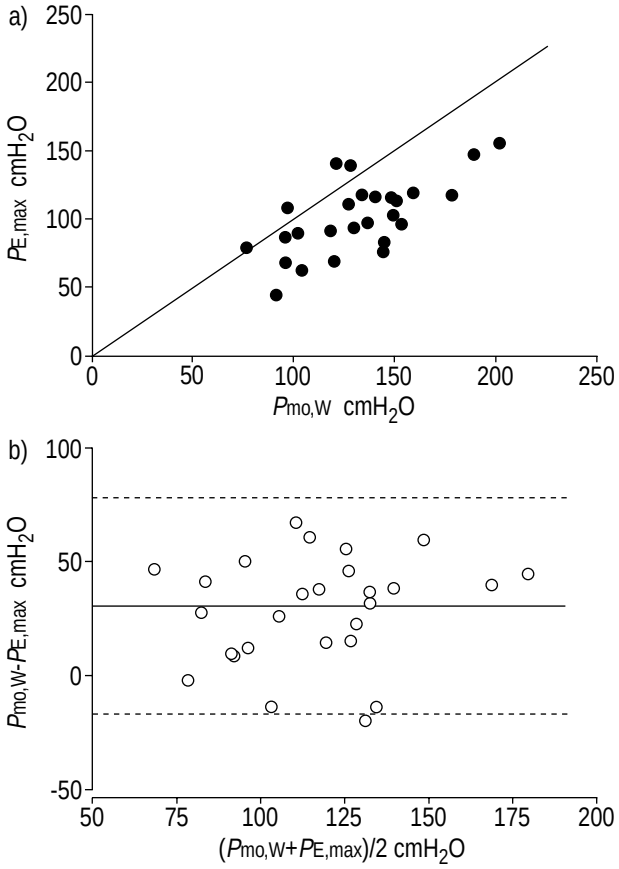

Fig. 2. – a) Relationship between mouth whistle pressure ($P_{mo,W}$) and maximum expiratory pressure ($P_{E,max}$) in 27 healthy subjects. The continuous line is the line of identity. $r=0.67$, $p=0.0001$. b) Plot of the difference between $P_{mo,W}$ and $P_{E,max}$ against the mean of $P_{mo,W}$ and $P_{E,max}$ in 27 healthy subjects. The bias, *i.e.* the mean of the difference between $P_{mo,W}$ and $P_{E,max}$ (continuous line), was 30 cmH_2O; the limits of agreement, *i.e.* bias±2SD (interrupted lines), were -17–77 cmH_2O.

In the same group of subjects, the mean value of cough P_{ga} was 201±57 cmH_2O ($p<0.01$ *versus* $P_{mo,W}$ and $P_{E,max}$) and the 95% confidence intervals of the mean were 165–238 cmH_2O. The ratios of $P_{mo,W}$/cough P_{ga} and $P_{E,max}$/cough P_{ga} were 0.73 (range 0.40–1.23) and 0.57 (0.35–0.92). Biases between $P_{mo,W}$ and cough P_{ga} and between $P_{E,max}$ and cough P_{ga} were -63 cmH_2O and -90 cmH_2O, respectively and limits of agreement ranged -167–41 cmH_2O and -193–13 cmH_2O, respectively (fig. 4). A typical example of the pressures during whistle, $P_{E,max}$ and maximal cough manoeuvres is shown in figure 5.

In the 8 subjects, in whom $P_{mo,W}$, $P_{oes,W}$ and $P_{ga,W}$ values were compared during whistles of variable intensity, $P_{mo,W}$, $P_{oes,W}$ and $P_{ga,W}$ ranged 7–222 cmH_2O, 4–161 cmH_2O and 9–235 cmH_2O, respectively. There was a significant correlation between $P_{mo,W}$ and $P_{oes,W}$ ($r=0.929$, $p<0.0001$) and between $P_{mo,W}$ and $P_{ga,W}$ values ($r=0.936$, $p<0.0001$) (table 1). Regression analysis showed that $P_{mo,W}=5.49+1.1P_{ga,W}$ and $P_{mo,W}=7.27+0.8P_{oes,W}$.

