The tussometer: accuracy and reproducibility

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SUMMARY

Tussometry is a new non-invasive technique for objectively assessing laryngeal function by analysis of the airflow waveform produced by a maximum effort voluntary cough manoeuvre. We describe the technique and present the calibration data. The tussometer has been calibrated for flows of up to 1100 litre min⁻¹ using a flowmeter with a quoted accuracy of ±1.75%. The variables measured (cough peak flow rate (CPFR) and peak velocity time (PVT)) were found to be reproducible; the within-subject variability for CPFR was found to be 23.9% and for PVT 9%. There was no inter-observer variation. We found that the size of the mask used did not influence the readings obtained, providing an adequate seal was achieved. (Br. J. Anaesth. 1994; 73: 145-148)

KEY WORDS


Tussometry, described recently by one of the authors [1, 2], is a new non-invasive technique for objectively assessing laryngeal function by analysis of the airflow waveform produced by a maximum effort voluntary cough manoeuvre. This allows measurement of the peak airflow generated, designated the cough peak flow rate (CPFR) and the time taken to achieve this, peak velocity time (PVT). The principle underlying this technique is based on earlier suggestions that a cough is initiated by the rapid abduction of the arytenoid cartilages [3] and that the time to reach the peak flow generated, on a flow–time curve, during a cough is dependent on laryngeal muscle activity [4]. These suggestions were later substantiated by studies on patients with vocal cord palsies [1, 5]. The potential of tussometry in anaesthetic research has been recognized recently [6-8]. Although previous reports on the subject had a brief outline of the technique and preliminary calibration, the details have not been described previously. Here, we describe the details of the technique and present data from the investigations related to the calibration of the equipment, inter-observer and intra-subject variability of the results and the effect of different types and sizes of face mask on CPFR and PVT.

MATERIALS AND METHODS

Equipment

The tussometer comprises a face mask attached to a 25-mm diameter Lilley pneumotachograph (Mercury Electronics, Glasgow), a Gaeltec flowmeter and transducer (model number E9307), an analogue to digital converter (model uPD7002IC) and a BBC master series microcomputer. The original face mask was a modified anaesthetic mask (fig. 1) which consisted of the top half of a size 2 and the bottom half of a size 6 MIE anaesthetic mask. A rubber partition and sealant were used to separate nasal airflow from oral airflow; the pneumotachograph was connected to the lower portion thus measuring only oral airflow.

The flowmeter and transducer has a frequency response of 0–250 Hz (measured by Gaeltec, Skye) and the analogue to digital converter has a digitalization voltage of 0–2.5 V, giving a total of 255 levels. Digitization of the analogue signal is carried out at 250 Hz [manufacturer's data]. The output of the tussometer, measured as volts using a 168-autoranging multimeter (Keithley Instruments, Cleveland, OH, USA), was calibrated against that of...
a standard flowmeter (metric series tube size 47 with a Korranite float type K, Rotometer Manufacturing Co. Ltd, Croydon, UK). This has a quoted accuracy of ±1.75% and can measure flows up to 1600 litre min⁻¹. Constant flows were generated using compressed air from an air cylinder through a pressure reducing valve, which reduced the pressure to 400 kPa. The oscillations from the pressure reducing valve were damped using six heat and moisture exchange filters placed in series between the reducing valve and the rotameter. Although this reduced the oscillations of the flowmeter bobbin considerably, small oscillations were still present, particularly at the higher flow rates. Therefore, for each flowmeter setting an average of five consecutive highest and lowest readings from the voltmeter was obtained.

As a subject coughs into the face mask, the pressure differential across the pneumotachograph is used to derive air flow using the Gaeltec flowmeter. The resultant waveform is displayed, via the analogue to digital converter, on the BBC master microcomputer as a flow–time wave (fig. 2). Figure 2 shows a trace from a normal individual with a CPFR value of 420 litre min⁻¹ and a PVT value of 34 ms.

