

## Paediatrics

# Ventilator hyperinflation in paediatric critical care: a survey of current physiotherapy practice in the United Kingdom and Ireland

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## Introduction

Physiotherapists in paediatric intensive care units (PICUs) use a variety of techniques to remove retained bronchopulmonary secretions and improve work of breathing in children who are mechanically ventilated. Ventilator hyperinflation (VHI) is commonly used in adults to aid secretion removal without disrupting the integrity of the ventilatory circuit. This study aimed to identify current practice of VHI within paediatrics in the United Kingdom (UK) and Ireland.

## Methods

A survey was designed and distributed via email to senior physiotherapists in all 22 PICUs across the UK and Ireland. Physiotherapists working in adult critical care were excluded. Responses were analysed via descriptive statistics, with content analysis used for free text open questions.

## Results

Twenty-nine surveys were completed, of which 17 individuals (58%) indicated that they used VHI. VHI was used infrequently (commonly less than once per month, N=13 76.5%) and techniques were generally taught at the bedside by senior colleagues. Indications for using VHI rather than manual hyperinflations included concerns over de-recruitment on disconnection from the ventilator (N=11, 64.8%), patients with COVID-19 and those with a high respiratory infection risk (N=8, 47%). Approaches to applying VHI varied, with target peak inspiratory pressures between 28cmH<sub>2</sub>O and 42cmH<sub>2</sub>O.

## Conclusion

The survey responses returned suggest that the use of VHI in PICU is infrequent, with no standard approach to its use. However, response rate is unknown owing to survey distribution method. There appear to be some occasions where respondents would choose VHI over manual hyperinflations and further research is needed to explore these further.

## INTRODUCTION

Physiotherapists are an integral part of the multi-disciplinary team within the Paediatric Intensive Care Unit (PICU). Children are admitted to PICU following life-saving interventions such as surgery, anaesthesia, sedation and invasive mechanical ventilation. Although these can be vital for survival, they may be accompanied by negative secondary effects such as reduced natural cough reflex, partial or total alveolar collapse (atelectasis), inability to clear secretions and abnormal gas exchange. The role of the physiotherapist in PICU is to address the negative effects of prolonged immobility and to remove retained bronchopulmonary secretions, reducing airway resistance and improving work of breathing.<sup>1</sup> Various techniques may be utilised, including

manual hyperinflation (MHI), chest wall vibrations, instillation of saline and suctioning.<sup>2</sup>

The use of MHI is reported in many chest physiotherapy studies and typically involve delivering a low flow, large volume inspiratory breath with a brief inspiratory hold followed by a quick release of the bag to enhance peak expiratory flow.<sup>3</sup> The process requires disconnection of the patient from the ventilator circuit, which can cause loss of peak end expiratory pressure and potentially poses a risk from airborne infections.<sup>4</sup>

An alternative technique of ventilator hyperinflation (VHI) is frequently utilised in adult intensive care units.<sup>5</sup> Ventilator settings are manipulated to aid secretion clearance via an increase in peak inspiratory flow to peak expiratory flow ratio (PIF:PEF). No disconnection is required, thereby potentially reducing the risks associated with MHI.

Despite these documented benefits, MHI is still the most frequently utilised technique by physiotherapists in PICU.<sup>3</sup>

To the author's knowledge, there has been no published research investigating the physiological effects of VHI and subsequent recommendations for its use within a paediatric population are lacking. The COVID-19 pandemic required a swift response to minimise the risk of airborne infection from ventilated patients. Anecdotally, paediatric critical care physiotherapists quickly adapted VHI recommendations from adult studies and implemented them within their PICU. This study aimed to explore the current use of VHI within PICUs in the UK and Ireland, including the training received and implementation of use. The objectives were:

- Investigate the practice of VHI in PICU's across the UK and Ireland
- Determine the frequency and clinical reasoning for VHI use
- Explore the education and preferred technique for VHI.

## METHODS

### PERMISSIONS AND APPROVALS

The study was registered as a service evaluation (005431) at the primary author's place of work.

