Does Experience Influence the Performance of Neonatal and Pediatric Manual Hyperinflation?

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BACKGROUND: Manual hyperinflation (MH) is used to improve mucociliary clearance and alveolar expansion in mechanically ventilated patients. Despite the popularity of MH, studies with adults have shown considerable variability in the results from its use. This study assessed if professional training on the application of MH influences its performance. METHODS: An experimental study was conducted with physiotherapists, including 11 with previous professional experience (experienced) and 11 without previous experience (inexperienced). They applied MH in a test lung model using self-inflating bags in 2 sizes (infant and pediatric) from 3 manufacturers (Hudson, Laerdal, and JG Moriya). The test lung simulated the lung mechanics of a newborn and a pediatric patient in 2 different clinical situations: at normal and reduced compliance. The professionals were instructed to perform MH as described in the literature. Measurements of inspiratory volume, peak inspiratory pressure, peak inspiratory flow, and peak expiratory flow were recorded using a pneumotachograph in each condition. RESULTS: The delivered peak inspiratory flow was higher in the experienced group ($P = .03$) than in the inexperienced group. This result was observed in both neonatal and pediatric self-inflating bags. There was no difference in the parameters delivered between the experienced and inexperienced groups. CONCLUSIONS: The experienced and inexperienced groups were similar in their overall MH performance; the only difference was the observation of the highest PIF in the results from the experienced group. *Key words: resuscitation; manual hyperinflation; respiratory therapy; self-inflating bag; pediatric; respiratory function monitor.*
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Introduction

Manual hyperinflation (MH) is a maneuver commonly used in the ICU,[1] to prevent complications by improving secretion clearance and alveolar expansion in mechanically ventilated patients.[2] The technique provides a tidal volume at least 50% greater than that delivered by a mechanical ventilator.[3] The MH uses a self-inflating bag (SIB) or a resuscitation circuit to hyperventilate patients who are intubated. The increase in tidal volume improves alveolar ventilation, prevents or reverses atelectasis,[2,4] and reduces

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airway resistance in adults.[2] The MH also increases expiratory flow, mobilizing bronchial secretions.[5-7] MH involves the disconnection of the patient from the ventilator, followed by inflation of the lungs, and can produce some side effects. The application of high airway pressure or tidal volume might be hazardous, especially to pediatric and neonatal lungs.[8]

The performance of MH differs between and within countries.[1,9] Guidelines for the performance of this maneuver are nonexistent; however, there are recommendations for the best practice of MH in adults.[10] Furthermore, several factors can influence the procedure's performance and consequently its results. It has been suggested that the type of SIB used,[7,11] the technique used for bag compression,[12] the patient's lung compliance,[13] and the use of a manometer for visual feedback[14,15] can affect the outcomes.

Despite concerns about the efficacy and safety of MH, there are no studies evaluating the influence of professional experience in the outcomes of pediatric MH. In addition, there are limited studies investigating operator reliability during manual ventilation.[16,17] It is unclear if the psychomotor ability of professionals in delivering target volumes and pressures during MH is dependent on the length of time of the activity.

In this study an investigation of the operator's reliability and consistency was conducted in order to ensure repeatable conditions in the performance of MH and to enhance its beneficial effects while minimizing potential detrimental effects. The aim of this study was to assess if professional experience influences the outcomes of MH in neonatal and pediatric lung models. The MH ventilatory parameters were also analyzed in view of the operator's physical characteristics.

QUICK LOOK

Current knowledge

Manual ventilation is frequently used to provide hyperinflation for secretion removal, and to prevent hypoxemia before and after airway suctioning. The adult literature suggests significant variability in the delivered airway pressures, volume, and flow during manual ventilation.

What this paper contributes to our knowledge

During manual hyperventilation of a neonatal or pediatric lung model, there was an increase in inspiratory volume, and peak inspiratory pressure correlated with the experience level of physiotherapists. There were no differences in rate or peak expiratory flow between inexperienced and experienced physiotherapists.

Methods

Design and Ethics

The study was conducted using a randomized crossover trial design approved by the University of Campinas ethics committee.

Study Population

Twenty-two physiotherapists were recruited at the university hospital of Universidade Estadual de Campinas, including 11 experienced and 11 inexperienced physiotherapists. The experienced group was composed of specialists in pediatric physiotherapy with at least one year of experience in the pediatric ICU. The inexperienced group was composed of recently graduated physiotherapy undergraduate students. These professionals were submitted to a standardized interview, when data on their weight, height, and length of experience were collected. Moreover, a hand-grip strength test, using a dynamometer (Crown manual, Oswaldo Filizola, São Paulo, Brazil) was performed, in which the participants were instructed to squeeze the dynamometer with the dominant hand and apply as much force as possible. The best result from 3 attempts was recorded.

