Thorax 1984;**39**:771–774

Temperature corrections in routine spirometry

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ABSTRACT Forced expiratory volume (FEV_1) and forced vital capacity (FVC) were measured in nine normal subjects with three Vitalograph and three rollng seal spirometers at three different ambient temperatures (4°C, 22°C, 32°C). When the results obtained with the rolling seal spirometer were converted to BTPS the agreement between measurements in the three environments improved, but when the Vitalograph measurements obtained in the hot and cold rooms were converted an error of up to 13% was introduced. The error was similar whether ambient or spirometer temperatures were used to make the conversion. In an attempt to explain the behaviour of the Vitalograph spirometers the compliance of their bellows was measured at the three temperatures. It was higher at the higher temperature (32°C) and lower at the lower temperature (4°C) than at the normal room temperature. These changes in instrument compliance could account for the differences in measured values between the two types of spirometer. It is concluded that the ATPS–BTPS conversion is valid and necessary for measurements made with rolling seal spirometers, but can cause substantial error if it is used for Vitalograph measurements made under conditions other than normal room temperature.

It is commonly supposed that when a patient breathes into a spirometer gas leaves the body fully saturated at 37°C but that in the spirometer it rapidly cools to room temperature, so that its volume is actually measured under ambient temperature and pressure saturated conditions.[1] Perks *et al*, however, found recently that estimates of FEV_1 and FVC measured with a bellows spirometer at three widely different room temperatures were very similar and became very different if they were corrected for body temperature and pressure saturated conditions.[2] They concluded that it was preferable to leave the readings in their uncorrected state. This paper describes a study which confirms their findings, offers an explanation, and shows that the conversion is still needed for a rolling seal spirometer.

Methods

FEV_1 and FVC were measured in nine healthy volunteers (mean FEV_1 3·76 l, mean FVC 4·47 l, ATPS with rolling seal spirometers) at three different ambient temperatures (4°C, 22°C, and 32°C).

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Accepted 30 April 1984

Measurements were made with three rolling seal spirometers (PK Morgan, type M8) and three bellow type spirometers (Vitalograph). The instruments were allowed to equilibrate in the appropriate room (a cold store room, the lung function laboratory, and a boiler room) for 24 hours before the study. All of the subjects performed three manoeuvres on each of the instruments in the three different environments and the best FEV_1 with its associated FVC was recorded. The order was determined by a Latin square design. All measurements were performed with the subjects standing. The instruments were calibrated with a six litre syringe before and after every experiment. Air and spirometer temperatures were measured with an electronic thermometer (Comark: type 1624, Copper/Constantan thermocouple, response time less than 0·3 seconds) at the beginning and end of each manoeuvre and the mean temperature was recorded. Measured volumes were converted from ATPS to BTPS on the basis of both room and spirometer temperatures. The compliance of the Vitalographs was measured under the different conditions by injecting a known volume of air at the appropriate temperature into the spirometer and recording the pressure inside the bellows with a water manometer. The results obtained at each temperature were averaged and volume–pressure curves were plotted.

Table 1 *Volumes recorded by Vitalograph and rolling seal spirometers at three different ambient temperatures after introduction of air with a six litre syringe (volumes shown are means (SD) of the three measurements made with each instrument at each of the temperatures)*

Instrument	*Room temp (°C)*	*Volume introduced (l, ATPS)*	*Mean volume recorded (l, ATPS)*	*Mean volume recorded as % of volume introduced*
Rolling seal spirometer	4·5	6·0	5·95 (0·03)	99·2 (0·49)
	22·4	6·0	6·0 (0·02)	100·0 (0·43)
	31·5	6·0	6·1 (0·05)	101·7 (0·77)
Vitalograph	4·4	6·0	6·61 (0·15)	110·2 (2·50)
	22·0	6·0	5·9 (0·09)	98·3 (1·60)
	32·6	6·0	5·85 (0·03)	97·5 (0·54)

The spirometric results obtained in the hot and cold rooms (32°C and 4°C) from each spirometer were compared with the results obtained from the same spirometer in the normal room (22°C), with Student's paired *t* test.

Results

Calibration of the instruments at the three temperatures are presented in table 1. The largest error recorded was for the Vitalograph, which overestimated the volume by 10·2% in the cold room. The greatest error for the rolling seal spirometer (in the hot room) was only 1·7%. The syringe used to calibrate the instruments was itself checked in the three environments with a water spirometer and the mean error was 0·36% (range 0·2% to 0·7%).