**Technique**

The technique was standardized throughout the study. The subject was seated in an upright position. The procedure was explained and two coughs made to clear any excess mucus. Each subject was then asked to perform a voluntary cough into the tightly applied face mask, taking care to prevent leaks. Each cough manoeuvre was performed after maximal inspiration and with maximum effort. Two practice attempts were made by each subject before recordings were made. As the technique may be effort-dependent, three attempts were measured and the "best" was taken as the most valid. The best effort was defined as the one with the lowest PVT value and the highest CPFR value. Occasionally the peak of the trace was rounded over two points rather than a single discrete point (fig. 3). In this situation each peak has the same CPFR value but different PVT values. The peak of the trace was taken as that with the lowest PVT value. If it was not possible to identify a peak clearly, the attempt was discounted and the manoeuvre repeated.

A series of experiments was carried out to test the reliability of the equipment. All subjects in these experiments were healthy and those with a history of atopy was excluded. None was receiving antitussive, bronchoconstrictor or bronchodilator medications.

**Inter-observer variation**

The aim of this part of the study was to investigate if a subjective element exists in the observer's assessment of CPFR and PVT. Twenty flow–time waves were selected randomly by an independent lay person unfamiliar with the technique. Four observers then independently assessed CPFR and PVT for each of these flow–time waves.

**Intra-subject variation**

The objective here was to assess the reproducibility of the technique. Twelve adult subjects performed voluntary cough manoeuvres on 15 separate occasions over a 4-week period. The coefficient of variance for each subject for both CPFR and PVT was calculated. The within-subject variability (S²W) and the between-subject (S²B) variability were obtained using one-way analysis of variance. These components were then expressed as percentages of total variability, this being the sum of the within-subject and between-subject variances.
**Mask size and type**

There were two objectives in this part of the study. First, we wished to assess the need to separate nasal and oral airflows using the modified anaesthetic mask. Second, we recognized that in order to achieve an adequate seal around the mask during a cough manoeuvre it may be necessary to use different sizes of mask for different subjects. This may influence the airflow being measured because of the difference in deadspace (and therefore gas available for compression) between masks.

Ten adult male volunteers were recruited. Each performed a voluntary cough manoeuvre into the tussometer using three different masks. Mask 1 was the modified mask described already, masks 2 and 3 were MIE anaesthetic masks of sizes 4 and 5. The CPFR and PVT readings obtained for each of the masks were compared using the two sample t test.

**RESULTS**

The oscillations from the pressure reducing valve were ±0.009 mV at a flowmeter setting of 200 litre min⁻¹ increasing to ±0.236 mV at a flowmeter setting of 1100 litre min⁻¹. The output of the tussometer was plotted against the flowmeter readings (fig. 4). This showed a strong positive relationship between these two parameters. Regression analysis produced the quadratic equations:

\[ Y = -0.01038 + 0.00086X + 1.20606 \times 10^{-6}X^2 \]

with a regression coefficient \( r = 0.99991 \) and \( P < 0.0001 \).

**Inter-observer variation**

All four observers agreed on the values for CPFR and PVT for all 20 of the flow-time waves presented. This represented an inter-observer variation of 0%.

**Intra-subject variation**

Mean weight of the subjects was 77.96 (sd 12.21) kg (range 60-98.2 kg). The coefficient of variance range for CPFR was 8.7-23.2% and for PVT 3.1-5.7% (table I). One-way analysis of variance showed that for CPFR, the within-subject variability was 23.9% of the total variability and therefore the estimated reliability of a single reading was 76.1%. For PVT, the within-subject variability was 9% and the estimated reliability of a single reading was 91%.

**Mask size and type**

The data for comparison of PVT and CPFR between the three masks are shown in table II. There were no statistically significant differences between masks for PVT or CPFR (\( P > 0.05 \)).

