Pediatric Pulmonology 42:764–772 (2007)

Effect of Electronic Compensation on Plethysmographic Airway Resistance Measurements

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Summary. Objectives: To compare the performance of a plethysmograph which incorporated electronic compensation (Jaeger) to one which incorporated a heated humidified breathing system (Hammersmith plethysmograph). Working hypothesis: The performance of a plethysmograph which incorporated electronic compensation would be impaired compared to that which incorporated a heated humidified system. Study design: In vitro and in vivo comparison. Patient selection: Eleven children, median postnatal age 13 (range 5–15) months. Methods: In vitro, the plethysmographs were assessed using known resistances (1.94, 4.85, and 6.80 kPa, equivalent to 20, 50, and 70 cm H_2O/L/sec, respectively). In vivo, comparison was made of the results of children studied in both plethysmographs. Results: In vitro, the resistance results of the two plethysmographs were similar to each other and to the known resistances. In vivo, the median "effective" airways resistance result of the Jaeger (4.15 kPa/L/sec) was significantly higher than the inspiratory resistance of the Hammersmith plethysmograph (3.0 kPa/L/sec), but the median inspiratory resistances of the Jaeger were significantly lower than those of the Hammersmith plethysmograph (2.8 kPa/L/sec vs. 3.0 kPa/L/sec). The mean within patient coefficient of variability for inspiratory resistance of the Jaeger plethysmograph (16.7%) was significantly higher than that of the Hammersmith plethysmograph (11.6%) ($P = 0.014$). Conclusion: These results suggest plethysmographs which incorporate electronic compensation may be inappropriate for use in infants and very young children. **Pediatr Pulmonol. 2007; 42:764–772.**

Key words: plethysmography; prematurity; airway resistance; inspiration; expiration; rebreathing.

INTRODUCTION

It is now 50 years since the measurement of airways resistance (R_{aw}) by total body plethysmography was first described by Dubois et al.[1] The problem of changes in plethysmograph chamber pressure due to differential temperature and humidity between the lung and the plethysmograph during inspiration and expiration, which in adults could be limited by rapid shallow breathing, delayed introduction of plethysmographic measurements in infants and young children until the 1970s when heated, humidified rebreathing systems were available.[2–4] Recently, electronic compensation has been introduced to overcome thermal artefacts during plethysmographic measurements in children and adults and a new generation of infant plethysmographs, which incorporate an electronic thermal compensation to close the flow/box pressure loop, negating the need for a humidified rebreathing system are now available.[5] Electronic compensation makes the measurement technique simpler and thus potentially would facilitate wider availability of plethysmographic measurements. Unfortunately, however, when one such plethysmograph was used to assess healthy infants and those with cystic fibrosis, surprisingly the R_{aw} results did not discriminate between the two groups.[5] Marked within- and between- subject variability in the results were demonstrated,[5] which may have precluded the expected differences[6] in the two groups being found. As a consequence of the marked variability in the results of the plethysmograph incorporating electronic compensation,[5] we hypothesized that its performance would be impaired compared to a plethysmograph which employed a heated humidified rebreathing system. No such a comparison was made in the previous study[5] and is necessary to

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Received 11 January 2007; Revised 10 May 2007; Accepted 3 June 2007.

DOI 10.1002/ppul.20661
Published online 20 July 2007 in Wiley InterScience (www.interscience.wiley.com).

determine the extent of any impaired performance by a plethysmograph with electronic compensation and whether it is sufficiently large to preclude its use in clinical and research studies. As a consequence, we have compared, in vitro and in vivo, the results of a plethysmograph which incorporated electronic compensation (Jaeger Master Screen Baby Body Plethysmograph, Viasys Ltd, Hoechberg, Germany) to a plethysmograph which incorporated a heated humidified rebreathing system (Department of Medical Engineering, Hammersmith Hospital, London, UK).

