SHORT REPORT

Effect of spirometer temperature on FEV_1 in a longitudinal epidemiological study

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Abstract

***Objectives*—To assess the magnitude of error in pulmonary function measurements introduced by variation in spirometer temperature under field conditions. In a large scale epidemiological study of school children, the influence was investigated of spirometer temperature on forced expiratory volume in 1 second (FEV_1) measured with dry rolling seal volumetric spirometers and conventional body temperature, pressure, and saturation (BTPS) corrections.**

***Methods*—Linear regression analyses were performed on data from 995 test-retest pairs on 851 different children, with 1–110 days between test and retest, and spirometer temperature differences between −13°C and +9°C.**

***Results*—After adjusting for effects of growth (test-retest intervals) and circadian variation (changes in times of testing), differences in standard BTPS corrected FEV_1 showed significant ($p<0.05$) dependence on differences in spirometer temperature between tests (−0.24%/°C).**

***Conclusions*—When spirometer temperatures vary widely, standard BTPS correction does not fully adjust for gas contraction. To improve accuracy of volume measurements in epidemiological studies, additional correction for variation in spirometer temperature should be considered.**

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Measurements of forced expired volume in 1 second (FEV_1) or peak flow with volumetric spirometers, and conventional corrections to 37°C body temperature, pressure, and saturation (BTPS), assume instantaneous transition of exhaled air from body temperature to spirometer temperature. Within the normal room (or spirometer) temperature range, the actual transition is not instantaneous; consequently, the measured air may contract less than is assumed, and the BTPS corrected volume or flow may be too large.[1–4] If the magnitude of the overestimate is substantial, use of the conventional BTPS correction may introduce inaccuracies. Laboratory and field studies indicate that the magnitude of the overestimate in volume or flow may be large enough to warrant additional correction.[1–4] Hankinson and Viola[1] measured the effect of varying spirometer temperature in a laboratory, with a typical dry rolling seal spirometer (Ohio Medical Products Model 840) and a physical system capable of delivering reproducible simulated forced expirations of water vapour saturated air at 37°C. They found that the conventional BTPS correction had an undetectable effect on measured FEV_1 at 32°C spirometer temperature, but that error in calculated FEV_1 increased in a nearly linear manner as temperature decreased, averaging 3.1% at 20°C and 7.7% at 3°C. These laboratory studies show that additional corrections beyond application of the standard BTPS factors may be needed, especially when the range in spirometer temperatures is large.

In epidemiological studies that use FEV_1 measurements conducted in field settings, spirometer temperature may vary over a range nearly as large as in these laboratory studies. Variation introduced by ignoring the effect of spirometer temperature on BTPS corrected FEV_1 has not been extensively studied in field settings. Judging from the laboratory results, such variation may cause non-differential measurement error and reduced statistical power if spirometer temperatures vary at random, or differential bias if temperatures differ systematically at different times or locations. To determine whether the relation between standard BTPS corrected FEV_1 and spirometer temperature as reported by Hankinson and Viola occurs in data collected under field conditions with wide ranging temperatures, we examined repeated pulmonary function measurements from a large scale field survey of school children. We assessed the relation between changes in spirometer temperature and measured pulmonary function change, after accounting for other potential sources of variability in spirometer measurement[5 6] and time dependent effects.

Regression results: change in FVC or FEV_1 v temperature and time factors

Data analysed	*Test*	*n*	*Intercept**	*Slope of change of FEV_1 or FVC % (95% CI)*			R^2
				Temperature (°C)	*Time of day (h)*	*Age (y)*	
Acceptable subjects	FVC	892	−0.63	−0.20 (−0.09 to −0.31)	0.06 (−0.14 to 0.26)	7.8 (3.6 to 11.4)	0.027
	FEV_1	879	−1.10	−0.24 (−0.12 to −0.36)	0.22 (0.00 to 0.44)	9.6 (4.9 to 14.3)	0.031
Good subjects	FVC	649	−0.77	−0.21 (−0.08 to −0.34)	0.06 (−0.16 to 0.28)	8.6 (3.6 to 13.6)	0.030
	FEV_1	646	−1.22	−0.24 (−0.10 to −0.38)	0.27 (0.02 to 0.52)	10.6 (5.2 to 16.0)	0.034
All lab tests (1)	FEV_1	†	8.09	−0.25 (−0.24 to −0.26)	—	—	0.99
Lab tests 13–29°C	FEV_1	‡	8.11	−0.25 (−0.22 to −0.28)	—	—	0.98