Patients

Patients had ALS of varying severity. The mean Norris limb and bulbar scales were 28±14 (range 9–50) and 35±6 (range 21–39), respectively. The mean ALS functional rating scale was 25±16 (range 13–32). Their personal details were: age, 61±5 yrs; height, 173±10 cm; weight, 73±12 kg; and body mass index, 24.4±3.7 $kg \cdot m^{-2}$. Spirometric values were: VC, 78±24 %pred; FEV_1, 76±32%pred; FEV_1/VC, 80±7%. $P_{I,max}$ values were 56±28 cmH_2O (range 15–104 cmH_2O).

The mean values of $P_{mo,W}$ and $P_{E,max}$ were 69±32 cmH_2O (range 17–128 cmH_2O) and 62±30 cmH_2O (range 11–116 cmH_2O), respectively. The 95% confidence intervals of the mean were 46–92 cmH_2O for $P_{mo,W}$ and 41–84 cmH_2O for $P_{E,max}$. The ratio $P_{mo,W}/P_{E,max}$ was 1.17 (0.87–1.55). There was a significant correlation between $P_{mo,W}$ and $P_{E,max}$ ($r=0.937$, $p<0.0001$). The bias between $P_{mo,W}$ and $P_{E,max}$ was 7 cmH_2O and the limits of agreement ranged -15–29 cmH_2O (fig. 3).

The mean P_{oes}, P_{ga}, and P_{di} values during both whistle and $P_{E,max}$ manoeuvres were 66±32 cmH_2O and 63±29 cmH_2O, 74±37 cmH_2O and 56±33 cmH_2O ($p<0.02$), and 8±7 cmH_2O and -7±10 cmH_2O ($p<0.002$), respectively. The ratios of $P_{mo,W}/P_{oes,W}$ and $P_{mo,W}/P_{ga,W}$ were 1.08 (range 0.82–1.31) and 1.17 (range 0.87–1.55). Biases between $P_{mo,W}$ and $P_{oes,W}$ and between $P_{mo,W}$ and $P_{ga,W}$ were 3 cmH_2O and -5 cmH_2O, respectively and limits of agreement ranged -10–16