MATERIALS AND METHODS

Equipment

The Department of Medical Engineering, Hammersmith Hospital (Hammersmith) plethysmograph had a total volume of 90 L, and was a variable pressure model with a fixed leak to improve pressure stabilization characteristics. The time constant of the leak was 11.3 sec (half life 7.2 sec) in accordance with ERS/ATS guidelines.[6] The rebreathing system consisted of a rigid rubber facemask connected to a mask support which in turn was attached to a heated pneumotachograph (Fleisch, Lausanne, Switzerland), shutter block and rebreathing bag which contained a thermostatically controlled heating element. Thermistors were incorporated in the mask support and rebreathing bag and attached to a temperature control unit (Department of Medical Engineering, Hammersmith Hospital, London, UK), which had digital displays of airway and rebreathing bag temperature. The thermostat of the heating element in the rebreathing bag could be adjusted on the temperature control unit to abolish thermal artefacts. In addition, the bag was filled with heated, humidified air from an external cylinder and heater/humidifier (Fischer Paykel HC500) to reduce equilibration time. The rebreathing system had a total deadspace (with mask) of 44.2 ml, consisting of 288 cm of 0.092 ml/cm plastic tubing (deadspace 26.5 ml), the shutter block, pneumotachograph and mask support (deadspace 10.2 ml) and the mask (deadspace 7.5 ml). Pressure at the airway opening was measured using a differential pressure transducer (range $\pm$5 kPa, MP45, Validyne Engineering Corporation, Northridge CA) connected to the mask support. The pneumotachograph was attached to a differential pressure transducer (range $\pm$0.2 kPa, MP45, Validyne Engineering Corporation) to measure airflow. Plethysmograph chamber pressure was measured using an identical differential pressure transducer (range $\pm$0.2 kPa, MP45, Validyne Engineering Corporation). All signals were amplified (CD18 carrier amplifiers, Validyne Engineering Corporation) and the flow signal integrated electronically to give tidal volume (FV 156 integrator, Validyne Engineering Corporation). The resultant four channels of data were acquired, analyzed and displayed in real time on a personal computer (Gateway GP7-500, Dublin, Ireland) running a computer programme custom-designed using Labwindows software (National Instruments, Austin, TX). All channels were calibrated prior to each test, using standard techniques, which have been previously described.[7] The Hammersmith infant plethysmograph was calibrated prior to the in vitro tests and before each clinical measurement. Airway pressure (Pao) was calibrated using a digital pressure meter (Comark C95051S, Welwyn Garden City, UK) over a range of 0–2 kPa and airflow calibrated using a rotameter (0–12 L/min, Platon Instruments, Basingstoke, UK) over 0–4 L/min. Tidal volume was calibrated using a 100 ml calibration syringe (5510, Hans-Rudolph, Inc., Kansas City, MO). The pressure changes within the plethysmograph were calibrated using an electrically powered sinusoidal pump with a stroke volume of 19.2 ml. During this calibration bags of saline equivalent to the patient's weight were placed inside the plethysmograph. The volume calibrations were performed at a rate approximately equivalent to the respiratory frequency of the patient (30 cycles per minute) to minimize any calibration errors from the controlled leaks and the possibility that the plethysmographs were functioning in a polytrophic manner, that is, somewhere between isothermal and adiabatic conditions. The Jaeger Master Screen Baby Body Plethysmograph is a 98-L Plexiglas variable pressure plethysmograph with a pneumotachograph with solid-state transducers. The half life of the leak of the plethysmograph was measured prior to every measurement and was found to be between 7 and 10 sec, as stated by the manufacturer. The Jaeger plethysmograph was calibrated according to the manufacturer's protocol. Box pressure was calibrated using a sinusoidal pump (stroke volume 8 ml) incorporated within the system and functioning at a frequency of 30 cycles per minute. Respiratory flow was measured using a screen pneumotachograph, which was calibrated using a 100 ml syringe (Viasys Healthcare GmbH, Höchberg, Germany [accurate $\pm$1 ml]). The accuracy of the mouth (shutter) pressure transducer and pneumotachograph flow measurements were assessed using Jaeger software (J-Scope). The Jaeger plethysmograph routinely measures the ''effective'' airways resistance. This is calculated throughout the entire respiratory cycle using all available data points for plethysmograph chamber pressure and flow and represents the total inspiratory and expiratory resistive load experienced by the infant. The software also permits the more conventional measurement of inspiratory and expiratory specific resistance over selected portions of the flow trace. Those results were used to calculate equivalent airways resistances by dividing the results by the functional residual capacity after half the anatomical dead space had been subtracted.[6]

In Vitro Study

Study Design

Each plethsymograph was assessed using a lung model and a linear sinusoidal pump attached to the lung model. Airway resistance measurements were made using known resistances.

Methods

Lung model. The lung model consisted of a glass bottle which was attached perpendicular to the patient mask connector of the pneumotachograph using a t-shaped connector (Fig. 1). The volume of the lung model was determined by water displacement to be 320 ml; this volume was chosen as it is similar to the expect lung volume of a 1 year old child. Fine copper wire wool was inserted to fill the glass bottle, spaces and connection pieces to create isothermal conditions.[8,9]

