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Clinical application of intrapulmonary percussive ventilation: A scoping review

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Impaired respiratory function secondary to acute or chronic respiratory disease poses a significant clinical and healthcare burden. Intrapulmonary percussive ventilation (IPV) is used in various clinical settings to treat excessive airway secretions, pulmonary atelectasis, and impaired gas exchange. Despite IPV's wide use, there is a lack of clinical guidance on IPV application which may lead to inconsistency in clinical practice. This scoping review aimed to summarise the clinical application methods and dosage of IPV used by clinicians and researchers to provide guidance. A two-staged systematic search was conducted to retrieve studies that used IPV in inpatient and outpatient settings. MEDLINE, EMBASE, CINAHL, Scopus, and Google scholar were searched from January 1979 till 2022. Studies with patients aged ≥16 years and published in any language were included. Two reviewers independently screened the title and abstract, reviewed full text articles,

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and extracted data. Search yielded 514 studies. After removing duplicates and irrelevant studies, 25 studies with 905 participants met the inclusion criteria. This is the first scoping review to summarise IPV application methods and dosages from the available studies in intensive care unit (ICU), acute inpatient (non-ICU), and outpatient settings. Some variations in clinical applications and prescribed dosages of IPV were noted. Despite variations, common trends in clinical application and prescription of IPV dosages were observed and summarised to assist clinicians with IPV intervention. Although an evidence-based clinical guideline could not be provided, this review provides detailed information on IPV application and dosages in order to provide clinical guidance and lays a foundation towards developing a clinical practice guideline in the future.

Keywords: Airway clearance; intrapulmonary percussive ventilation; IPV; percussive ventilation.

Introduction

Impaired respiratory function secondary to acute or chronic underlying respiratory disease poses a significant clinical and healthcare burden.[1,2] Patients with impaired respiratory function often require hospital admission, and patients with stable respiratory conditions continue to require interventions in outpatient settings. Further, the incidence of pulmonary complications such as pulmonary atelectasis, pneumonia, and respiratory failure are common in hospitalised patients and are associated with increased morbidity and mortality.[3–5] In addition to medical management, multimodal respiratory physiotherapy interventions have been used to treat patients with these pulmonary complications.[6–8] These multimodal respiratory physiotherapy interventions aim to promote airway clearance and increase alveolar recruitment, thereby improving ventilation and gas exchange.[9,10]

Intrapulmonary percussive ventilation (IPV) is an intervention used by physiotherapists as an adjunct or as an alternate respiratory physiotherapy treatment. IPV has been used in various clinical settings in patients with various pulmonary conditions to promote airway clearance, treat or prevent pulmonary atelectasis, improve gas exchange and/or respiratory failure.[11–15] IPV is provided via a pneumatic device that delivers high-frequency sub-physiological tidal breaths that are superimposed on a patient's or the mechanical ventilator's breathing cycle.[12,16] The proposed mechanisms of action of IPV are that the high-frequency breaths cause mucolysis[17,18] and the asymmetrical (higher peak expiratory flow) wave flow pattern propels the mucus towards the proximal airways.[19–21] Furthermore, the positive pressure breaths increase alveolar recruitment.[11,22]

IPV has been used in ICU, acute inpatient (non-ICU), and outpatient settings for several decades in various pulmonary conditions such as COPD,[13] post-thoracic and abdominal surgery,[23] bronchiectasis,[24] cystic fibrosis,[25] neuromuscular conditions,[16] and inhalation injuries.[26] Despite its wide use, there is a lack of evidence-based guidelines for clinicians in the use of IPV. Recent systematic reviews have reported some inconsistencies in the methods of application and dosage of IPV, such as patient–machine interface, airway pressure, frequency, duration, and patient positioning during IPV treatment.[27,28] This scoping review aims to summarise the application methods and dosages of IPV used by clinicians and researchers in order to provide guidance in the use of IPV.

Methods

The review protocol was registered in open science framework (doi.org/10.17605/OSF.IO/SEFN5). Recommendations from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) were followed.[29]

Search strategy

A two-staged literature search was conducted to identify all the studies that met the search criteria. The first stage included a search on MEDLINE (via Ovid), EMBASE (via Ovid), CINAHL, Scopus and Google Scholar from January 1979 (when IPV was first introduced) to 2022. The second stage search included a supplemental approach by searching the reference list of the relevant studies. The databases were searched using keywords and search terms for IPV, relevant clinical conditions,

and clinical settings. The details of the search strategy are presented in Table S1.

Inclusion criteria

Study type

Studies considered for this scoping review included experimental designs such as randomised controlled trials (RCT), quasi-randomised trials, randomised cross-over studies, comparative studies, experimental studies which used random allocation, prospective or retrospective cohort studies, case-control studies, and case studies. Studies published in all languages between 1979 and January 2022 were considered for review. Study abstracts, conference proceedings with incomplete data and descriptions of IPV intervention were excluded.

Types of participants

Studies included stable or acutely ill adults aged ≥16 who received invasive mechanical ventilation via an endotracheal or tracheostomy tube, treated with non-invasive mechanical ventilation, spontaneously breathing, and presenting with acute or acute-on-chronic respiratory impairment were considered. Studies on human subjects only were included in this review.

Types of interventions

All the studies that used IPV, percussive ventilation, and high-frequency oscillation, where these interventions were mainly used for therapeutic purposes, were included. We included studies using any pneumatic devices delivering oscillating or high-frequency bursts of air into the airways/lungs, synonymous with IPV therapy. This included Percussionator®, IPV-1®, IPV-2®, Percussionaire®, Impulsator®, MetaNeb® or IMP2® system. The studies which used these interventions for continuous mechanical ventilation were excluded.