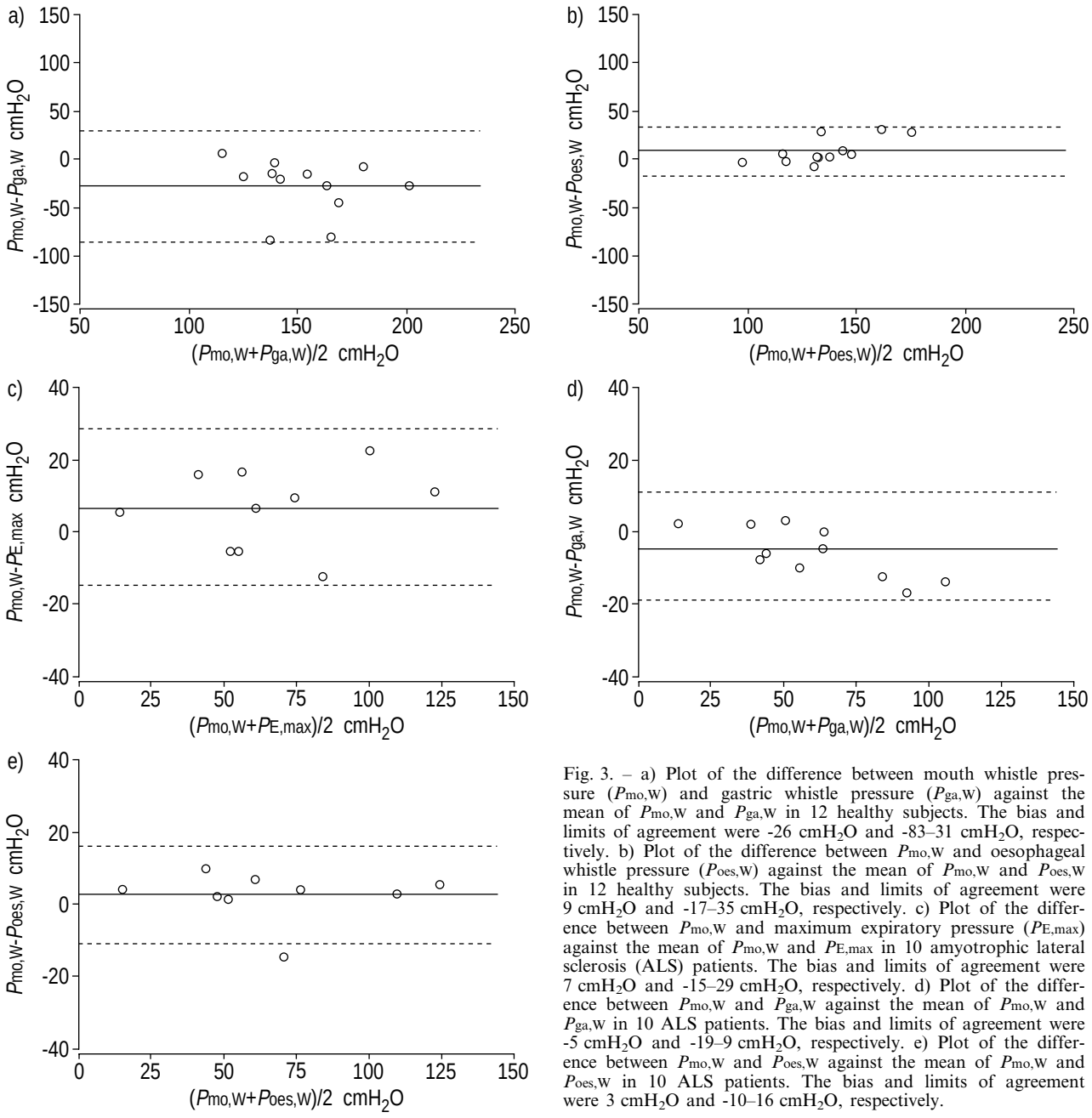

Fig. 3. – a) Plot of the difference between mouth whistle pressure ($P_{mo,W}$) and gastric whistle pressure ($P_{ga,W}$) against the mean of $P_{mo,W}$ and $P_{ga,W}$ in 12 healthy subjects. The bias and limits of agreement were -26 cmH_2O and -83–31 cmH_2O, respectively. b) Plot of the difference between $P_{mo,W}$ and oesophageal whistle pressure ($P_{oes,W}$) against the mean of $P_{mo,W}$ and $P_{oes,W}$ in 12 healthy subjects. The bias and limits of agreement were 9 cmH_2O and -17–35 cmH_2O, respectively. c) Plot of the difference between $P_{mo,W}$ and maximum expiratory pressure ($P_{E,max}$) against the mean of $P_{mo,W}$ and $P_{E,max}$ in 10 amyotrophic lateral sclerosis (ALS) patients. The bias and limits of agreement were 7 cmH_2O and -15–29 cmH_2O, respectively. d) Plot of the difference between $P_{mo,W}$ and $P_{ga,W}$ against the mean of $P_{mo,W}$ and $P_{ga,W}$ in 10 ALS patients. The bias and limits of agreement were -5 cmH_2O and -19–9 cmH_2O, respectively. e) Plot of the difference between $P_{mo,W}$ and $P_{oes,W}$ against the mean of $P_{mo,W}$ and $P_{oes,W}$ in 10 ALS patients. The bias and limits of agreement were 3 cmH_2O and -10–16 cmH_2O, respectively.

cmH_2O and -19–9 cmH_2O (fig. 3). There was a significant correlation between $P_{mo,W}$ and $P_{oes,W}$ ($r=0.980$, $p<0.0001$) and between $P_{mo,W}$ and $P_{ga,W}$ values ($r=0.990$, $p<0.0001$). Regression analysis showed that $P_{mo,W}=-5.33+1.1P_{ga,W}$ and $P_{mo,W}=-1.78+0.9P_{oes,W}$.