A linear sinusoidal motorised pump (Parvalux electric motors Ltd, Bournemouth, UK) was attached to the lung model. A rate of 30 cycles per minute and a stroke volume of 8 ml was used, so that the resulting airway pressure during the occlusion remained within the range of the pressure transducer. At the start of testing, each plethysmograph was sealed and no measurements were made for 10 min to allow for equilibration of pressure. To measure the volume of the lung model, an occlusion was performed when the piston of the pump was at the maximum inspiratory position and maintained for three cycles of the pump. The signals were checked on the computer screen to ensure that the changes in plethysmograph chamber and lung model pressures were in phase and that throughout the occlusion there was no flow through the pneumotachograph. The measured volume of the lung model was calculated by relating the pressure within the lung model to the pressure changes within the plethysmograph using Boyle's Law. Airway resistance (Raw) measurements were made with each of the plethysmographs using known calibrated resistances. The resistances (Hans Rudulph, Inc., US0 of 1.94 and 4.85 kPa [20 and 50 cm/H_2O/L/sec]) were placed between the lung model and the mask connector either singly or in series to create resistances of 1.94, 4.85, and 6.80 kPa (20, 50, and 70 cm H_2O/L/sec). When the Jaeger plethysmograph was tested the automated correction factor for body weight was overridden by setting the patient weight to the minimum (1 kg), as has previously been described.[10] The in vitro measurements were made with the ''ambient'' conditions set at 37°C, 1,013 mbar and 100% humidity, overriding the automatic correction to BTPS. The computer programme which analyzed the results of the Hammersmith plethysmograph reported the results in BTPS conditions. For each resistance measured, 15 acceptable measurements were recorded from each plethysmograph and the coefficient of variation calculated for each set of measurements. The

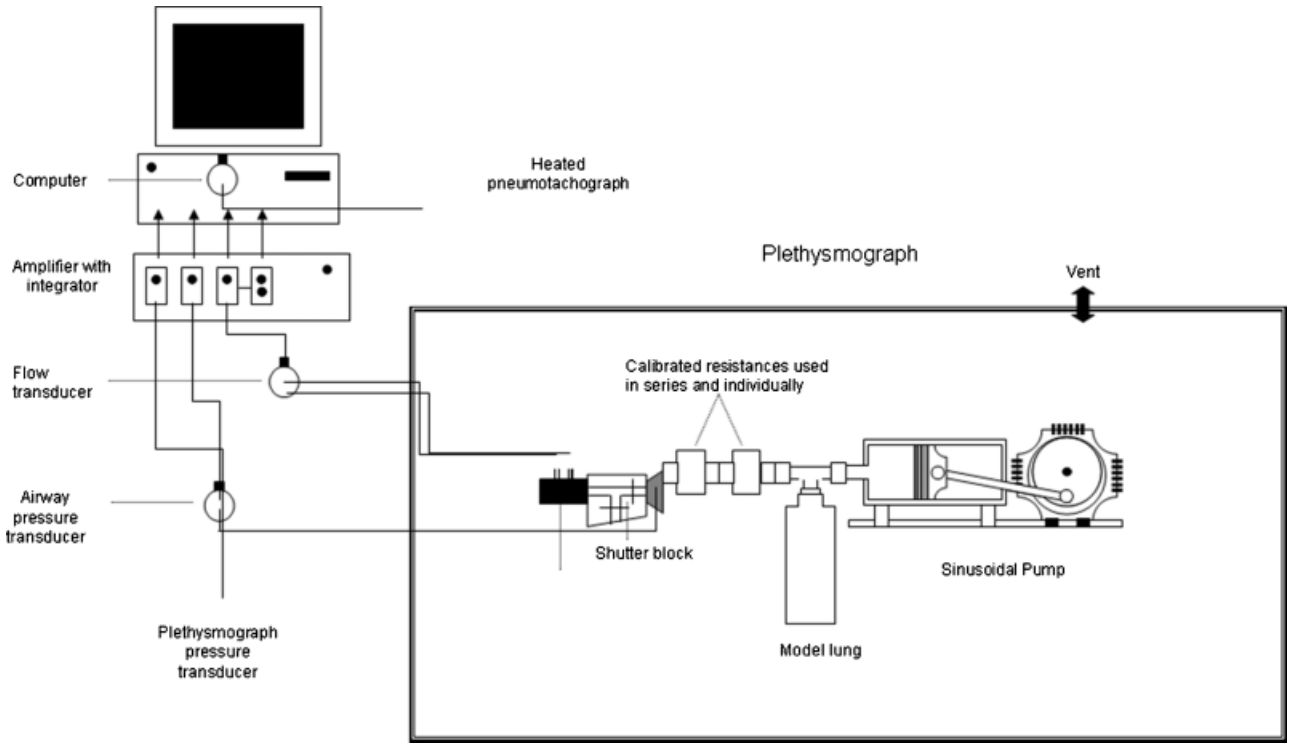

Fig. 1. Diagram of in vitro testing equipment.

Jaeger plethysmograph calculated the resistance from data points through out the respiratory cycle, the Hammersmith plethysmograph from the inspiratory flow trace from 0% to 50% of peak flow.[11]

In Vivo Study

Study Subjects

Infants were eligible for this study if they were undergoing plethysmographic measurements for clinical purposes or as part of a research study for which ethics committee approval has been obtained. Infants were seen in the Amanda Smith neonatal lung function laboratory. If they had any signs of a respiratory tract infection, the study was postponed for at least 2 weeks. They were recruited into the study if their parents gave informed written consent. The study was approved by the King's College Hospital Research Ethics Committee. Eleven infants were studied. The lung volumes of ten of the patients have been previously reported.