Settings

Studies that used IPV intervention in acute care, such as inpatient (non-ICU) and ICU settings and studies in outpatient settings, such as hospital-based outpatients or community-based healthcare settings, were included.

Study selection and data extraction

Covidence® software was used for study screening and data extraction. After removing duplicate studies, the remaining studies were screened independently by two authors (AH and ST) by reviewing the study titles and abstracts, followed by data extraction of the included studies. In case of disagreement with study inclusion/exclusion and data extraction, a third reviewer (SO) was consulted to reach a consensus. Authors of eligible studies with incomplete or unavailable data or where clarification of data was needed were contacted by email for further details and clarifications; if no response was obtained, the study was excluded.

Data extraction and management

Data were extracted from the included studies that met the inclusion criteria. Data charting included study design, clinical setting, IPV application (indications, contraindications, device set-up, interface, and patient position), and IPV dosage (IPV frequency, applied pressure, I: E ratio, treatment duration, and treatment frequency), and outcome measures used by the studies (Table 1).

Results

A total of 514 studies were obtained from the database search, of which 190 were duplicates. After screening 324 remaining articles, 269 irrelevant studies were removed. A full-text article review was conducted on 55 studies, where 30 studies were excluded with reasons (Fig. 1). The remaining 25 studies with 905 patients met the review criteria for data extraction (Fig. 1).

Study characteristics

Among 25 included studies, 14 were conducted in critical care settings, five in the acute inpatient (non-ICU) setting, and the remaining six in outpatient settings (Table 1). There were five RCTs, seven randomised cross-over studies, and two non-RCT experimental studies. The remaining studies were observational studies, quasi-experimental trials, and case reports (Table 1).

Table 1. Study characteristics, application and dose of IPV.

Author	Study design/setting	IPV aims of use	IPV setting		IPV delivery			Patient position	Outcomes
			Frequency	Pressure	Duration	Session(s)/day	Interface		
Antonaglia *et al.*[13]	RCT ($N = 80$)	↑ Gas exchange	225 cpm	<40 cm H_2O	25–30 min	Twice	Facemask or Mouthpiece	Not reported	↓ ICU LOS*
	IPV: 20, CPT: 20, C = 40	↓ incidence of pneumonia			Days: 2				↑ P/F ratio*
	Population: COPD								↓ $PaCO_2$*
	Age (IPV): 73 ± 7 y								↓ RR*
	Setting: ICU								Safe and well tolerated
Vargas *et al.*[14]	RCT ($N = 33$)	↑ Gas exchange	250 cpm	20 cm H_2O	30 min	Twice	Facemask	Sitting 45° head up	↑ PaO_2*
	IPV: 16, C: 17	↑ Airway clearance			Days: 3 ± 1				↓ $PaCO_2$*
	Population: COPD								↓ RR*
	Age (IPV): 69 ± 6 y								↑ Sputum clearance: NS
	Setting: ICU								↓ Hospital LOS*
									Safe and well tolerated
Clini *et al.*[34]	RCT ($N = 46$)	↑ Gas exchange	200–300 cpm	40 cm H_2O	10 min	Twice	Tracheostomy attachment	Not reported	↑ PaO_2*
	IPV: 24, CPT: 22	↓ incidence of pneumonia			Days: 15				↓ $PaCO_2$: NS
	Population: Hypersecretory airways	↓ or resolve pulmonary atelectasis							↓ Atelectasis*
	Age (IPV): 68 ± 10 y								↓ Pneumonia*
	Setting: ICU								↑ MEP*
									Safety: not reported
Dimassi *et al.*[36]	RCT ($N = 17$)	↑ Gas exchange	250 cpm	Not reported	20 min	Once (single intervention study)	Face mask	Not reported	↑ PaO_2: NS
	IPV: 17, NIV: 17	↓ Reintubation			Day: 1				↓ $PaCO_2$: NS
	Population: Post-extubation patients								↓ RR*
	Age (IPV): 73 [58–75] y								Safe and well tolerated
	Setting: ICU								
Tsuruta *et al.*[12]	Observational study ($N = 10$)	↓ or resolve pulmonary atelectasis	300 cpm	Not reported	Duration not reported	Not reported	In-line with MV	Supine lying	↑ P/F ratio*
	Population: Atelectasis	↑ Gas exchange			Day: 1				↓ $PaCO_2$: NS
	Age (IPV): 52 ± 19 y								↓ Atelectasis*
	Setting: ICU								Safe
Lee *et al.*[32]	Non-RCT ($N = 40$)	↑ Gas exchange	200 cpm	Not reported	15 min	Three times	Not reported	Not reported	↓ ICU LOS
	PV: 20, CPT: 20	↑ Airway clearance			Days: Till discharge				↑ PaO_2*

Table 1. (*Continued*)