**DISCUSSION**

Previous workers have suggested that during a voluntary cough manoeuvre supramaximal airflows are generated and that the time taken to achieve these flows is determined by laryngeal opening at the onset of the cough [4]. Tussometry allows us to record these flows on a timed scale. There are however several factors which may potentially influence the collection and interpretation of these data. The factors relating to equipment include calibration and quantification, the mask size and provision of an adequate seal.

We have shown that there was no difference in PVT and CPFR measurements when oral airflow only was measured, compared with measuring both oral and nasal airflow. This reflects the minimal airflow through the nose during a voluntary cough manoeuvre, as the soft palate elevates and seals the nasal airway [9]. Differences in the size of the mask have been shown to have no significant effect on measurement of PVT and CPFR, although it was
postulated that the different volume of deadspace may alter gas compressibility. This may be because the surface area of the pneumotachograph head is much greater than the area of the open glottis, thereby minimizing the effect of deadspace on the compressibility of the gas.

Calibration of the tussometer was carried out using constant flow rates, although we measured rapidly increasing flow rates during a cough. We believe this is not likely to cause significant errors in the use of the tussometer because the absolute flow is of less interest than the time taken to achieve that flow, the peak velocity time, which is the more important variable in determining laryngeal function [4, 10]. The frequency response of the tussometer was greater than that used by previous workers [4].

Another area of potential bias is observer variation. We found that there was no inter-observer variation when examining the flow–time waves generated by the tussometer. However, it is important that a clear peak is seen before the waveform is analysed to measure CPFR and PVT. If there is no distinct peak, then we recommend that the manoeuvre is repeated.

There are several variables that may influence the accuracy of the readings obtained. The first is the reproducibility of the measurements. Intra-subject variation was found to be 23.9% of the total variation for CPFR. For PVT it was found to be 9% of the total variability. The data for variability of these variables compares favourably with the variability of lung volumes [11]. This suggests that both measurements, but PVT in particular, are consistent findings for any given individual.

The effects of lung function, age, height, weight and sex on CPFR and PVT have been reported previously [12]. In that study, the authors compared 79 subjects from four age bands and both sexes. The effects of forced expiratory volume in 1 s (FEV₁), vital capacity (VC), peak expiratory flow rate (PEFR), forced expiratory flow rate at 50% of vital capacity (FEF₂₅), total lung capacity, age, height and weight on CPFR and PVT were assessed using univariate analysis and stepwise multiple regression. The stepwise model showed that CPFR was significantly related to PEFR and there was no advantage in including the other variables. Univariate analysis showed that only weight was related to PVT at the 5% significance level.

The technique of tussometry does depend on patient co-operation. This implies that the technique cannot be used in the early phases of recovery. The inability of the patient to achieve an adequate seal around the mask can be overcome by the investigator supporting the mask. There are two other areas that may potentially influence the values obtained by tussometry in the postoperative period. The first of these is reduction in functional residual capacity (FRC). The effects of lung volume on the relationship of PVT and CPFR have been investigated previously [13]. This has led to suggestions that it may be the ratio of CPFR to PVT that is a more reliable indicator of laryngeal function than PVT alone. Work is currently in progress to investigate this. The second aspect is that of effort in the postoperative period. It has been shown that the initial supramaximal flow generated during a cough is ordinarily independent of muscle strength or effort [14]. The time taken to generate peak pleural pressures during a cough is greater than the time taken to generate supramaximal flows [14]. It has also been shown that there is no reduction in flow rates during coughing at FRC in partially curarized subjects, despite a marked reduction in pleural pressure [15].

We have found that the tussometer allows us to measure CPFR and PVT accurately. These variables were not related to observer bias and were readily reproducible. The tussometer has already been shown to be useful in the assessment of laryngeal function in the presence of gross lesions [1, 2]. We feel that the data presented here show that it may be able to assess the more subtle changes in laryngeal function that are associated with anaesthesia and sedation, providing that the subjects are able to perform the cough manoeuvres maximally.

REFERENCES