Study Design

On the day of testing, the infants had their height and weight measured. The infants were then sedated with 80–120 mg/kg of chloral hydrate given orally. The infants' oxygen saturations (Datex-Ohmeda 3800, Hatfield, UK) were monitored continuously throughout the study.

Methods

Once asleep, the infants were first laid supine in the Hammersmith plethysmograph. A face-mask (Rendell Baker, Laerdal, Norway) was positioned over the infant's nose and mouth and putty (Rainbow putty Firm Blue, North Coast Medical, Morgan Hill, CA) was used to obtain an airtight seal. The plethysmograph was closed and no measurements of lung volume (FRC_{pleth}) or R_{aw} were performed for at least 5 min to allow for equilibration of pressure to occur. FRC_{pleth} was measured from end inspiratory occlusions with at least 15 breaths between occlusions. Each occlusion was maintained for three inspiratory efforts. The results from the occlusions were considered acceptable if the plethysmograph chamber pressure (V_{pleth}) and the mouth pressure (P_{ao}) were in phase and there was evidence of no airflow. The results of three acceptable occlusions were averaged to calculate FRC_{pleth}. The infant's tidal breathing then was diverted to the heated humidified rebreathing bag. Individual breaths acquired during periods of rebreathing were displayed as x/y plots of V_{pleth}/flow by the computer. Only technically acceptable breaths, that is the loop was closed or nearly closed at points of zero flow, were used in the analysis.[6] Inspiratory and expiratory R_{aw} were calculated electronically using an established formula[11] by applying a regression line to the selected portions of the loop, that is during initial inspiration between 0% and 50% maximal inspiratory flow and between 0% and 50% of expiratory flow.[11] During all R_{aw} measurements, the computer calculated the apparatus resistance of the selected portion of the individual breath by relating the change in Pao to the change in flow and then subtracted this value from the total measured resistances.[11]

The infant was then moved to the Jaeger plethysmograph and the mask repositioned using extra putty if necessary to ensure a leak free seal around the nose and mouth. Time was again allowed after closing the plethsymograph to allow equilibration of pressure. Data were recorded from three acceptable end inspiratory occlusions (as previously defined). Each occlusion was maintained for three inspiratory efforts and an occlusion performed only after at least 15 breaths. Effective R_{aw} was calculated using the automated resistance software. In addition, inspiratory and expiratory R_{aw} were calculated from the results of specific inspiratory and expiratory resistance, both measured from 0% to 50% of peak tidal flow, so that results could be obtained comparable to those from the Hammersmith plethysmograph.

At least 15 resistance results were collected from each infant in each plethysmograph and the coefficient of variation of the results from each plethysmograph calculated. In addition, the mean inspiratory and expiratory times and respiratory rates, and the tidal volumes of the breaths over a minute period immediately before the resistance measurements were made and their co-efficients of variation calculated to determine whether breathing patterns were constant throughout the studies.

Statistical Analysis

The results were tested using the Shapiroo–Wilk test of normality. Although the FRC and resistance results of the Hammersmith plethysmograph were found to be normally distributed, the resistance results of the Jaeger plethysmograph failed the test of normality, hence differences in the resistance results were assessed for statistical significance using the Wilcoxon-signed-rank test. Differences in the other results, including the co-efficient of variations, were assessed for statistical significance using the student's *t*-test. Bland and Altman[12] analyses were undertaken to compare the in vivo R_{aw} results obtained from the two plethysmographs. Comparisons were made of the Jaeger effective resistance and the Hammersmith inspiratory resistance results and of the inspiratory and expiratory resistance results from the two plethysmographs. A Spearman's correlation coefficient was calculated to determine the relationship of any differences in the R_{aw} results with the mean R_{aw} of the results of the two plethysmographs. The breathing patterns (respiratory

rates, inspiratory and expiratory times, and tidal volumes) during the measurement of inspiratory resistances in the two plethysmographs were also compared.

RESULTS

In Vitro Study

The R_{aw} results of the two plethysmographs were similar to each other ($P = 0.54$) and to the known resistances ($P = 0.75$) (Table 1). The mean coefficient of variation (SD) of the results of the Jaeger plethysmograph was 1.7 (0.5)% and of the Hammersmith plethysmograph was 2.9 (0.6)% ($P = 0.11$).

In Vivo Study

Fifteen infants attended for lung function measurements, but four woke up before the measurements could be completed in the Jaeger plethysmograph. The eleven infants who had satisfactory measurements in both plethysmographs had a median age at testing of 13 (range 5–15) months (corrected for gestational age) (Table 2).