Author	Study design/setting	IPV aims of use	IPV setting		IPV delivery			Patient position	Outcomes
			Frequency	Pressure	Duration	Session(s)/day	Interface		
	Population: COPD, CCF, Sepsis								↓ $PaCO_2$: NS
	Age (IPV): 57.8 ± 13 y								↓ RR = NS
	Setting: ICU								Safe
Huynh *et al.*[23]	Non-RCT ($N = 419$)	↓ PPC	170–230 cpm	10–20 cm H_2O	10 min	Six times	Mouthpiece, in-line with ventilator	Not reported	↓ ICU LOS: NS
	IPV: 209, CPT: 210	↓ incidence of pneumonia			Days: >2 days				Pneumonia: NS
	Population: Thoracic, abdominal, and aortic surgery								↓ Hospital LOS*
	Age: 61.1 ± 13 y								↓ MV duration
	Setting: ICU								Safe
Hassan *et al.*[39]	Observational study ($N = 35$)	↑ Oxygenation	170–230 cpm	10–20 cm H_2O	15 min	Twice	Face mask and mouthpiece	Upright sitting or side lying	↓ ICU LOS: NS
	IPV: 22, CPT: 13	↓ or resolve pulmonary atelectasis			Days: Till discharge				↑ SpO_2: NS
	Population: COPD, pneumonia, sepsis								↓ Atelectasis
	Age: 60 ± 17 y								Safe and feasible
	Setting: ICU								
Vargas *et al.*[38]	Observational study ($N = 25$)	↑ Gas exchange	250 cpm	20 cm H_2O	30 min	Not reported	Face mask	Sitting up 45°	↑ PaO_2*
	IPV = 25	↑ Airway clearance			Day: 1 day (Single intervention study)				↓ $PaCO_2$*
	Population: COPD								↓ RR*
	Age: 63 ± 8 y								↑ Sputum clearance: NS
	Setting: ICU								↑ Diaphragm unloading*
									Safety: not reported
Reper *et al.*[26]	Retrospective observation study ($N = 10$)	↑ Oxygenation	Not reported	6–12 cm H_2O	30 min	Every 2 h	Mouthpiece or face mask	Not reported	↑ P/F ratio
	Population: Inhalation injury (Burns)	↑ Airway clearance			Days: 3				↓ Atelectasis
	Age: 41 ± 8 y	↓ or resolve pulmonary atelectasis							Safe
	Setting: ICU								

Table 1. (*Continued*)

Author	Study design/setting	IPV aims of use	IPV setting		IPV delivery			Patient position	Outcomes
			Frequency	Pressure	Duration	Session(s)/day	Interface		
Ortiz-Pujols *et al.*[44]	Case report ($N = 1$)	↓ or resolve pulmonary atelectasis	230 cpm	Not reported	10 min	Every 2 h	Not reported	Not reported	↓ Atelectasis Safety: not reported
	Population: Inhalation injury (Burns)	↑ Airway clearance			Days: 5				
	Age: 17 y								
	Setting: ICU								
Niisato *et al.*[33]	Case report ($N = 1$)	↓ or resolve pulmonary atelectasis	Not reported	Not reported	15 min	Once	Mini tracheostomy tube	Not reported	↑ P/F ratio
	Population: Post diaphragm repair	↑ Airway clearance			Days:17				↓ Atelectasis
	Age: 82 y								Safe
	Setting: ICU								
Fujita *et al.*[35]	Case report ($N = 1$)	↓ or resolve pulmonary atelectasis	300 cpm	Not reported	Not specified	Not reported	In-line via ventilator	Not reported	Improved pneumonia
	Population: Pneumonia	↑ Airway clearance			Days: 3				↓ Consolidation
	Age: 57 y								Atelectasis resolved
	Setting: ICU								Safety: not reported
Varekojis *et al.*[40]	Randomised crossover study ($N = 24$)	↑ Airway clearance	2–5 Hz (120–300 cpm)	Not reported	24 min	Three times	Not reported	Sitting up	↑ Sputum yield (wet)*
	IPV versus PD versus HFCWO				Days: 6				Safe
	Population: CF								
	Age: 24 ± 11 y								
	Setting: Inpatient (non-ICU)								
Toussaint *et al.*[16]	Randomised crossover study ($N = 8$)	↑ Gas exchange	120 cpm	<40 cm H_2O	5 min	Three times	Tracheostomy	Sitting up	SpO_2: NS
	IPV + CPT CPT	↑ Airway clearance			Days: 5				$PaCO_2$: NS
	Population: DMD								↓ RR*
	Age: 22.2 ± 3.7 y								↑ Sputum yield
	Setting: Inpatient (non-ICU)								↑ PEF
									Safe
Dingmans *et al.*[41]	Randomised crossover study ($N = 4$)	↑ Lung function	−200 cpm	Not reported	30 min	Twice	Not reported	Not reported	↑ FEV_1
	AD + IPV (200 cpm)		−400 cpm		Days: 5–10				↑ FVC
	AD + IPV (400 cpm)								Safe
	AD alone								
	Population: CF								
	Age: 26.5 ± 2.1 y								

Table 1. (*Continued*)