Spirometric measurements are summarised in tables 2 and 3. They show that the Vitalographs measured about the same expired volumes under hot, normal, and cold conditions. Thus when the readings were corrected from ATPS to BTPS they diverged, resulting in errors of up to 11·8% ($p < 0·001$) when the spirometer temperature was used as the basis for the conversion and up to 12·5% ($p = < 0·001$) if the room temperature was used. This did not happen when values obtained from the rolling seal spirometers were corrected from ATPS to BTPS. In this case they became more uniform and the maximum error was only 1·6% (NS) when spirometer temperature was used and 3·1% (NS) with room temperature. On each occasion the spirometers were used to measure three successive expirations in each of three subjects; no change in the baseline instrument temperature was observed.

The compliance results are presented in the figure. They show that the Vitalographs became more compliant with increasing temperature. The difference between the mean compliances measured in the hot and normal rooms is +13%, which is not significant. The difference between the mean compliances measured in the normal and cold rooms is −20%, which is significant ($p < 0·01$).

Discussion

It is reasonable to assume that expired air temperatures are the same whether a patient is breathing

Table 2 *Volumes of FEV_1 and forced vital capacity (FVC) in nine normal subjects performed at three different ambient temperatures with rolling seal and Vitalograph spirometers to show the effect of conversion from ATPS to BTPS (results expressed as percentages (SD) of the unconverted values obtained at "normal" room temperature†)*

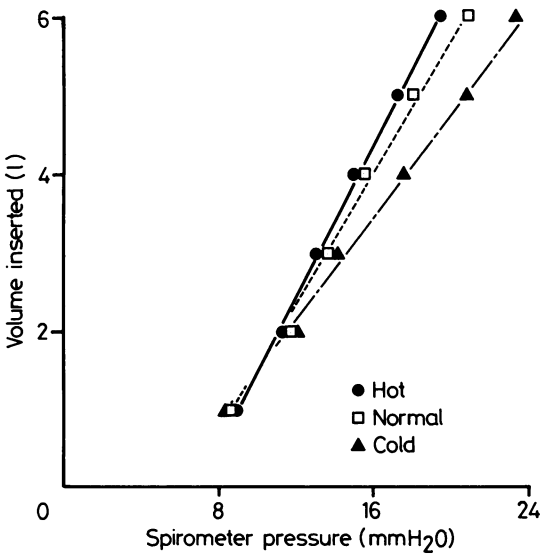
Room temp (°C)	*Vitalograph*			*Rolling seal spirometer*		
		ATPS	*BTPS*		*ATPS*	*BTPS*
4·0		*	***		**	NS
	FEV_1:	102·9 (2·9)	121·6 (3·4)	FEV_1:	94·5 (3·4)	111·7 (4·0)
		NS	***		***	NS
	FVC:	99·8 (3·0)	119·0 (3·0)	FVC:	93·3 (3·4)	110·3 (3·8)
22·0	FEV_1:	100·0	109·1	FEV_1:	100·0	109·1
	FVC:	100·0	109·1	FVC:	100·0	109·1
		NS	***		*	NS
32·0	FEV_1:	98·1 (4·1)	101·3 (4·2)	FEV_1:	102·7 (3·2)	106·0 (3·3)
		NS	***		**	NS
	FVC:	98·4 (4·1)	101·5 (3·3)	FVC:	103·5 (3·2)	106·8 (3·1)

†Where the results obtained in the hot and cold rooms differ significantly from those obtained in the normal room this is indicated as follows: *$p < 0·05$; **$p < 0·01$; ***$p < 0·001$. Mean FEV_1/FVC values at room temperature with the Vitalograph spirometer are 3·9/4·5 l at ATPS and with the rolling seal spirometer 3·8/4·5 l at ATPS.