The FRC results were obtained from three occlusions, each maintained for three breaths. As we have previously reported,[9] the mean FRC measured by the Jaeger plethysmograph was significantly lower than those obtained using the Hammersmith device (19.6 ml/kg body weight vs. 26.5 ml/kg, $P < 0.02$) (Table 2). The resistance results were based on a mean of 22 (range 14–30) measurements per infant in the Jaeger plethysmograph and 18 (range 14–20) measurements per infant in the Hammersmith plethysmograph.

The median effective R_{aw} result of the Jaeger plethysmograph (4.15, range 2.6–6.6 kPa/L/sec, mean 4.27, SD 1.81 kPa/L/sec) was significantly higher than the inspiratory resistance of the Hammersmith plethysmograph (3.0, range 1.4–5.2 kPa/L/sec, mean 2.80, SD 1.08 kPa/L/sec) $P = 0.003$. The differences between the R_{aw} results of the two plethysmographs increased with increasing R_{aw} ($r = 0.82$, $P = 0.002$) (Fig. 2). The mean within patient coefficient of variation of the effective R_{aw} results of the Jaeger plethysmograph was 17.8% (SD 7.6), which was significantly higher than that of the inspiratory resistance of Hammersmith plethysmograph (11.4% (SD 2.8) $P < 0.001$). The median inspiratory resistance of the Jaeger plethysmograph (2.8, range 2.22–8.2 kPa/L/sec, mean 2.34, SD 0.94 kPa/L/sec) was significantly lower than that of the Hammersmith plethysmograph (3.0, range 1.4–5.6 kPa/L/sec, mean 2.8, SD 1.08 kPa/L/sec) ($P = 0.026$) and the Jaeger plethysmograph had a significantly higher coefficient of variation (16.7% vs. 11.6%) ($P = 0.009$). The expiratory resistance results of the Jaeger plethysmograph (median 3.78, range 2.8–12.1 kPa/L/sec, mean 3.61, SD 1.8 kPa/L/sec) tended to be lower than those of the Hammersmith plethysmograph (median 4.38, range 2.4–7.4 kPa/L/sec, mean 4.71, SD 2.1 kPa/L/sec) but the difference was not statistically significant ($P = 0.66$). The coefficient of variation of the expiratory resistance results tended to be higher with the Jaeger plethysmograph (14.7% vs. 11.4%) ($P = 0.052$). The differences between the inspiratory Raw and expiratory Raw results showed no significant tendency to increase with increasing Raw results (Figs. 3 and 4). The mean tidal volumes, inspiratory and expiratory times and respiratory rates (and their coefficient of variations) of the infants when studied in the two plethysmographs were similar, with no significant differences in the breathing patterns in the two plethysmographs (Table 3).

DISCUSSION

We have demonstrated that, although in vitro the two types of plethysmograph functioned similarly, in vivo the Jaeger plethysmograph gave less reproducible results with effective R_{aw} values that were higher than the inspiratory R_{aw} results from the Hammersmith plethysmograph, but lower inspiratory R_{aw} results. It has been previously emphasized[5] that it is important to validate R_{aw} measurements obtained with electronic compensation against the current ''gold standard,'' that is, those collected under BTPS conditions. We were fortunate our infant lung function facilities were sufficiently large to permit two plethysmographs within a single room with the necessary stable environmental conditions. This allowed movement of the sedated infants from one plethysmograph to the other and only 4 of the 15 infants recruited, woke up before they could be studied in the second plethysmograph.

Given previous concerns about the results of the Jaeger plethysmograph[5] and the possibility that the infants might wake up before they could be studied in the second plethysmograph, we did not randomize the order of use of the two plethysmographs. We, thus, cannot exclude that

TABLE 1—In Vitro R_{aw} Results From the Jaeger and Hammersmith Plethsymographs

	Measured resistance	
Added resistance	Jaeger plethysmograph	Hammersmith plethysmograph
1.94	2.03 (0.03)	1.94 (0.07)
4.85	5.10 (0.12)	4.86 (0.14)
6.80	6.91 (0.14)	6.70 (0.16)

The results are given as mean (SD) (kPa/L/sec).