### SURVEY DEVELOPMENT

A survey was developed based on a previous adult VHI survey by Hayes et al,<sup>6</sup> which had utilised experts in the field and previous surveys to ensure face, content and construct validity. The survey was adapted with permission of the authors to include specific questions relevant to the paediatric population. A pilot study was undertaken with four paediatric physiotherapists, one working in clinical academia and three working in paediatric intensive care who used VHI within their practice. Following feedback, minor amendments were made with additional demographic and clinical questions added. The final 27-item survey contained both closed and open-ended questions and was transcribed for electronic use via Google forms (see Appendix). Key domains included frequency of use, presence of a protocol, indications and contraindications, clinical decision making, choice of technique and outcome measures.

### SAMPLE

Inclusion criteria were qualified physiotherapists, of any level of clinical experience, currently working in a paediatric intensive care unit in the United Kingdom or Ireland. Exclusion criteria were physiotherapy staff working solely in adult intensive care.

### DATA COLLECTION

The author obtained details of all 22 PICUs within the UK and Ireland via the PICANet database.<sup>7</sup> In April 2022, a named senior physiotherapist (Agenda for Change Band 7

or above) was contacted directly via email under the "legitimate interest" section of the General Data Protection Regulation. An explanation of the survey, including management of the data, was included alongside a link for survey completion. The physiotherapist was asked to share the survey with other physiotherapy team members within their department to ensure that different perspectives and experience levels could be explored. A weekly reminder was sent to the named senior physiotherapist for four weeks, when the survey link closed. Consent was implied by completion of the survey.

### DATA ANALYSIS

All survey responses were inputted to Microsoft Excel for analysis and are detailed below. Demographic and quantitative responses were analysed via descriptive statistics and presented as means and standard deviations (or median and range as appropriate) as a measure of spread, alongside percentages. Open-ended questions, which provided free-text data, were analysed via content analysis. A coding framework was created by both authors collaboratively, based on the nature of the questions. Codes were assigned to the content independently by both authors, compared and discussed. Themes were identified.

## RESULTS

### DEMOGRAPHICS

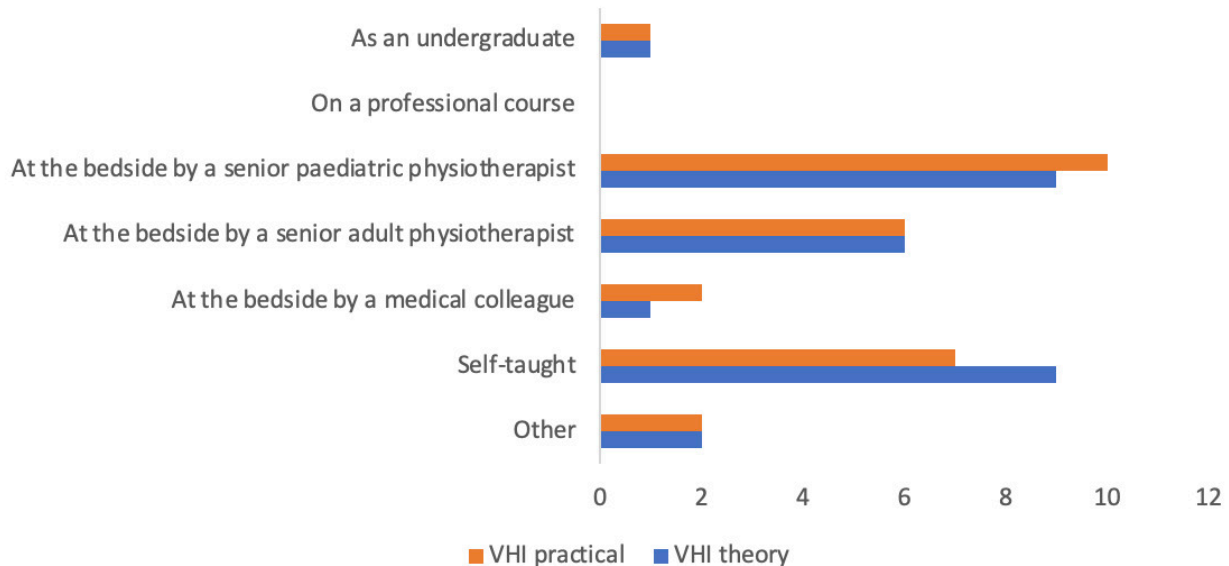
Completed surveys were received from 29 respondents. Responses were received from all areas, except the North East and Northern Ireland. Due to the unknown potential number of respondents, a response rate could not be calculated. The physiotherapists who completed the survey had been working in a level 3 PICU, providing intensive and critical care, for a median of 6-10 years, ranging from less than two years to greater than 20 years (Table 1). The mean (SD) number of PICU beds on their units was 18 (5.8).