Author	Study design/setting	IPV aims of use	IPV setting		IPV delivery			Patient position	Outcomes
			Frequency	Pressure	Duration	Session(s)/day	Interface		
	Setting: Inpatient (non-ICU)								
Birnkrant *et al.*[43]	Case reports ($N = 2$)	↑ Oxygenation	Not reported	8–10 cm H_2O	15–20 min	4–6 times	Not reported	Not reported	↑ SpO_2
	Population: Neuromuscular disease	↓ or resolve pulmonary atelectasis			Days: 4–10				Atelectasis resolved
	Age: 22 ± 5.3 y								Pneumonia resolved
	Setting: Inpatient (non-ICU)								↓ Hospital LOS: NS
									Safety: not reported
Tashiro *et al.*[45]	Case report ($N = 1$)	↑ Oxygenation	300 cpm	Not reported	15 min	Twice	Face mask	Not reported	↑ Oxygenation
	Population: Protein alveolar proteinosis	↑ Airway clearance			3 times/week for 6 months				↑ Sputum yield
	Age: 52 y								Safe
	Setting: Inpatient (non-ICU)								
Testa *et al.*[17]	Quasi-experimental trial ($N = 20$)	↑ Oxygenation	Not reported	Not reported	15 min	Twice a day	Not reported	Sitting up	↑ PaO_2 and SpO_2^*
	IPV + CPT: 10	↑ Lung function			Days: 10				RR: NS
	CPT: 10								↑ MIP*
	Population: COPD								↑ MEP*
	Age (IPV): 70 ± 10 y								Safe
	Setting: Inpatient (non-ICU)								
Nicolini *et al.*[30]	RCT ($N = 63$)	↑ Airway clearance	Not reported	Not reported	15 min	Twice	Not reported	Sitting up	↑ Sputum yield
	IPV: 20	↑ Lung function			Days: 14				↑ MIP and MEP*
	HFCWO: 21								↑ Lung function*
	Control: 22								↓ Breathlessness*
	Population: COPD								Safe
	Age (IPV): 72.8 ± 6 y								
	Setting: Outpatient								
Paneroni *et al.*[24]	Randomised cross-over design ($N = 22$)	↑ Airway clearance	Not reported	Not reported	30 min	Once	Not reported	Sitting up	↑ Oxygenation: NS
	IPV/CPT	↑ Oxygenation			Days: 2				↓ RR*
	Population: Bronchiectasis								Sputum clearance: NS
	Age: 22 ± 7 y								Safety: Safe
	Setting: Outpatient								
Van Ginderdeuren *et al.*[37]	Randomised cross-over study ($N = 20$)	↑ Airway clearance	4–6 Hz (240–360 cpm)	15–20 cm H_2O	15 min	Once a day	Mouthpiece	Sitting up	↑ Sputum yield
	IPV + AD: 10				Days: 2				SpO_2: NS

Table 1. (*Continued*)

Author	Study design/setting	IPV aims of use	IPV setting		IPV delivery			Patient position	Outcomes
			Frequency	Pressure	Duration	Session(s)/day	Interface		
	Nebuliser + AD: 10 **Population:** CF **Age:** 22 ± 7 y **Setting:** Outpatient								Safety: not reported
Newhouse *et al.*[25]	Randomised cross-over study ($N = 10$) IPV/Flutter/CPT **Population:** CF **Age:** 17 [9–25] y **Setting:** Outpatient	↑ Airway clearance ↑ Oxygenation	3–5 Hz (180–300 cpm)	10–30 cm H_2O	20 min Days: 1	Once a day	Mouthpiece	Not reported	Sputum yield: NS Safe
Natale *et al.*[15]	Randomised cross-over study ($N = 9$) IPV + Nebs + PD Sham IPV + nebs + PD Nebuliser + PD **Age:** 14.6 ± 3.4 y **Population:** CF **Setting:** Outpatient	↑ Airway clearance	200–300 cpm	Not reported	Not reported Days: 1	Once (single session)	Not reported	Sitting up	↑ Sputum yield Safe
Gatani *et al.*[31]	Case report ($N = 4$) **Population:** localised pneumothoraces **Age** (IPV): 64 y **Setting:** Outpatient	Resolve pneumothoraces	100–300 cpm	10–20 cm H_2O	12 min Days: 21	Once every other day	Mouthpiece	Not reported	↑ SaO_2 Radiological improvement of pneumothoraces Safe

Notes: AD: autogenic drainage, CPT: chest physiotherapy, cpm: cycles per minute, C: control, CF: cystic fibrosis, DMD: Duchenne muscular dystrophy, FEV: forced expiratory flow, FVC: forced vital capacity, ICU-LOS: intensive care unit length of stay, IPV: intrapulmonary percussive ventilation, MEP: maximal expiratory pressure, MIP: maximal inspiratory pressure, NS: non-significant, PaO_2: partial pressure of arterial oxygen, $PaCO_2$: partial pressure of arterial carbon dioxide, PD: postural drainage, PEF: peak expiratory flow, P/F ratio: partial pressure of arterial oxygen and a fraction of inspired oxygen ratio, PPC: Post-operative pulmonary complication, RCT: randomised controlled trial, RR: respiratory rate, SaO_2: saturation of arterial oxygen, SpO_2: saturation of peripheral oxygen, and *: significant.

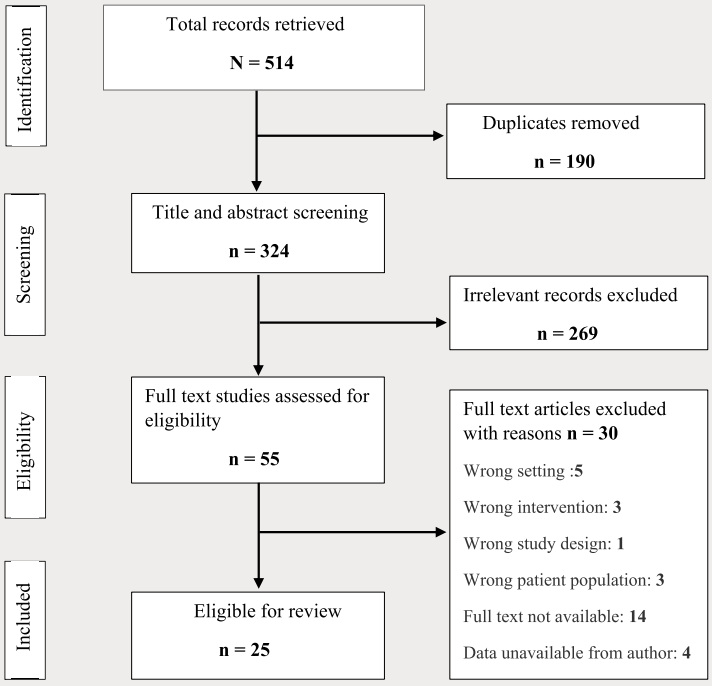

Fig. 1. PRISMA flow chart.