No training was conducted with participants prior to the study start. Participants were just instructed to perform 10 MH maneuvers as described in the literature: slow inflation, inspiratory pause, and fast bag release.[17] Each participant used only the dominant hand.

Lung Test

The MH was simulated in a test lung model (Ventilator Tester 2, Biotek, Winooski, Vermont) to set up the respiratory mechanics of a neonate and a pediatric intubated patient. Measurements were recorded at different values of pulmonary compliance and resistance in order to simulate 2 clinically distinct situations: a healthy lung (normal respiratory mechanics), and a restrictive lung (decreased pulmonary compliance). The test lung resistance was adjusted for newborns at 50 cm H_2O/L/s and for children at 20 cm H_2O/L/s. The pulmonary compliance value for a healthy newborn was represented at 3 mL/cm H_2O and for reduced compliance at 1 mL/cm H_2O. In the pediatric model a physiological situation was simulated as compliant at 10 mL/cm H_2O and reduced at 3 mL/cm H_2O. The values of compliance and resistance were based on a previous study.[18] The test lung apparatus was calibrated considering the environmental temperature, atmospheric pressure, and relative air humidity before its use in the experiments.

Self-Inflating Bag

Each physiotherapist used 6 new SIB units. They were obtained from 3 different manufacturers: Hudson RCI (Research Triangle Park, North Carolina), Laerdal Medical (Stavanger, Norway), and JG Moriya (São Paulo, Brazil).

All SIBs were used in the 2 models: neonatal and pediatric. The SIBs were connected to a 50-psig source of air, and 0, 5, 10, and 15 L/min of oxygen was delivered to the oxygen reservoir. The oxygen reservoir was attached to the units when the oxygen flow was above 5 L/min. The pressure valve relief was kept unlocked.

Pneumotachograph

A sensor (Capnostat, Novametrix, Wallingford, Connecticut) in the pneumotachograph (CO_2SMO Plus, Novametrix, Wallingford, Connecticut) was fitted at the interface between the test lung and SIBs with no substantial increase in dead space. The signals were recorded by software (AnalysisPlus, Novametrix, Wallingford, Connecticut) for further analysis. The variables measured were manual hyperinflation rate, inspiratory volume, peak inspiratory pressure (PIP), peak inspiratory flow (PIF), and peak expiratory flow (PEF).

Data Collection

The order of the SIB distribution, compliance settings, and experience levels of the subjects were randomized. No visual or verbal feedback was provided during testing. The participants were given one minute to familiarize with the equipment and environment, and instructed to ventilate the test lung as they would ventilate a patient. They were also encouraged to rest as long as necessary between measurements, to avoid fatigue.

Statistical Analysis

Statistical analysis was performed using statistics software (SAS 9.1.3, SAS Institute, Cary, North Carolina). The results were transformed into ranks for the analysis, because of the absence of a normal data distribution. The average of 10 breaths per individual test was calculated. The Spearman rank correlation test was performed to evaluate the correlation between ventilatory outcomes and professionals' physical characteristics. The Mann-Whitney test was performed to compare physical characteristics among the experienced and inexperienced groups. The ventilatory parameters were compared between groups using analysis of variance for repeated measurements. The Tukey test was used for post hoc analysis. The results were reported as averages ± standard deviation. The significance level for the statistical tests was $P < .05$. According to previous studies,[11,19] it was predicted that at least 10 subjects would be required for the proposed evaluation.

Table 1. Comparison of Physical Characteristics Between the Inexperienced and Experienced Groups

	Inexperienced (n = 11)	Experienced (n = 11)	P*
Hand-grip strength, kg force	27 (18–43)	26 (23–41)	.95
Weight, kg	60 (43–70)	53 (48–84)	.29
Height, cm	163 (152–174)	161 (155–174)	.65

Results presented by mean (minimum–maximum).
* Mann-Whitney test.

Table 2. Comparison of Ventilatory Parameters Delivered by the Inexperienced and Experienced Groups

	Models	Inexperienced (n = 11)	Experienced (n = 11)	P
Manual Hyperinflation Rate, cycles/min	Neonatal	26.63 ± 13.00	31.06 ± 12.55	.80
	Pediatric	28.72 ± 11.52	27.02 ± 9.61	.78
Inspiratory Volume, mL	Neonatal	44.81 ± 18.99	49.81 ± 16.22	.07
	Pediatric	151.08 ± 47.33	164.17 ± 48.99	.15
Peak Inspiratory Pressure, cm H_2O	Neonatal	23.16 ± 7.61	26.09 ± 5.96	.06
	Pediatric	25.88 ± 9.21	28.25 ± 8.62	.05
Peak Inspiratory Flow, L/min	Neonatal	11.03 ± 4.36	13.93 ± 3.65	.03
	Pediatric	25.20 ± 7.79	32.11 ± 9.75	.03
Peak Expiratory Flow, L/min	Neonatal	14.62 ± 3.53	15.57 ± 5.05	.36
	Pediatric	38.01 ± 6.14	39.48 ± 4.23	.33

Values are mean ± SD.