The mean value of cough P_{ga} was 85±39 cmH_2O ($p<0.05$ *versus* $P_{E,max}$) and the 95% confidence intervals of the mean were 57–112 cmH_2O. Ratios of $P_{mo,W}$/cough P_{ga} and $P_{E,max}$/cough P_{ga} were 0.88 (range 0.50–1.39) and 0.78 (0.44–1.36), respectively. Biases between $P_{mo,W}$ and cough P_{ga} and between $P_{E,max}$ and cough P_{ga} were -16 cmH_2O and -23 cmH_2O, respectively, and limits of agreement ranged -75–43 cmH_2O and -91–45 cmH_2O, respectively (fig. 4). There was a significant correlation between $P_{mo,W}$ and cough P_{ga} ($r=0.67$, $p<0.05$).

Discussion

The main finding of this study was that pressure measured at the mouth during a short sharp whistle has a close relationship with the pressure measured in the oesophagus and stomach during the same manoeuvre. This confirms that this measurement ($P_{mo,W}$) is a valid reflection of expiratory muscle strength. The studies, conducted in normal subjects and patients with expiratory muscle weakness, show that the limits of agreement with the $P_{E,max}$ are wide; *i.e.* high values of $P_{mo,W}$ could be obtained when $P_{E,max}$ was low and, less often, high values of $P_{E,max}$ were observed when $P_{mo,W}$ was low. This suggests that $P_{mo,W}$ and $P_{E,max}$ are complementary tests for the noninvasive evaluation of expiratory muscle strength. However, when