*In subject tests, regression intercept represents theoretically expected FVC or FEV_1 change from test to retest with no change in temperature or time. In lab tests, intercept represents expected FEV_1 difference between measurements at 0°C and 32°C.
†Twelve waveforms tested at 11 temperatures from 3–32°C.
‡As above, seven temperatures from 13–29°C.

Methods

More than 3000 children, attending elementary, intermediate, and high schools in 12 different communities, were tested at their schools during winter or spring of 1993, 1994, and 1995. Forced expiratory variables including forced vital capacity (FVC) and FEV_1 were measured with Spiroflow Model 132 spirometers (P K Morgan, Gillingham, UK), which are physically similar to the spirometer tested by Hankinson and Viola.[1] Within each year, about 10% of students were retested as a validity check. In each session, subjects repeated the test until they produced three technically acceptable blows, with two FVC and FEV_1 values differing by <5%, or a maximum of seven blows. To account for small differences between individual spirometers, test data were adjusted according to closely preceding and following calibration checks with volumetric syringes.[5] The best single FVC and FEV_1 were analysed. For subjects with good data (defined below), the test-retest interval averaged 55 days and ranged from 1 to 110 days. Preliminary analyses indicated that differences between testing years and between sexes were not significant; therefore, all data were pooled for analysis. Among 995 test-retest pairs, 892 had FVC data and 879 had FEV_1 data judged to be acceptable for these analyses, in that values differed by no more than 10% between test and retest, and back extrapolation volume (BEV) did not exceed 8% in either test or retest. Of these, 649 FVC pairs and 646 FEV_1 pairs had good data—that is, BEV within the American Thoracic Society recommended limit of 5%.[7] Each of these groups was analysed.

Linear regressions were performed with BMDP statistical software (SPSS, Chicago). The dependent variable was change in FEV_1 (or FVC) from initial test to retest, expressed as a percentage of the mean of test and retest values. Independent variables were age change from test to retest (expressed in years), difference in time of day between test and retest (in hours) and temperature change (in °C). Age change was included to account for growth effects. Time of day change was included to account for possible circadian variation in lung function, which might bias the estimate of temperature effects. Test sessions typically ran from cool early mornings to warmer noontime hours, so that both circadian effects and temperature effects would tend to increase lung function measured at later times. Time of day and spirometer temperature changes were appreciably correlated ($r = 0.34$); but other measured factors expected to influence lung function acutely—symptoms of asthma, use of medication, recent exposure to tobacco smoke, and recent exercise—were uncorrelated with temperature change and therefore were not included in regression models. Additional regression analyses were performed on the data of Hankinson and Viola for FEV_1 produced by their laboratory simulator loaded with saturated air (table 1 in reference[1]), both for their entire temperature range (3°C–32°C), and for the range most relevant to our test-retest data (13°C–29°C). These additional regressions related the weighted mean error at each spirometer temperature (the mean percentage difference between actual and BTPS corrected FEV_1, weighted by the inverse of the SD^2) to spirometer temperature itself, rather than temperature change.

If our spirometric measurements calculated with conventional BTPS correction were subject to temperature related errors comparable with those found by Hankinson and Viola, then all the analyses would be expected to yield similar regression slopes for % change in FEV_1/°C. For FVC, Hankinson and Viola found little temperature related error, as expected because their technique allowed time for thermal equilibration. In most of our subjects, however, FVC exhalation was essentially complete in 1–2 seconds, so that incomplete thermal equilibration and temperature related error might be expected for FVC as well as FEV_1.