Table 3 *Measurement of FEV_1 and forced vital capacity (FVC) in nine normal subjects at three different ambient temperatures made with rolling seal and Vitalograph spirometers to show the effect of conversion to BTPS using the spirometer temperature (results expressed as percentages (SD) of the unconverted values obtained at "normal" room temperature†)*

		Vitalograph			*Rolling seal spirometer*	
		ATPS	*BTPS*		*ATPS*	*BTPS*
		*	***		**	NS
"*Cold*" *room* (4°C)	FEV_1	102·9 (2·9)	118·1 (3·4)	FEV_1	94·5 (3·4)	109·4 (3·9)
Vitalograph temperature 11°C		NS	***		***	NS
RSS temperature 9°C	FVC	99·8 (3·0)	114·5 (3·4)	FVC	93·3 (3·4)	108·0 (3·7)
"*Normal*" *room* (22°C)	FEV_1	100·0	106·3	FEV_1	100·0	107·8
Vitalograph temperature 26·7°C	FVC	100·0	106·3	FVC	100·0	107·8
RSS temperature 24·5°C						
		NS	***		*	NS
"*Hot*" *room* (32°C)	FEV_1	98·4 (4·1)	99·5 (4·2)	FEV_1	102·7 (3·2)	106·4 (3·3)
Vitalograph temperature 34·8°C		NS	***		**	NS
RSS temperature 31·7°C	FVC	98·4 (4·1)	99·7 (3·2)	FVC	103·5 (3·2)	107·2 (3·1)

†Instrument temperatures are the means of measurements recorded at the beginning and end of each expiratory manoeuvre. Where the results obtained in the hot and cold rooms differ significantly from those obtained in the normal room this is indicated as follows: *$p < 0·05$; **$p < 0·01$; ***$p < 0·001$.
RSS—rolling seal spirometer.



Volume–pressure curves of the Vitalograph spirometers when measured at three different temperatures. Each point on the graph is the mean value obtained for the three instruments. In each graph the points lie on a straight line. The difference between the slopes obtained in the normal (22°C) and cold (4°C) rooms is significant ($p < 0·01$). The difference between the slopes obtained in the normal and hot (32°C) rooms is not significant. Mean compliance in the normal room was 4·17 (range 3·85–4·46) l/cm H_2O, in the hot room 4·72 (range 4·11–5·55) l/cm H_2O and in the cold room 3·35 (range 2·78–4·04) l/cm H_2O.

into a bellows or a rolling seal spirometer, provided that they have not inspired from it beforehand. In the present case all subjects inspired room air and then expired it as rapidly as possible into one or other spirometer. Why is it that the bellows spirometer masks the expected differences in expired volumes at ambient temperature, while the rolling seal spirometer does not?

The conversion of spirometric measurements of respired volumes from APTS to BTPS is based on the assumption that the temperature of the gas within the spirometer cools to room temperature and that the mechanics of the spirometer do not alter with a change in temperature. The rolling seal spirometer consists of a stainless steel piston, which moves within a cylinder of similar material. Because steel has a high thermal conductivity and thermal capacity it will allow the equilibration of expired air and room air temperatures. Since the steel piston is rigid, changes in spirometer compliance with temperature will be negligible, as indicated in table 1. The Vitalograph, however, consists of a wedge shaped polyvinyl chloride (PVC) bag that unfolds when gas enters the bellows, displacing a stylus at the end of a metal curved arm. Van Fleet *et al* have suggested that the Vitalograph bellows may become more compliant with increasing temperature (although they did not measure this property directly), so that more volume is retained in the horizontal distension of the bellows, which results in less vertical displacement.[3] The measurements presented in the figure show that a change does occur,

which is linear with temperature over the range observed. The change in compliance with temperature is, however, functionally significant only at volumes greater than 2 litres, which is relevant when we are studying patients with reduced expired volumes.

In addition to the change in compliance that takes place in the Vitalograph, we believe that there is a second factor, imperfect temperature equilibration, which is acting in an opposing direction in the PVC bellows with their low thermal conductivity and low thermal capacity. The temperature measurements show that for the Vitalograph there is a difference of up to 7°C between the temperature in the spirometer and the ambient air temperature. The effect of this is to counter the changes in bellows compliance caused by change in temperature if the temperature of the environment is less than room temperature.

Our conclusion, then, is that the ATPS–BTPS conversion is practical when applied to the values obtained from a rolling seal spirometer, irrespective of the temperature at which the measurements are made. With the Vitalograph, however, while it is reasonable to apply the conversion factor under temperate conditions because Vitalograph and rolling seal values are almost identical at room temperatures, at other temperatures the conversion is impractical because substantial error may be introduced.

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