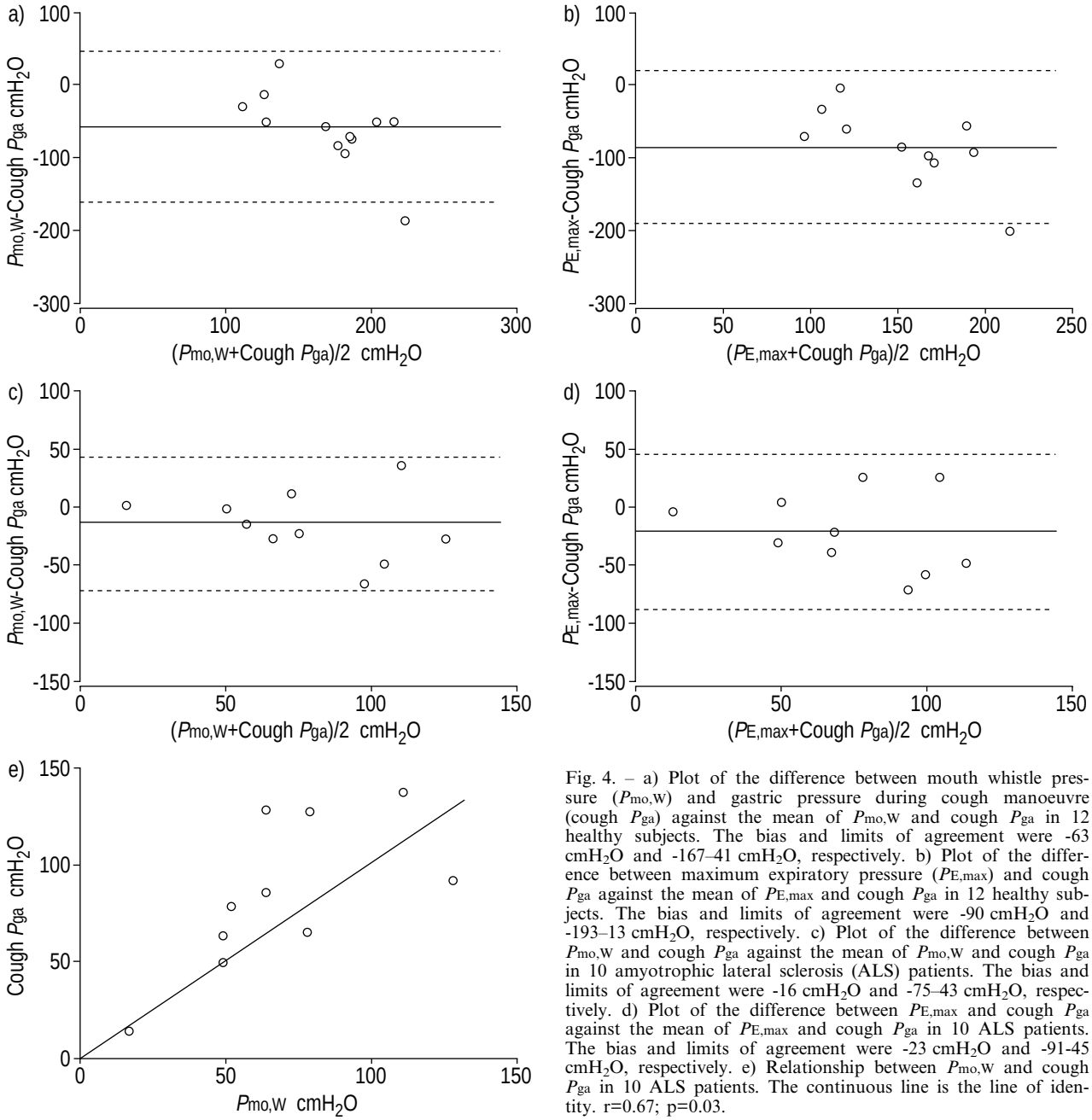

Fig. 4. – a) Plot of the difference between mouth whistle pressure ($P_{mo,W}$) and gastric pressure during cough manoeuvre (cough P_{ga}) against the mean of $P_{mo,W}$ and cough P_{ga} in 12 healthy subjects. The bias and limits of agreement were -63 cmH_2O and -167–41 cmH_2O, respectively. b) Plot of the difference between maximum expiratory pressure ($P_{E,max}$) and cough P_{ga} against the mean of $P_{E,max}$ and cough P_{ga} in 12 healthy subjects. The bias and limits of agreement were -90 cmH_2O and -193–13 cmH_2O, respectively. c) Plot of the difference between $P_{mo,W}$ and cough P_{ga} against the mean of $P_{mo,W}$ and cough P_{ga} in 10 amyotrophic lateral sclerosis (ALS) patients. The bias and limits of agreement were -16 cmH_2O and -75–43 cmH_2O, respectively. d) Plot of the difference between $P_{E,max}$ and cough P_{ga} against the mean of $P_{E,max}$ and cough P_{ga} in 10 ALS patients. The bias and limits of agreement were -23 cmH_2O and -91-45 cmH_2O, respectively. e) Relationship between $P_{mo,W}$ and cough P_{ga} in 10 ALS patients. The continuous line is the line of identity. r=0.67; p=0.03.

compared to the gastric pressure during maximal cough, both $P_{mo,W}$ and $P_{E,max}$ underestimate expiratory muscle strength. Further discussion of the significance of the findings follows a critique of the method.