### USE OF VHI IN PICU

Seventeen (58.6%) individuals used VHI within their practice, with band 7 (highly specialist) physiotherapists being the most likely to undertake the intervention (100%). Eight respondents (27.6%) did not currently use VHI but were interested in using it in the future. The following results are from the 17 individuals using VHI, all 27 items are represented and there was no missing data for any question. The frequency with which VHI is utilised in PICU was low, with 23.5% (n=4) of those who used VHI using it less than once per week and the majority (n=13, 76.5%) using VHI less than once per month. Of those who used VHI, the majority of respondents (n=13, 76.5%) were able to apply the technique without the need for additional medical approval. Seven respondents (41.2%) stated that they used a paediatric protocol to guide their practice, one (5.9%) followed an adult protocol and nine (52.9%) did not utilise a VHI protocol.

**Table 1. Demographics of respondents**

Demographic information (N=29)		N (%)
Years qualified as a physiotherapist	0-2	1 (3.4)
	3-5	4 (13.8)
	6-10	8 (27.6)
	11-15	6 (20.7)
	16-20	3 (10.3)
	>20	7 (24.1)
Years of paediatric ICU experience	0-2	6 (20.7)
	3-5	4 (13.8)
	6-10	7 (24.1)
	11-15	7 (24.1)
	16-20	1 (3.4)
	>20	4 (13.8)
Highest level of qualification	Diploma of Physiotherapy	2 (6.9)
	Bachelor of Physiotherapy / Graduate entry Masters in Physiotherapy	23 (79.3)
	Post graduate Diploma	1 (3.4)
	Postgraduate Masters degree	3 (10.3)
	PhD / Doctorate of Physiotherapy	0 (0)
Geographical location	East Anglia	1 (3.4)
	East Midlands	1 (3.4)
	Greater London	11 (37.9)
	Ireland	1 (3.4)
	North East	0 (0)
	Northern Ireland	0 (0)
	North West	6 (20.7)
	Scotland	1 (3.4)
	South East	2 (6.9)
	South West	2 (6.9)
	Wales	1 (3.4)
	West Midlands	2 (6.9)
	Yorkshire and the Humber	1 (3.4)