Patient characteristics

In the included studies, patients' age ranged from 17 years to 95 years, with approximately 40% females. Three studies did not report patients' sex. Common clinical conditions included COPD, pulmonary atelectasis, post-abdominal and thoracic surgeries, sepsis, pneumonia, pulmonary consolidation, cystic fibrosis, bronchiectasis, burns (inhalation injury), and Duchenne muscular dystrophy (DMD). Acutely ill patients in the studies were either admitted to the ward (non-ICU) or ICU (spontaneously breathing or mechanically ventilated). In contrast, studies in outpatient settings included clinically stable patients mostly with hypersecretory airway diseases. Acute exacerbation of COPD and pulmonary atelectasis (secondary to surgery, inhalation injury, and mechanical ventilation) were the most treated conditions in acute inpatients (non-ICU) and ICU, whereas patients with stable cystic fibrosis and bronchiectasis were treated in outpatient settings.

IPV application

Indications: The indications for IPV use in the studies were poor gas exchange, retained airway secretions, pulmonary atelectasis, and impaired lung function. Studies in acute inpatient (non-ICU) and ICU used IPV to promote airway clearance, improve gas exchange, and/or recruit atelectatic lung regions. In outpatient settings, patients received IPV mainly to aid airway clearance.

Contraindications: Contraindications to IPV treatment cited in the included studies were pneumothorax, hemodynamic instability (systolic blood pressure $\leq$80 mm Hg, severe cardiac arrhythmia, acute myocardial infarction), fractured ribs, pneumonectomy, esophagectomy, hemoptysis, pulmonary haemorrhage, gastro-intestinal bleed, facial injuries, uncooperative patient, and patients with a Glasgow coma scale $\leq$8. Additional contraindications and precautions to positive pressure therapy should also be considered prior to IPV application.

IPV device: The IPV device used by the studies were Percussionator®, IPV-1®, Percussionaire®, MetaNeb®, and IMP2® system. A nebuliser was inbuilt into all the IPV devices for aerosolisation. Normal saline (0.9% NaCl) was used in 11 studies. In contrast, only one study used hypertonic saline (3% NaCl) in patients with stable COPD,[30] and six studies used bronchodilators with or without normal saline (0.9% NaCl). One study used mucolytics,[31] whereas another study in ICU used sterile water for nebulisation.[32]

The studies used various types of interfaces to deliver IPV. The face mask was the most used

interface, followed by the mouthpiece (Table 1). For tracheostomised patients, a tracheostomy tube connector was used,[16,33,34] whereas, for patients with endotracheal tubes, IPV was connected to the inspiratory limb of the mechanical ventilator circuit.[12,23,35] In most studies, IPV was delivered by physiotherapists and respiratory therapists, except for two studies where IPV was delivered by nurse specialists[31] and medical professionals.[36]

Patient position

Patient position during IPV was reported by 11 out of 25 studies.[12,14–17,24,30,37–40] In studies that described patient position, seven studies, mostly in outpatient settings, positioned patients in an upright sitting position for airway clearance,[15–17,24,30,37,40] while the remaining studies from ICU used a 45° long-sitting position,[14,38] side-lying[39] or supine position[12] (Table 1).

IPV treatment dosage

IPV dosages, such as the frequency of IPV, airway pressure, inspiratory to expiratory ratio (I:E ratio), treatment duration, and the length of IPV treatment (in days), varied among the included studies. The components of the dose are summarised below.

IPV frequency: A total of 19 studies reported on IPV frequency cycle (Table 1). Most studies, especially from ICU, used a frequency range of 200–300 cycles per minute (cpm) mainly for airway clearance and/or to treat pulmonary atelectasis and improve gas exchange (Tables 1 and 2). Some variations in IPV frequency cycles were observed where one study used 400 cpm to reduce bacterial colonisation and improve lung function in hospitalised (non-ICU) CF patients,[41] and another case study in an outpatient setting used a lower frequency (100 cpm) to treat loculated pneumothoraces[31] (Table 1).

IPV pressure: Studies also reported the pressure applied during the IPV intervention; however, out of 25 studies, only 12 studies reported applied pressure, of which seven were ICU-based studies, three were conducted in the outpatient setting, and only two were from inpatient (non-ICU) settings (Table 1). Some variations were noted in three studies from ICU where the lowest pressure applied was 6 cm H_2O to treat patients with inhalation injury to reverse atelectasis and aid airway clearance,[42] whereas two ICU-based studies, one including patients with COPD and the other in tracheostomised patients with hypersecretory lungs, used airway pressure of up to 40 cm H_2O to treat atelectasis, improve gas exchange, and prevent the incidence of pneumonia.[13,34] The most common range of airway pressure reported in ICU ranged between 10 cm H_2O and 20 cm H_2O to promote airway clearance, improve gas exchange, and treat atelectasis, whereas, in studies in the outpatient setting, IPV pressure ranged from 10–30 cm H_2O mainly for airway clearance (Table 2).[14,23,25,26,31,38,39,43]

I:E ratio: I:E ratio was underreported as only four studies mentioned the I:E ratio, out of which three studies used a 1:2.5 ratio to treat critically ill patients with respiratory failure secondary to COPD[14,36,38] and one study used 1:1.2 ratio in tracheostomised patients with increased airway secretions.[34]

Duration: Twenty-two studies reported the duration of IPV sessions (Table 1). A study in DMD patients delivered IPV for 5 min in a single session to promote airway clearance.[16] In contrast, six studies used IPV for 30 min to facilitate airway clearance in patients with COPD,[13,14,38] bronchiectasis,[24] cystic fibrosis,[41] and smoke inhalation injury[42] in ICU, inpatient (non-ICU) and outpatient settings. In the remaining studies, the duration of IPV varied between 10 and 25 min. Overall, the duration ranged from 10 to 20 min in ICU, 15–20 min in inpatient (non-ICU) and 15–20 min in outpatient settings were the most common (Tables 1 and 2).