TABLE 2—In vivo Study: Demographics and Lung Function Results

					Jaeger plethysmograph		Hammersmith plethysmograph	
	Gestational age (weeks)	Length (cm)	Weight (kg)	Corrected age (months)	FRC (ml)	R_{aw} (Eff) kPa/L/sec	FRC (ml)	R_{aw} (Insp) kPa/L/sec
	30	76	8.30	13	298	2.7	203	1.5
	31	83	10.84	13	274	2.9	207	2.3
	31	77	9.88	13	232	3.5	199	2.4
	28	73	7.80	13	295	4.0	282	3.1
	28	78	10.2	13	233	3.4	164	2.3
	28	77	11.22	13	208	4.1	189	1.7
	24	75	10.90	14	153	4.5	140	3.0
	32	80	9.10	12	225	6.4	152	3.9
	37	75	9.95	12	307	1.1	287	2.0
	39	61	4.9	6	150	5.8	107	3.4
	40	70	6.5	6	342	6.7	234	5.2
Mean (SD)	31.6 (5.0)	75.0(5.8)	9.1(2.0)	11.6 (2.8)	247 (62)	4.1 (1.7)	197 (56)	2.8 (1.1)

FRC, functional residual capacity; Raw (Eff), effective airway resistance; Raw (Insp), inspiratory airway resistance.

the infants were in a different stage of sleep when studied in the two plethysmographs, in particular that they might have been less deeply asleep when examined in the Jaeger plethysmograph. If this was the case, it might have contributed to the higher coefficient of variation of the R_{aw} results from the Jaeger plethysmograph. We were, however, unable to detect any differences in the breathing patterns in the infants in the two plethysmographs suggesting that the infants were in the same sleep state for both measurements In addition, the mean within patient coefficient of variation was similar to that previously reported using the Jaeger plethysmograph.[5]

In vivo, we initially compared effective R_{aw} measurements from the Jaeger plethysmograph with inspiratory R_{aw} results from the Hammersmith plethysmograph, as the two plethysmographs are set to function in those modes and thus likely to be so used in clinical practice and possibly also in research studies. We found significantly higher effective R_{aw} results with the Jaeger compared to the inspiratory R_{aw} results with the Hammersmith plethysmograph. This finding was not surprising as the effective R_{aw} calculations include data points from both expiration and inspiration and also from peak tidal flows when flow is unlikely to be laminar, particularly in infants

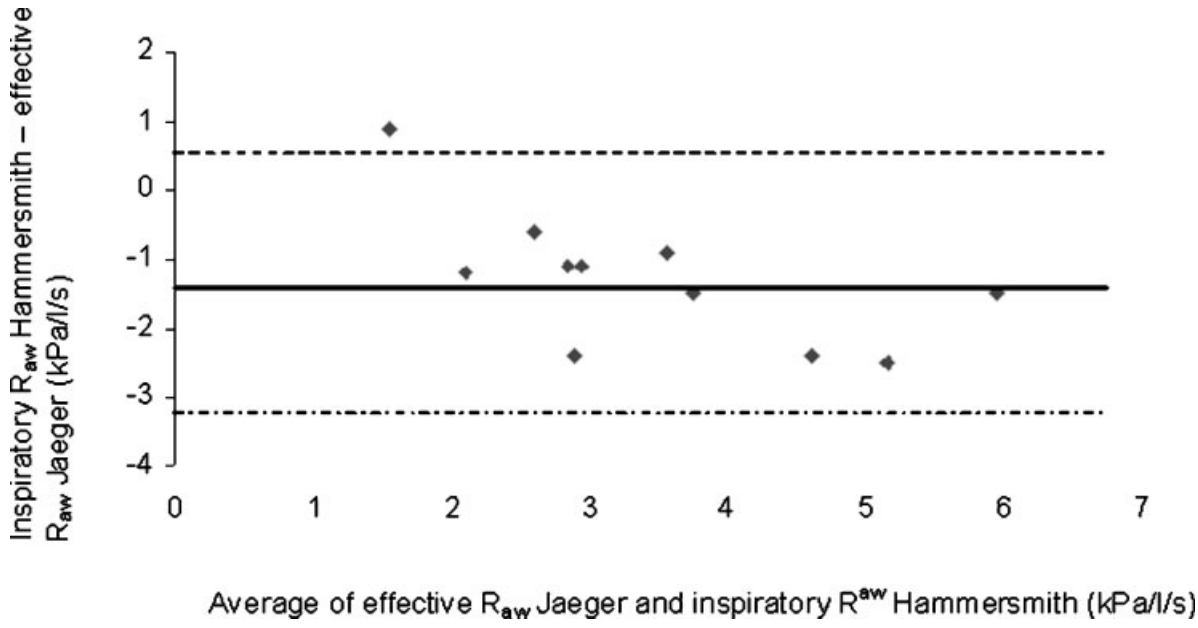

Fig. 2. Inspiratory R_{aw} measured by the Hammersmith plethysmograph compared to effective R_{aw} measured by the Jaeger plethysmograph. Bland and Altman plot of R_{aw} results. The solid line represents the mean difference and the dotted lines two standard deviations of the mean difference.