Critique of the method

Do mouth measurements reflect expiratory muscle strength? The aim of the study was to develop a test which reflected abdominal muscle strength, since these muscles are the main muscles of active expiration and are an important determinant of cough function. In the present study, P_{ga} was almost invariably greater than P_{oes} during both $P_{mo,W}$ and $P_{E,max}$ indicating that the abdominal muscles are the driving force in both manoeuvres. In healthy subjects, for whom P_{oes}, P_{ga} and P_{di} were measured during both manoeuvres, P_{ga} was similar for both manoeuvres, though P_{oes} was different, resulting in higher P_{di} values with $P_{E,max}$ compared to $P_{mo,W}$. This suggests that $P_{mo,W}$ may be a more accurate reflection of abdominal muscle strength than $P_{E,max}$.

However, for the group as a whole, P_{ga} was incompletely transmitted from the abdomen to the chest; thus P_{oes} was 79% and 68% of P_{ga} during whistle and $P_{E,max}$ manoeuvres, respectively. The reduced transmission of gastric pressure could be the result of

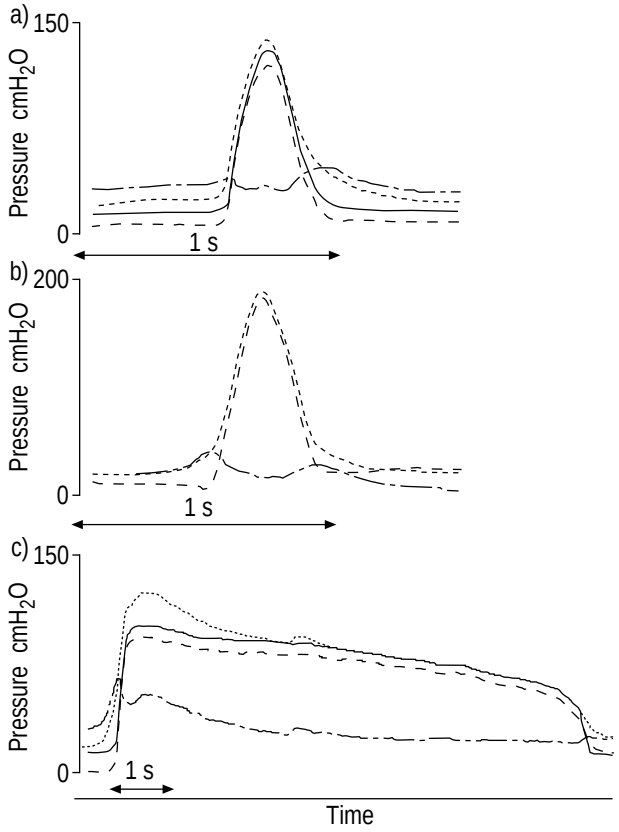

Fig. 5. – Pressures produced by: a) maximal whistle; b) maximal cough; and c) maximum expiratory pressure ($P_{E,max}$) manoeuvres by a healthy subject. —: mouth pressure; – – : oesophageal pressure; - - - : gastric pressure; — -: transdiaphragmatic pressure.

diaphragm activation and the "inspiratory" action of the abdominal muscle on the lower rib cage [19, 20]. As further confirmation that $P_{mo,W}$ closely reflects both $P_{oes,W}$ and $P_{ga,W}$, a strong correlation between $P_{mo,W}$ and $P_{ga,W}$ and between $P_{mo,W}$ and $P_{oes,W}$ was found in healthy subjects over a wide range of pressures obtained during whistles of different intensity. This predicts that the $P_{mo,W}$ test will remain valid in patients with expiratory muscle weakness, a prediction supported by the data from ALS patients shown in figure 3. Most importantly, it was found that, in patients with ALS of varying severity, $P_{mo,W}$ values strongly correlated with $P_{ga,W}$.