Session frequency: Treatment frequency was reported by 22 studies. Treatment frequency varied between the studies from once every second day in patients with chronic loculated pneumothorax in an outpatient setting[31] to 2nd hourly in two studies in patients with inhalation injury to promote airway clearance and treat atelectasis.[26,44] Eight studies in ICU and inpatient (non-ICU) used IPV twice a day to improve gas exchange, aid airway clearance, reverse pulmonary atelectasis and prevent incidence of pneumonia, and seven studies mainly in outpatient settings used IPV once a day for airway clearance (Table 1). Two studies, one with a large sample size including 419 post-operative patients in ICU[23] and another case report including two acutely ill patients with

Table 2. Summary of common IPV application methods and dosage in included studies.

Clinical setting	IPV aims of use	Patient groups	Frequency	Pressure	Duration	Sessions	Interface	Patient position
Critical care[13,14,32,34,38,39]	↑ Airway clearance	— COPD	200–300 cpm	10–20 cm H_2O	10–20 min	Twice/day (Daily)	— In-line with MV	— Side-lying
	↑ Gas exchange	— Pulmonary atelectasis					— Tracheostomy	— Sitting up 45°
	↓ or resolve pulmonary atelectasis	— CCF					— Facemask	
	↓ Incidence of pneumonia	— Pneumonia						
		— Inhalation injury (Burns)						
		— Abdominal and thoracic surgery						
Inpatient (non-ICU)[17,41,45]	↑ Airway clearance	— CF	120–300 cpm	Unclear (lack of studies)	Unclear (lack of studies)	Twice/day (Daily)	— Tracheostomy	Unclear (lack of studies)
	↑ Gas exchange	— NMD					— Facemask	
		— COPD						
Outpatient[24,25,30,37]	↑ Airway clearance	— COPD	100–360 cpm	10–30 cm H_2O	15–20 min	Once/day (Daily)	Mouthpiece	Sitting up
		— CF						
		— Bronchiectasis						

Notes: Abbreviations: cpm: cycles per minute, CCF: congestive cardiac failure, CF: cystic fibrosis, MV: mechanical ventilator, NMD: neuromuscular disease.

neuromuscular disease,[43] applied IPV intervention up to 4–6 times a day (Table 1).

Treatment length (days): The length of IPV application (in days) ranged from one day in single-intervention studies[36,38] to up to 22 days of IPV intervention in an outpatient setting.[31] Another ICU-based study applied IPV until discharged from ICU.[32] The treatment length between 2–5 days was the most common among studies in inpatient (non-ICU) and ICU settings (Tables 1 and 2).[13,16,23,24,26,35,37,39,43,44]

Measurements used to evaluate outcomes

The commonly reported outcomes included change in oxygenation and carbon dioxide (CO_2) levels, airway clearance, resolution of pulmonary atelectasis, resolution of pulmonary consolidation, reduced postoperative pulmonary complications, respiratory rate, ICU length of stay (ICU-LOS), and hospital length of stay (LOS) (Table 1).

Airway clearance

Twelve studies used IPV for airway clearance in ICU, inpatient (non-ICU) and outpatient settings (Table 1)[14–16,24–26,30,37,38,40,44,45] only six studies measured sputum weight (wet or dry).[16,24,25,37,38,40]

Resolution of pulmonary atelectasis

Changes in pulmonary atelectasis were assessed and reported by eight studies, seven from ICU[12,26,33–35,39,44] and one from an inpatient (non-ICU) setting.[43] Chest radiographs were used for assessment by six studies; one used a radiological atelectasis score,[39] and another used CT scans.[12]

Oxygenation

Change in oxygenation was measured by the partial pressure of arterial oxygen (PaO_2), a saturation of peripheral oxygen (SpO_2), a ratio of PaO_2, and a fraction of inspired oxygen (P/F ratio). Eighteen studies measured oxygenation, of which 11 were conducted in ICU,[12–14,16,26,32–34,36,38,39] four in outpatient settings[24,25,31,37] and the remaining three in the inpatient (non-ICU) setting.[17,43,45]

CO_2 elimination

Eight studies, all based in ICU, reported CO_2 elimination.[12–14,16,32,34,36,38] Three studies included patients with an acute exacerbation of COPD.[13,14,38] The remaining five studies included patients with hypersecretory airways, sepsis, hypoxemic respiratory failure, pulmonary atelectasis, DMD and patients at risk of reintubation.[12,16,32,34,36]

Pneumonia

Five studies assessed pneumonia incidence, of which four studies were conducted in ICU settings[13,23,34,35] and one in an inpatient (non-ICU) setting.[43]

Respiratory rate

Change in respiratory rate was assessed and reported by nine studies in acute setting. Of which, five studies were conducted in ICU[13,14,32,36,38] and remaining four in an inpatient (non-ICU) setting.[16,17,24,30]

Length of stay

A total of eight studies measured the LOS. ICU-LOS was reported by five studies.[13,23,32,35,39] Three studies measured hospital LOS.[14,23,43]