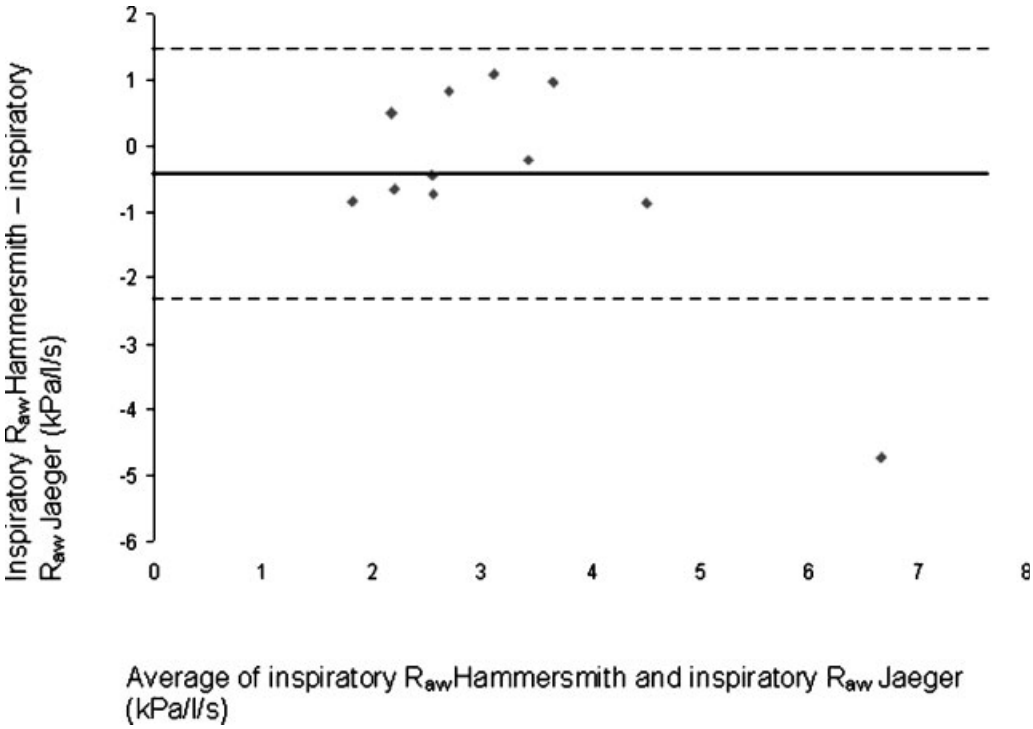

Fig. 3. Inspiratory R_{aw} measured by the Hammersmith plethysmograph compared to inspiratory R_{aw} measured by the Jaeger plethysmograph. Bland and Altman plot of R_{aw} results. The solid line represents the mean difference and the dotted lines two standard deviations of the mean difference.

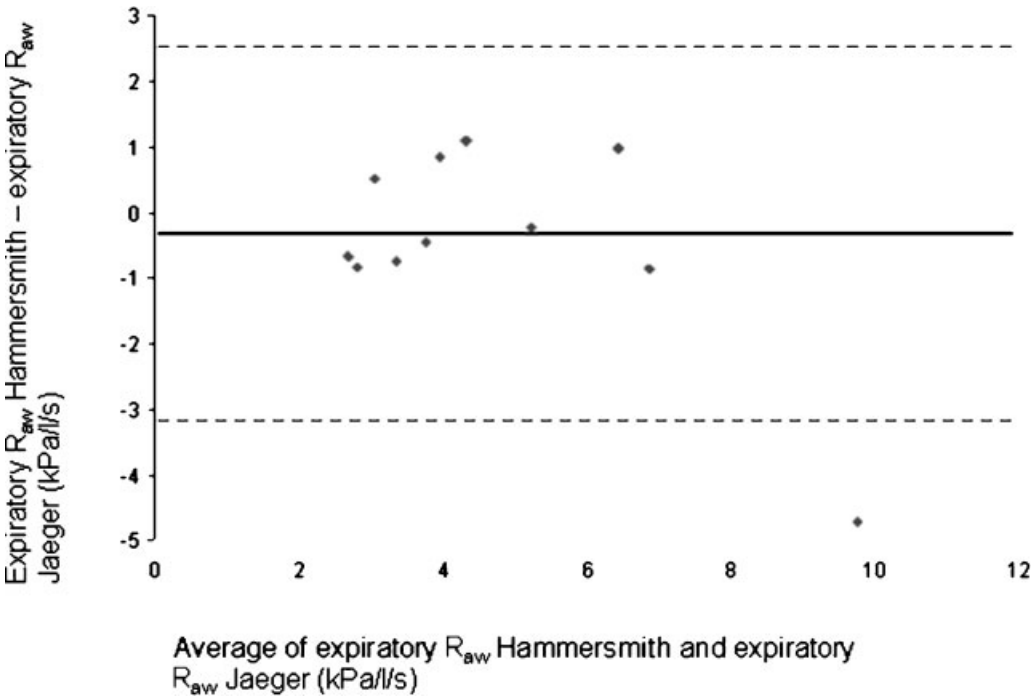

Fig. 4. Expiratory R_{aw} measured by the Hammersmith plethysmograph compared to expiratory R_{aw} measured by the Jaeger plethysmograph. Bland and Altman plot of R_{aw} results. The solid line represents the mean difference and the dotted lines two standard deviations of the mean difference.