Results

Twenty-two female physiotherapists, ages between 22 and 48 years old (mean 26.90 ± 7.30 y), were recruited for the study. A total of 10,560 MHs have been previously conducted by these physiotherapists. There were no significant differences in physical characteristics and hand-grip strength between the experienced and inexperienced groups (Table 1). Nevertheless, variations in ventilation performance and a significant difference in PIF were observed between the groups. The PIF delivered by the experienced group was significantly greater than that delivered by the inexperienced group ($P = .03$ for neonatal and .03 for pediatric) (Table 2). The experienced group delivered a PIF 2.9 L/min higher than that generated by the inexperienced group in the neonatal SIB experiment. A difference of 6.9 L/min between groups was observed in the pediatric SIB experiment.

An increase in inspiratory volume and PIP was correlated to practice levels; however, the difference was not significant (see Table 2). There were no differences in MH

Table 3. Spearman Correlation Between Inspiratory Volume, PIF, PIP, and Professionals' Physical Characteristics

	Inspiratory Volume		Peak Inspiratory Flow		Peak Inspiratory Pressure	
	Neonatal	Pediatric	Neonatal	Pediatric	Neonatal	Pediatric
Hand-grip strength	0.147	–0.02780	0.326	0.11518	0.365	0.12936
Weight	0.039	–0.30752	0.231	0.11702	0.190	–0.10401
Height	0.076	–0.34127	0.120	–0.17234	0.165	–0.24830

Table 4. Comparison Between Ventilatory Parameters Delivered With Neonatal and Pediatric Self-Inflating Bags in a Normal and Reduced Compliance

	Model	Compliance	Mean ± SD	95% CI	*P*
Manual Hyperinflation Rate, cycle/min	Neonatal	Normal	26.39 ± 12.74	28.61–31.70	.14
		Reduced	31.60 ± 12.78	30.06–33.15	
	Pediatric	Normal	28.17 ± 10.92	26.85–29.49	.50
		Reduced	27.57 ± 10.35	26.32–28.83	
Inspiratory Volume, mL	Neonatal	Normal	60.37 ± 15.95	58.43–62.30	< .001
		Reduced	34.25 ± 6.30	33.49–35.01	
	Pediatric	Normal	192.69 ± 34.05	188.57–196.81	< .001
		Reduced	122.56 ± 33.19	118.54–126.59	
Peak Inspiratory Pressure, cm H_2O	Neonatal	Normal	19.99 ± 5.19	19.36–20.62	< .001
		Reduced	29.26 ± 5.26	28.62–29.89	
	Pediatric	Normal	21.03 ± 3.83	20.57–21.50	< .001
		Reduced	33.11 ± 8.61	32.06–34.15	
Peak Inspiratory Flow, L/min	Neonatal	Normal	14.23 ± 4.26	13.71–14.74	< .001
		Reduced	10.73 ± 3.50	10.31–11.16	
	Pediatric	Normal	32.83 ± 8.95	31.74–33.91	< .001
		Reduced	24.48 ± 8.04	23.51–25.45	
Peak Expiratory Flow, L/min	Neonatal	Normal	15.47 ± 3.03	15.10–15.84	.01
		Reduced	14.72 ± 2.92	14.37–15.08	
	Pediatric	Normal	38.34 ± 3.77	37.89–38.80	.35
		Reduced	39.16 ± 6.49	38.37–39.94	
		Reduced	0.75 ± 0.32	0.71–0.79	

rate and PEF between inexperienced and experienced physiotherapists. These results were obtained independently of the compliance settings, type of SIB, or oxygen flow provided.

MH volumes, airway pressures, and PIF did not show a correlation with the operator's physical characteristics or hand-grip strength (Table 3).

The ventilatory parameters were significantly different between the normal and reduced compliance settings ($P < .001$) (Table 4). The study participants delivered a significantly lower inspiratory volume in the low compliance setting than in the physiological compliance setting. A significant difference in the delivered PIP was observed; the simulated neonatal and pediatric physiological compliance setting showed a lower PIP than the reduced compliance setting. Furthermore, the PIF analysis also showed a significant difference between the low and high compliance settings. No differences were observed in the manual hyperinflation rate ($P = .14$ for neonatal, and $P = .50$ for pediatric), and pediatric PEF ($P = .35$) between different compliance settings, except for neonatal PEF ($P = .01$).