Adverse events

Only two studies reported minor events. An ICU-based study reported two episodes of tachycardia ($HR > 150$) and one episode of a drop in $SpO_2 < 90\%$.[39] Another study, including 22 hospitalised patients with bronchiectasis, reported nausea, dry throat, and fatigue in 27% of patients during IPV and CPT intervention. The authors stated that the adverse events were too minor to warrant discontinuation of treatment.[24]

Discussion

This is the first scoping review to summarise clinical application methods and dosages of IPV interventions in various clinical settings which enabled the provision of clinical guidance. The findings of this review addressed the existing gap in the current clinical practice to aid clinicians'

knowledge of IPV prescription and application. Due to the broader clinical use of IPV in various clinical scenarios, heterogeneities in the clinical application of IPV were noted. Two recently published systematic reviews also reported some variations in IPV applications.[27,28] In our review, despite some variations in clinical practice, common IPV applications and dosages were observed, which are summarised in order to assist clinicians in IPV prescription and application.

Airway clearance is one of the main indications of IPV. The shearing force from the high-frequency IPV breaths is theorised to alter sputum rheology by reducing viscosity,[14,46,47] and the larger expiratory flow waves propel secretions proximally.[19,21,48] In addition, sustained positive pressure during the inspiratory and expiratory cycle increases collateral ventilation and promotes airway clearance.[49,50] In this review, the included studies showed variations in the use of IPV cycle frequency and pressures. An experimental study in normal subjects showed that the application of high-frequency breaths (500 cpm) led to increased airway clearance.[51] Similar findings were reported by another study where an IPV frequency of 400 cpm was more effective in reducing bacterial colonisation and improving lung function in acutely ill cystic fibrosis patients compared to 200 cpm.[41] In contrast, a study of eight hospitalised DMD patients reported improved airway clearance in patients with hypersecretory lungs with a lower frequency of 120 cpm.[16] These variations in applied breath cycle frequency could be attributed to a lack of evidence and guidance on the most effective frequency to aid airway clearance. Although *in-vitro* studies have shown that high-frequency breath cycles have increased percussive effects which may increase airway clearance, there is little evidence to establish an association between IPV frequency and its effect on airway clearance and improved lung function in human subjects.[52] In addition to the effectiveness, a study in stable COPD patients reported that a frequency of 250 cpm was better tolerated than 350 cpm.[53] In this review, besides a small number of studies with variations in IPV frequency, we found that IPV frequency between 200–300 cpm was used more consistently across all the clinical settings (Table 1). Future studies to assess the effect of IPV frequency on airway clearance would further add to the current knowledge.

Summary statement: IPV frequency of 200–300 cpm was commonly used for airway clearance.

Positive airway pressure delivered by IPV has increased lung volumes and reversed pulmonary atelectasis.[12,54] During IPV application, the lungs are held in a state of partial inspiration, which splints the airways, augments tidal volume, and increases functional residual capacity.[12,53] A study by Nava and colleagues in patients with stable COPD postulated that a higher airway pressure was more effective in increasing lung volumes and alveolar ventilation compared to lower airway pressure when IPV frequency was kept constant at 250 cpm.[53] The IPV pressure used by the studies in this review varied. Studies in critically ill COPD and tracheostomised patients with hypersecretory airways used airway pressures up to 40 cm H_2O to improve gas exchange and enhance airway clearance.[13,34] In contrast, the application of pressures as low as 6 cm H_2O also improved airway clearance, oxygenation, and pulmonary atelectasis in patients with inhalation injuries in ICU.[26] The observed inconsistencies make it difficult to establish a correlation between the applied airway pressure and its effect on airway clearance and the reversal of pulmonary atelectasis.

Summary statement: Pressure settings in the range of 10–20 cm H_2O were commonly prescribed in acute settings, whereas pressures in the range of 15–20 cm H_2O were used in outpatient settings.

There is a lack of guidance in the literature about the duration of IPV treatment sessions in different clinical conditions. Session length was found to vary across all the clinical areas in the included studies with treatment duration ranging from five minutes to 30 minutes.[16,24,41] From the included studies, it was difficult to establish any association between treatment duration and clinical condition or acuity of clinical condition. Patients in acute inpatient (non-ICU) and outpatient settings generally received slightly longer IPV sessions (10–20 min) than those in ICU (15–20 min). Although shorter treatment duration in critically ill patients is seemingly more achievable and realistic due to issues with patient fatigue, more studies are required to establish the treatment duration that is most effective.

Summary statement: IPV treatment sessions of 10–20 minutes were used most frequently in ICU with slightly longer treatment duration (15–20 min)

in both inpatient (non-ICU) and outpatient population.

The frequency of IPV sessions in a day also was inconsistent across the studies, especially in ICU, varying from two treatments daily[14] up to six times daily.[23] In a study including critically ill patients with inhalation injury who received IPV second hourly, improved airway clearance and resolution of atelectasis were reported.[26] Similarly, post-thoracic and abdominal surgery patients admitted to intensive care were treated six times daily with IPV.[23] It is unclear how the authors determined the frequency of IPV sessions for these study protocols. Since the higher-frequency of IPV sessions were mostly reported in critical care studies, it is possible that the clinical acuity and shorter treatment duration might be a significant contributor to a high number of treatment sessions; however, the scarce number of available studies render the establishment of a correlation between the number of sessions per day and clinical benefit difficult. Since critically ill patients do not often tolerate longer treatment sessions, it would be interesting to compare if multiple short sessions are feasible and as effective as fewer long IPV sessions. Besides these few ICU-based studies[23,26] that applied IPV several times per day, most studies in ICU used two IPV sessions a day whereas one IPV session a day was used in most studies conducted in outpatient settings (Table 1).