TABLE 3— Tidal Breathing Parameters in the Jaeger and Hammersmith Plethysmographs

	Jaeger		Hammersmith	
	Mean (SD)	CV %	Mean (SD)	CV %
Tidal volume (ml/kg)	6.2 (0.4)	11.7	6.3 (0.3)	10.8
Inspiratory time (sec)	0.86 (0.1)	15.0	0.84 (0.1)	16.2
Expiratory time (sec)	0.93 (0.09)	17.2	0.92 (0.1)	17.5
Respiratory rate (/min)	33.8 (4.6)	13.6	34.9 (4.4)	12.6

with lung disease. The higher coefficient of variation results for effective R_{aw} compared to those for inspiratory R_{aw} may in part be due to this, as relatively small changes in flow which is not laminar will have striking effects on effective R_{aw} results.

We also compared the inspiratory and expiratory resistance results, as this gives a more appropriate comparison of the results of the two plethysmographs. It was possible to calculate these resistance values for the Jaeger plethysmograph by dividing the inspiratory and expiratory specific resistance results, data routinely provided on screen, by the FRC corrected for half the anatomical dead space. The resistances were measured over the 0% to 50% part of peak inspiratory and expiratory flow. The Hammersmith plethysmograph software enabled us to obtain data over the same portions of the flow traces. The Jaeger plethysmograph inspiratory and expiratory R_{aw} results were lower and less reproducible than those obtained using the Hammersmith plethysmograph. Subbarao et al.[5] also found what they described as some ''implausibly low results'' in similarly aged infants using the Jaeger plethysmograph, but unfortunately were unable to compare results with a conventional plethysmograph. The reason for the low values remains unclear. We have, however, previously reported that the FRC results were significantly lower using the Jaeger compared to the Hammersmith plethysmograph in vivo[8] and in vitro.[9] Given that low FRC results would increase R_{aw} results, the discrepancy we report in R_{aw} results between the two plethysmographs is even more marked.

The most likely factor for the difference in the resistance results of the two plethysmographs lies in the electrical compensation incorporated by the Jaeger plethysmograph. This compensation attempts to correct gross looping of the flow/plethysmograph chamber pressure trace by measuring and allowing for differences in alveolar and chamber temperature and saturation. It has been calculated that the effect of this artifact on plethysmograph chamber pressure may be ten times greater than that generated by changes in alveolar pressure due to the resistance of the airways[13] and has even been used to monitor tidal breathing in young infants.[14] Thus small errors in compensation are likely to have significant effects on the results. Use of electronic BTPS compensation has proved useful in assessment of school and preschool children, differentiating between those with and without lung disease and in tests of bronchial reactivity.[15,16] One possible explanation for failure of the Jaeger infant plethysmograph to discriminate between healthy infants and those with cystic fibrosis[5] is that the sleeping infants have lower respiratory rates than unsedated children so that the degree of compensation needed would be greater.[5] Furthermore, the infants currently studied had a relatively long inspiratory time to total respiratory cycle (0.48 compared to 0.4 usually found in older children) and hence their breaths would require greater compensation. A frequency dependency of R_{aw} has been demonstrated when electronic compensation is used.[14,17] We, however, do not feel this explains the differences in the results of the two plethysmographs, as there were no statistically significant differences in the breathing patterns of the infants when studied in the two plethysmograph types (Table 2). The respiratory rates of the infants were also very similar to the frequencies used to calibrate the plethysmographs.

In the in vitro situation there are obviously no differences in plethysmograph chamber and test lung temperature and saturation, and the flow through the resistances was linear through out the tidal volume. It is, thus, not surprising we found the Jaeger plethysmograph gave reproducible and accurate results which were very similar to those from the Hammersmith plethysmograph when tested in vitro despite comparing ''effective'' R_{aw} with inspiratory R_{aw}.

In conclusion, electronic compensation to simulate body temperature, atmospheric pressure and saturation with water vapor resulted in lower and less reproducible R_{aw} results compared to results obtained when the expired air was maintained at BTPS conditions. As a consequence, we recommend that infant plethysmographic assessment of airway resistance in infants should be undertaken with an instrument that incorporates a heated rebreathing system.

ACKNOWLEDGMENTS

Dr Simon Broughton is supported by a peer reviewed grant from WellChild, who received funding from Abbott Laboratories. We thank Mrs Deirdre Gibbons for secretarial assistance.

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