Results

The table summarises the regression results. Either the acceptable or the good test-retest data showed significant ($p<0.05$) negative relations between % change in FEV_1 and change in spirometer temperature, with estimated slopes near −0.24%/°C, nearly the same as the slope of -0.25%/°C estimated from the published laboratory data.[1] The age (growth) effect was also significant, with estimated slopes near 10%/year. The time of day (circadian) effect was at least marginally significant, with estimated increases in FEV_1 >0.2%/hour, after allowing for the temperature effect. For FVC, the effect of spirometer temperature change was slightly smaller than for FEV_1, but was still significant. The age effect also was slightly smaller for FVC than for FEV_1. The FVC showed no significant circadian effect.

Discussion

We found that the assumption of instantaneous cooling of exhaled air, implicit in conventional BTPS correction methods, is not entirely valid for spirometry conducted under field conditions where large variations in spirometer temperature are encountered. Conventionally BTPS corrected FEV_1 and FVC data from our large scale field survey of children depended greatly on spirometer temperature. The size of the temperature effect was essentially the same as found by Hankinson and Viola in laboratory simulations[1] with a similar spirometer, but different from that reported by Perks *et al*[2] in human testing, or by Pincock and Miller[3] in laboratory simulations, with differently designed volumetric spirometers. Thus, the close agreement between our results and those of Hankinson and Viola may depend on similar spirometer designs. Error correction procedures should be made specifically for the equipment used and the temperature range experienced in a given study.

The implications of spirometer temperature variation for studies of changes in lung function during a working shift have been discussed previously.[8] The implications for longer term longitudinal surveys or cross sectional surveys also need to be considered. From our results, it seems that a mean temperature difference of 4°C–5°C from one test circumstance to another would artifactually shift the estimated mean FEV_1 by 1%. An effect of this size, if not taken into account, may introduce meaningful change in estimates of other effects.

Circadian variation also seemed to influence our measurements of FEV_1 (but not FVC), with a slightly smaller effect size and level of significance than the effect of spirometer temperature. It represents another subtle influence which needs to be accounted for to estimate longer term effects accurately.

As expected, our simple analytical model explains only a small proportion of the variance in test-retest lung function differences. Acute changes in underlying health, recent environmental exposures, and varying genetic or environmental influences on lung growth probably explain more of the variance, and will be considered in future investigations. In general, these substantive influences would not be expected to correlate with spirometer temperature, and so are not likely to bias our estimates of its effect.

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1 Hankinson JL, Viola JO. Dynamic BTPS correction factors for spirometric data. *J Appl Physiol* 1983;**55**:1354–60.
2 Perks WH, Sopwith T, Brown D, *et al*. Effects of temperature on Vitalograph spirometer readings. *Thorax* 1983;**38**:592–4.
3 Pincock AC, Miller MR. The effect of temperature on recording spirograms. *Am Rev Respir Dis* 1983;**128**:894–8.
4 Quanjer, PH, Tammeling GJ, Cotes JE, *et al*. Standardized lung function testing: lung volumes and forced ventilation flows-1993 update. *Eur Respir J* 1993;**6**(suppl 16):5–40.
5 Linn, WS, Solomon JC, Gong H Jr, *et al*. Standardization of multiple spirometers at widely separated times and places. *Am J Respir Crit Care Med* 1996;**153**:1309–13.
6 Linn WS, Solomon JC, Gong H Jr, *et al*. Temperature standardization of multiple spirometers. *J Occup Environ Med* 1998;**40**:148–52.
7 American Thoracic Society. Standardization of spirometry—1987 update. *Am Rev Respir Dis* 1987;**136**:1285–98.
8 Hankinson JL, Castellan RM, Kinsley KB, *et al*. Effect of spirometer temperature on measurement of FEV_1 shift changes. *J Occup Environ Med* 1986;**28**:1222–5.

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