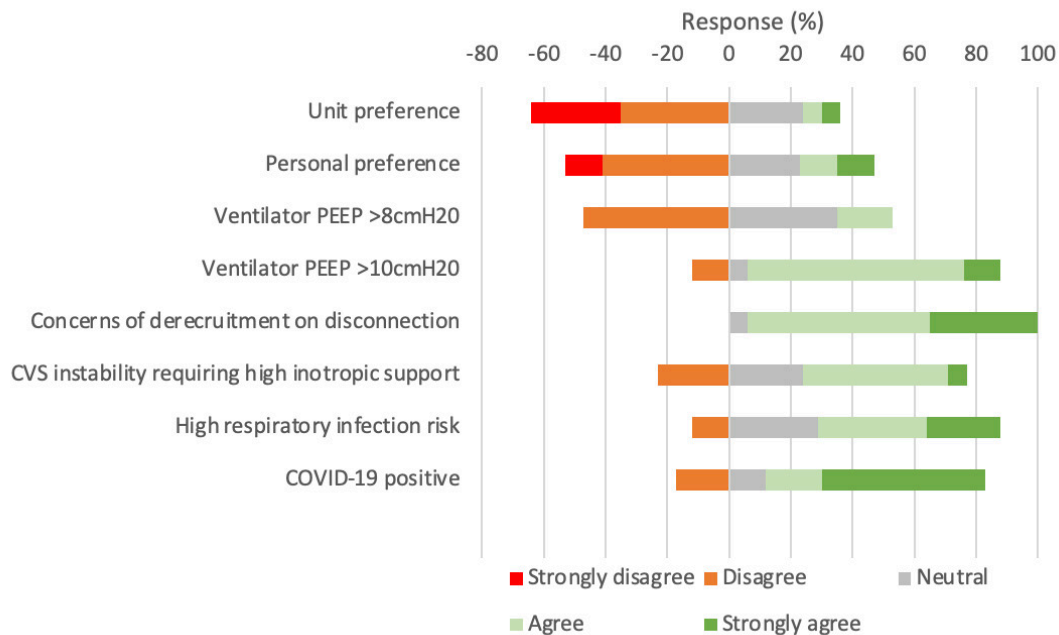
**Figure 1. Responses to the question, "where did you learn the practical and theoretical technique of VHI?"**

Regarding VHI training, one physiotherapist was taught the theoretical and practical aspects of VHI as an undergraduate whilst the majority were taught either at the bedside by a senior physiotherapist or were self-taught (Figure 1).

Respondents were asked to consider their own practice and state when they would choose to undertake VHI rather than MHI, which is the more commonly used intervention in PICU (Table 2, Figure 2).

**Table 2. Main indications and contraindications for VHI**

Main indications for VHI	Number	Main contraindications for VHI	Number
Poor tolerance to disconnection	11 (64.8%)	Undrained pneumothorax	14 (82.4%)
High risk of de-recruitment	11 (64.8%)	Significant cardiovascular instability	8 (47%)
High ventilation pressures	10 (58.8%)	Bullae / surgical emphysema	6 (35.3%)
Infection control	8 (47%)	High peak airway pressures	4 (23.5%)

**Figure 2. Responses to the question, "to what extent do the following factors influence your decision to use VHI?"**

## TECHNIQUE

One respondent routinely requested pharmacological paralysis for their patients prior to undertaking VHI (n=1, 5.9%). Four main ventilation modes were commonly used during VHI; synchronised intermittent mandatory ventilation (SIMV) pressure control (n=11, 64.7%), SIMV volume control (n=10, 58.8%), pressure regulated volume control (n=10, 58.8%) and bi-level mode (n=8, 47.1%). Three individuals (17.6%) used VHI during continuous positive airway pressure (CPAP) and pressure support modes.

In preparation for VHI, respondents variously stated that they would calculate target tidal volume, agree maximal peak airway pressure, adjust ventilator alarm limits and reduce respiratory rate to maintain minute ventilation. Adjusting the inspiratory time was mentioned by two individuals (11.8%). The majority of respondents (n=14, 82.4%) stated that they would position the patient according to their assessment findings and subsequent treatment aims. Four respondents (23.5%) advised that they would use position changes during the treatment session if the patient was able to tolerate it. A maximum peak inspiratory pressure was identified by eight individuals, which ranged be-

tween 28cmH<sub>2</sub>O to 42 cmH<sub>2</sub>O. The most common responses were 30cmH<sub>2</sub>O (n=3, 37.5%) and 40cmH<sub>2</sub>O (n=3, 37.5%).

During an average treatment session with VHI, either three to four hyperinflation breaths were delivered to the patient (n=10, 58.8%), or five to ten hyperinflation breaths (n=4, 23.5%) per set. The majority of individuals stated that they would repeat each set of hyperinflation breaths three to four times (n=14, 83.4%). [Table 3](#) documents the individual responses regarding VHI technique with answers grouped using content analysis.

The commonest outcome measures used to assess the effectiveness of the treatment was a change in tidal volume (n=13, 76.5%) or a change in auscultation findings (n=13, 76.5%).