Dynamic nature of the manoeuvre. Unlike the $P_{E,max}$ test, which is based on a static manoeuvre, the whistle test is based on a dynamic one. With dynamic tests, concern can arise because airflow can render the manoeuvre not truly isovolumic. For the sniff this tendency is minimized because the nose acts as a Starling resistor, so that nasal flow is reduced, largely independent of driving pressure [21]. For the whistle, our *in vitro* assessment showed that flow increased with driving pressure and this might have resulted in $P_{mo,W}$ being lower than $P_{E,max}$; this was not so, indicating that the volume expired before peak pressure is not sufficient to importantly detract from the value of the test. This is because the whistle orifice acts as a resistor, substantially reducing expiratory flow. In this regard, the mean value we measured in healthy subjects for peak flow through the device, was 92 $L \cdot min^{-1}$, approximately 6–8 times lower than their peak expiratory flow rate.

Recoil pressures. $P_{E,max}$ is normally measured at TLC because subjects find it easier to maximize expiratory efforts at high volumes. In this study the whistle test manoeuvre was also performed at TLC and, at this lung volume, the pressure measured reflected both the pressure developed by the expiratory muscles and the passive elastic recoil pressure of the respiratory system. Specifically, at TLC the passive elastic recoil pressure can add up to 40 cmH_2O, equal to the pressure generated by the expiratory muscles [22]. However the whistle is a dynamic manoeuvre and recent data obtained using the peak expiratory flow [23] suggest the possibility that the recoil force generated by the chest wall might be greater in this situation than after the static manoeuvre. Whilst this might contribute to $P_{mo,W}$ being higher than $P_{E,max}$, it does not explain the wide limits of agreement and therefore does not alter our conclusion that $P_{mo,W}$ could be of value as a complementary test of expiratory muscle strength.

Facial muscles. Conceptually, the facial muscles might contribute to $P_{mo,W}$, although the orifice of the whistle should serve the same function as the mouth leak proposed by RINQVIST [13]. Consistent with this, the present study found no significant differences between $P_{mo,W}$ measurements taken with or without cheek support and it is therefore concluded that this is not a matter of practical clinical importance.

Table 1. – Values of mouth whistle pressure ($P_{mo,W}$), oesophagus whistle pressure ($P_{oes,W}$), and gastric whistle pressure ($P_{ga,W}$) during whistles ranging from minimal to maximal intensity performed by eight healthy subjects

Subject	Whistles	$P_{mo,W}$ (cmH_2O)	$P_{oes,W}$ (cmH_2O)	$P_{ga,W}$ (cmH_2O)	$P_{mo,W}/P_{oes,W}$	$P_{mo,W}/P_{ga,W}$	r $P_{mo,W}$ *versus* $P_{oes,W}$	r $P_{mo,W}$ *versus* $P_{ga,W}$
1	42	13–151	11–145	15–177	1.01 (0.08)	0.92 (0.08)	0.997	0.993
2	52	11–153	12–138	13–147	1.07 (0.07)	1.03 (0.06)	0.998	0.997
3	44	18–177	18–115	22–196	1.15 (0.20)	0.83 (0.07)	0.984	0.998
4	41	20–159	20–161	19–178	0.96 (0.05)	0.76 (0.12)	0.997	0.971
5	35	7–117	4–119	6–134	1.09 (0.19)	0.87 (0.10)	0.999	0.998
6	22	23–96	20–99	50–179	1.09 (0.08)	0.51 (0.06)	0.989	0.964
7	20	34–152	20–87	40–182	1.82 (0.39)	0.90 (0.12)	0.864	0.986
8	23	31–114	26–104	32–117	1.09 (0.07)	0.98 (0.07)	0.983	0.986
All	278	7–222	4–161	9–235	1.12 (0.25)	0.87 (0.16)	0.929	0.936

Pressure data are given as ranges and ratios as mean±SD. r: correlation coefficient.