Discussion

The most striking feature in the results was the overall similarity in the MH performance between the inexperienced and experienced groups. Both groups achieved an increase in volume that was delivered within a safe and effective pressure range. The instructions given to participants to ventilate the test lung as described in the literature may partly explain the overall similarity in the MH performance between the inexperienced and experienced volunteers.

Significant differences in the PIF delivered by the groups with different experience levels were observed, regardless of the homogeneity in physical characteristics and hand-grip strength among the physiotherapists. Maxwell and Ellis[20] also observed a wide variability in MH procedure performed by physiotherapists using adult SIBs, despite the standardization of this ventilation technique. The PIF generated by the experienced physiotherapists was higher than that delivered by the inexperienced ones. The inexperienced professionals asked basic questions regarding the handling of the SIB during the experiments and performed the ventilation maneuver with caution, whereas the experienced group showed more confidence during the procedure. It is assumed that the theoretical-practical knowledge of the experienced group provided enhanced self-confidence in performing MH and affected how the therapists manipulated the bag. The higher PIF delivered by the experienced group without significant volume increase can be explained by the increase in the compression speed of the bag.

It is known that an important mechanism during mucus movement in the airways is a 2-phase gas/liquid interaction. This refers to how the high peak flows create instability and turbulence on the surface of the mucus, disrupting the mucus layer.[21] Based on this assumption, the group of experienced professionals would be better prepared for enhancing secretion clearance. On the other hand, there is growing scientific evidence showing that the enhancement of secretion clearance is dependent on the ratio or difference between inspiratory and expiratory peak flows.[22-24] The PEF should be at least 10% higher than PIF in order to improve secretion clearance. In this study, a similar PEF between the groups was observed ($P = .36$ for neonatal and $P = .33$ for pediatric). The complete or rapid release of the SIB allows maximizing air flow from distal to proximal parts.[12]

Differences in inspiratory volume or PIP provided by the different groups were not observed; this result agrees with the results obtained by Roehr et al[25] and other researchers.[26] Volumes and pressures delivered during the MH should be monitored to obtain accurate ventilation. The use of a manometer attached to the SIB is recommended to provide visual feedback to the professional handling the SIB.[14,15]

Manual ventilation is a complex skill to learn. It is known that exposure to intensive care activities increases this skill when handling critical patients, and therefore leads to more effective treatment.[26] However, an important variation has been reported between the performance of different operators applying pediatric SIB[17,18,27] and adult SIB.[28] The absence of volume and pressure feedbacks during ventilation using SIBs affects the accuracy and increases the variability during ventilation.[14,17]

The ventilatory variability provided by experienced and inexperienced professionals applying the MH might become more evident in a clinical setting with adverse conditions, especially during the ventilation of a preterm infant. Accurate ventilation can prevent complications such as barotrauma, hypoventilation, and hyperventilation in daily practice. Manual ventilation requires education and practical training in order to prevent these risks.[29]

The characteristics of the operator that could influence the ventilation performance are not well defined yet.[30,31] No correlation between the operator's characteristics and ventilatory parameters was observed in the present study.

Irrespective of the different experience levels tested, it was observed that the different compliance levels influenced the ventilatory parameters. Low compliance settings reduced inspiratory volume and increased PIP, when compared with high compliance settings. The PIP was increased because it reflected an increased plateau pressure due to the low adjusted compliance, even in the presence of a reduced generated inspiratory volume. PEF is mostly the result of the compliance of the lungs and surrounding tissues such as muscles, fat, and bony structures of the thorax[1]; therefore, no difference was detected in this variable between the outcomes from the studied groups. In the Paulus et al study[1] the nurses were capable of producing a PEF at least 10% larger than PIF in the noncompliant lung only. This might suggest that MH could be more effective in stiff lungs than in normal or over-compliant lungs.[1]

Although the test lung can be programmed to simulate the normal lung respiratory mechanics, it does not allow the professional to receive the feedback that is common in clinical practice, such as chest expansion and vital signs. Even though subjective, these signs could show improper ventilation.

The SIB is a simple device to handle. This study showed that the MH could be used in a safe and efficient way by professionals who do not have specific and practical experience. In addition, the standardization of operator performance and documentation of the pattern of ventilation in clinical studies, examining the efficacy of MH for preventing or treating lung derecruitment and assisting secretion clearance, is highly recommended.

Conclusions

MH was performed safely by experienced and inexperienced professionals, and the outcomes produced by these groups were similar. Experienced professionals delivered a higher PIF than the inexperienced ones. The operator's physical characteristics are not predictors of appropriate ventilation performance.

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