## DISCUSSION

The use of VHI in PICU's in the UK and Ireland appears low, with high variability in the technique. Of the 29 physiotherapists who responded to the survey, 17 stated that they utilised the technique, with the majority (n=13, 76.5%) using it less than once per month. Training and skill acqui-

**Table 3. Responses to the question, “how would you most commonly perform VHI?”**

	Ventilation	Pressure	Volume	Inspiratory hold	Duration of each cycle	Additional information
1						Patient specific
2	<10kgs SIMV PC set RR, set i time	Set PIP to 20% above delivered PIP			1 minute, return settings to baseline	
2	>10kgs SIMV VC set RR, set i time		Gradually increase Vt by 10mls to target a peak pressure of 40cmH <sub>2</sub> O		1 minute, return settings to baseline	
3		Increase PIP		Yes		Depends on situation
4			Increase Vt by 20%			
5		Increase PS/PC by 2 at a time to obtain 1.5x increase from baseline Vt	Aiming 1.5x increase from baseline Vt	Yes		Add manual techniques and manually assisted cough
6		Increase PC to achieve 20-50% increase in Vt dependent on starting pressures and chest wall compliance	Aiming 20-50% increase of Vt	3-5 seconds depending on age of child, followed by normal ventilator breaths x2		Vibrations on expiration
7						Depends on patient and stability. Use saline and vibrations as well if indicated
8		Increase PIP by 2cmH <sub>2</sub> O until reach desired peak pressure			7-8 breaths with or without vibrations, return pressures and alarms to pre- treatment settings	Monitor minute ventilation and etCO <sub>2</sub> through-out to keep in target range
9	PC or Vt increased (no set amount) Rate decreased			Yes, used to increase frequency of breaths and increase i time		
10						No specific guidance, used with COVID adults
11					3 breaths	

	Ventilation	Pressure	Volume	Inspiratory hold	Duration of each cycle	Additional information
12	Only use pressure ventilation on our unit	Increase PIP to increase Vt by 50%. If PIP is already 38cmH <sub>2</sub> O then preference is to increase inspiratory time to achieve more volume		Yes	10 breaths	Vibrations on expiration after inspiratory holds, inline suction with vibrations
13						Follow guidelines kindly shared by another PICU
14			Increase Vt to 1.25-1.5 times above baseline settings	Yes	Multiple inspiratory holds at higher tidal volume until secretions are felt more centrally	Expiratory vibrations after inspiratory hold if indicated. Suction
15		Alter ventilation to achieve desired Vt, including inspiratory time, respiratory rate and Vt		Yes, 2-3 secs		Return all settings to baseline and ask nursing staff to verify
16		Increase by increments of 2cmH <sub>2</sub> O to achieve 50% increase in Vt from starting volume	If in pressure mode increase volumes by increments of 10% of starting volume to achieve Vt 50% greater than starting volume	Yes, length dependent on patient		Assess stability through-out, utilise flow loops to assess expiratory flow rate generated. Can use expiratory manual techniques in synch with VHI to increase expiratory flow rate
17		Increase PIP		Yes		

**Key:** <=less than, >=greater than, etCO<sub>2</sub>=end tidal carbon dioxide, i time=inspiratory time, PC=pressure control, PIP=peak inspiratory pressure, PS=pressure support, RR=respiratory rate, SIMV=synchronised intermittent mandatory ventilation, VC=volume control, Vt=tidal volume, VHI=ventilator hyperinflation.

sition of VHI theory and technique was via teaching from senior physiotherapists, or by independent learning. This is comparable to a survey of VHI in adults by Hayes et al<sup>6</sup> which showed that 69% of individuals were taught the technique by a senior physiotherapist at the bedside.

A recent systematic review of chest physiotherapy for mechanically ventilated children did not identify any studies which included VHI as part of a chest physiotherapy intervention.<sup>3</sup> Paediatric physiotherapists are therefore limited to the information found in adult literature and applying their knowledge regarding physiological differences between children and adults. VHI was first described in the literature in 2002<sup>8</sup> and there remains limited quality evidence of the effect of VHI in adults. A systematic review by Anderson et al<sup>9</sup> identified four studies and reported no significant differences between manual hyperinflation (MHI) and VHI with regard to cardiovascular stability, oxygenation, lung compliance and sputum weight.