Significance of the findings

In healthy subjects, it was found that $P_{mo,W}$ and $P_{E,max}$ values correlated with wide limits of agreement, although $P_{mo,W}$ values were significantly higher than $P_{E,max}$ and in all but three subjects the $P_{mo,W}/P_{E,max}$ ratio was >1. In ALS patients, it was also found that $P_{mo,W}$ and $P_{E,max}$ values were closely related. $P_{mo,W}$ mean values were numerically, but not statistically significantly, higher than those of $P_{E,max}$, and the $P_{mo,W}/P_{E,max}$ ratio was >1 in seven of the 10 patients.

Although the $P_{E,max}$ manoeuvre is not complicated, it is not one with which many subjects will be familiar on a daily basis and requires full cooperation from subjects. In contrast, the whistle manoeuvre may be more natural and has the advantage of audible feedback. Low $P_{E,max}$ values can occur even in healthy subjects, perhaps due to a lack of motivation or poor technique and thus may not indicate reduced expiratory muscle strength. Predicted $P_{E,max}$ values are readily available for adults, the elderly, and children [2, 24] but the normal ranges are wide, making it difficult to accurately identify weakness. In the present study, the whistle manoeuvre was easily performed, with minimal instruction, and was well accepted both by healthy subjects and ALS patients. The high mouth pressures achieved and the relatively high lower limits suggest that the $P_{mo,W}$ could be a clinically useful, additional method for assessing expiratory muscle strength. The day to day reproducibility of $P_{mo,W}$ was good, suggesting the test could also be useful for serial measurements.

The ALS patients had variable severity of disease; some had severe respiratory muscle weakness whereas others had normal strength. In the patients, as in healthy subjects, the whistle manoeuvre was found to generate gastric, oesophageal and mouth pressures that were higher than those generated at $P_{E,max}$. In particular, P_{ga} values during whistle were significantly higher than those during $P_{E,max}$, indicating that the whistle manoeuvre could better recruit abdominal muscle contraction than $P_{E,max}$. Because of the small sample size, bulbar and nonbulbar patients were not specifically compared; clearly a theoretical concern could be that bulbar patients do not achieve satisfactory transmission of pleural pressure to the mouth during a whistle.

Interestingly, in ALS patients, P_{oes} values were less than P_{ga} values during whistle, but were higher than P_{ga} values during $P_{E,max}$. This might suggest that the rib cage expiratory muscles play a different role during the two manoeuvres with a greater involvement during the $P_{E,max}$. Alternatively, one could hypothesize that the process of ALS leads to compensatory hypertrophy or recruitment of muscles not yet affected by the disease as suggested by ATTALI *et al.* [25].

$P_{mo,W}$ and $P_{E,max}$ values were significantly lower than corresponding cough P_{ga} values, both in healthy subjects and in ALS patients. Additionally, gastric pressure during whistle and $P_{E,max}$ manoeuvres was numerically lower than cough P_{ga}. The present data confirm the results of a previous paper [1] that showed that cough is the most physiological expiratory manoeuvre and that cough P_{ga} is the gold standard for measuring pressure caused by abdominal muscle contraction. However, it was also observed that the bias and the limits of agreement between $P_{mo,W}$ and cough P_{ga} were respectively smaller and narrower than those between $P_{E,max}$ and cough P_{ga}, both in patients and healthy subjects. Additionally, in ALS patients, $P_{mo,W}$ values did not significantly differ and were strictly related to cough P_{ga}. Lastly, the shape of the pressure tracings recorded during the whistle manoeuvre were very similar to those during cough (fig. 5). Considered together, these findings suggest that whistle is a manoeuvre physiologically closer to cough than $P_{E,max}$.

In conclusion, this study indicated that, in both healthy subjects and in amyotrophic lateral sclerosis patients, mouth whistle pressure is an accurate reflection of expiratory muscle strength. The limits of agreement between mouth whistle pressure and maximum expiratory pressure were wide, suggesting a role for mouth whistle pressure as an additional method for the evaluation of expiratory muscle strength, for use in both in the physiology laboratory and in clinical settings.

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