Peak inspiratory pressure is a key safety consideration and children are at a higher risk of barotrauma and volutrauma than adults.<sup>1</sup> The range of PIP recommended by physiotherapists in this survey varied from 28cmH<sub>2</sub>O to 42cmH<sub>2</sub>O. In a randomised crossover study in 48 adults, Jacob et al<sup>5</sup> found that VHI with a peak pressure of 30-32cmH<sub>2</sub>O yielded a significant increase in sputum weight compared to MHI (median 2.84g, IQR 1.81 to 4.22). Conversely, Linnane et al<sup>10</sup> used a higher PIP of 35 to 40 cmH<sub>2</sub>O to compare the effects of MHI and VHI on restoring end-expiratory lung volume (EELV) after suctioning. This pilot study (N=10) used electrical impedance tomography to measure EELV and concluded that both MHI and VHI were effective, although post MHI the EELV declined within the first minute possibly due to disconnection of the MHI circuit from the ventilator. Studies in adult populations should be extrapolated to paediatrics with caution.

Whilst PIP is important when treating atelectasis, flow is an important factor to aid sputum clearance. In a laboratory study, Chapman et al.<sup>11</sup> report significant increases in sputum movement (2.42cm, 95% CI 1.59 to 3.94) when the inspiratory rise time was increased between 5% and 20% to achieve the optimal PIF:PEF ratio of 0.9. In this survey, only two individuals mentioned altering the inspiratory time during VHI but did not specifically mention the rise time.

Adult studies show no significant difference between MHI and VHI regarding cardiovascular stability, oxygenation and lung compliance. The safety profile must therefore be considered. MHI requires disconnection of the patient from the ventilator circuit with subsequent loss of peak end expiratory pressure (PEEP) and possibly end expiratory lung volume, alongside potential increased risk of airborne infections. Respondents from this survey identified loss of PEEP and infection control risk as primary indicators for using VHI although uptake of the technique remained low.

## LIMITATIONS

Distribution of the survey was via email to a named senior physiotherapist of each PICU in the UK and Ireland. A re-

quest for the survey to be disseminated amongst all members of staff within each team means that a response rate could not be calculated. There is also a risk of response bias, in that only those interested in VHI may have completed the survey. Finally, there is a risk that responses were received from a higher proportion of physiotherapists from some larger hospitals, leading to local practices being over-represented.

## CONCLUSION

This survey has identified that the use of VHI in PICU appears low, with a preference towards MHI. Application of the technique is varied, with some respondents utilising protocols to assist in their decision-making. Robust, quality research is needed to help physiotherapists make informed choices regarding the safety, efficacy and optimal technique of VHI in paediatrics.

### Key points

- VHI is used infrequently by paediatric physiotherapist in PICU.
- Indications for using VHI over MHI include patients who are ventilated with a high peak end expiratory pressure (PEEP), where frequent disconnections from the ventilator could have a deleterious effect on the patient and concerns over infection risk.
- The way that VHI is applied, including manipulating rise time, volumes and pressures, varies between physiotherapists and is a key area for future research

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## CORRESPONDING AUTHOR

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## SUPPLEMENTARY MATERIALS

### Appendix 1

Download: [https://acprjournal.scholasticahq.com/article/90181-ventilator-hyperinflation-in-paediatric-critical-care-a-survey-of-current-physiotherapy-practice-in-the-united-kingdom-and-ireland/attachment/187005.pdf?auth\\_token=gLeLpNnlmiPKETvD3mKk](https://acprjournal.scholasticahq.com/article/90181-ventilator-hyperinflation-in-paediatric-critical-care-a-survey-of-current-physiotherapy-practice-in-the-united-kingdom-and-ireland/attachment/187005.pdf?auth_token=gLeLpNnlmiPKETvD3mKk)

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