Summary statement: Two IPV sessions per day was used commonly for acutely ill patients, whereas patients with chronic, stable conditions received one session per day.

IPV was delivered via different interfaces, such as facemasks or tracheostomy mouthpieces, tracheostomy connector[33,34] or the ventilator circuit using an in-line connector.[12,23] In spontaneously breathing critically ill patients, using a mouthpiece requires maintaining a tight seal around the lips, which can be difficult due to reasons such as drowsiness, fatigue, and the presence of ICU-acquired weakness, leaving a facemask as the most appropriate interface. Most studies included in this review used facemasks in non-ventilated ICU patients, whereas a mouthpiece was used in outpatient settings.[25,31,37]

Summary statement: A facemask was commonly used for acutely ill patients, and a mouthpiece was used for patients with stable chronic conditions.

The patient position plays an important role during respiratory physiotherapy interventions, with the position chosen specifically aiming to facilitate airway clearance, improve gas exchange, or treat atelectasis.[55,56] Surprisingly, patient position during IPV was underreported in ICU and inpatient-based studies. Despite some physiological evidence that a supine position can reduce chest wall and lung compliance and functional residual capacity leading to poor gas exchange,[48,57,59] a small observational study positioned patients in the supine to treat pulmonary atelectasis and reported resolution.[12] IPV devices are position independent and, therefore, it can be used in a position that maximises therapeutic effects, such as upright sitting, side-lying, or modified postural drainage positions.

The types of patient outcomes reported varied widely across the studies. Depending on the purposes and objectives of the studies, some studies reported short-term outcomes such as oxygenation or elimination of CO_2, while other studies reported longer-term outcomes such as the resolution of atelectasis, incidences of pneumonia or length of ICU and hospital stay. Although one of the advantages of using short-term outcomes is that the clinician can get immediate feedback on treatment efficacy, the correlation between these short-term outcomes and actual medium to long-term clinical outcomes is unknown, including the impact of IPV on morbidity and mortality in these patients.

There are some limitations to this scoping review. Although the database search was extensive, covering five databases from 1979 to 2022 to retrieve all the studies that used IPV for therapeutic purposes, it is possible that we may have missed some studies. The included studies provided insufficient evidence to synthesise a guideline due to heterogeneity. However, the IPV application and dosage summary provided in this review may be useful in guiding clinicians in treating patients with IPV intervention and will contribute to developing clinical practice guidelines in future.

Conclusions

In conclusion, this is the first scoping review to summarise the current literature on the therapeutic application methods and dosages of IPV across various clinical settings for patients with different diseases and respiratory pathophysiology. We

found variations and inconsistencies in clinical application and prescribed dosages of IPV. Some common applications and dosages of IPV were summarised in this review which may assist clinicians in the application of IPV and contribute towards developing a guideline in future once more studies of patient groups of similar acuity and pathophysiology are available. Until such evidence is available, the findings of this review can be utilised for guidance in the application and dosage of IPV as long as the treatment is individually tailored based on the pathophysiology and the patient's response to treatment.

Conflicts of Interest

Authors have no conflicts of interest to declare.

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Author Contributions

Anwar Hassan: Concept, study protocol, database search, data extraction, data synthesis and analysis, manuscript preparation and revision.

Sidney Takacs: Database search, data extraction, data collation, manuscript preparation.

Sam Orde: Study protocol, data extraction, manuscript preparation and revision.

Jennifer Alison: Concept, study protocol, manuscript preparation and revision.

Stephen Huang: Concept, study protocol, data synthesis, manuscript preparation and revision.

Maree Milross: Concept, study protocol, data synthesis, manuscript preparation and revision.

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Supplementary Material

Table S1.

Search strategy
1. intrapulmonary percussive ventilation.mp.
2. intrapulmonary percussive ventilator.mp.
3. continuous high frequency oscillation.mp.
4. CHFO.mp.
5. Percussionator.mp.
6. IPV-1.mp.
7. Percussionaire.mp.
8. Metaneb.mp.
9. Metan*.mp.
10. Impulsator.mp.
11. IMP2.mp.
12. pneumonia/or pneumonia.mp.
13. bronchiectasis.mp. or Bronchiectasis/
14. COPD.tw.
15. chronic obstructive pulmonary disease.mp. or Pulmonary Disease, Chronic Obstructive/
16. chronic obstructive airway disease.mp.
17. cystic fibrosis.mp. or Cystic Fibrosis/
18. ciliary dyskinesia.mp.
19. asthma/ or asthma.mp.
20. bronchitis.mp. or Bronchitis/
21. fibrotic lung disease.mp.
22. pulmonary fibrosis.mp. or Pulmonary Fibrosis/
23. respiratory failure.mp. or Respiratory Insufficiency/
24. hypoxemi*.mp.
25. hypercapnia/or hypercapn*.mp.
26. neuromuscular disease.mp. or Neuromuscular Diseases/
27. muscular dystrophy, Duchenne/ or muscular dystroph*.mp.
28. pulmonary atelectasis.mp. or Pulmonary Atelectasis/
29. atelectasis.mp.
30. pulmonary consolidation.mp.
31. hypersecretion.mp.
32. burn*.mp. or Burns/
33. smoke Inhalation Injury/ or smoke inhalation injur*.mp.
34. postoperative.mp.
35. surgery.mp.
36. post surg*.mp.
37. tracheostomy/ or tracheostom*.mp.
38. airway clearance.mp.
39. intensive care units/ or critical Illness/ or critical* ill*.mp.
40. critical care.mp. or critical care/
41. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11
42. 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35, or 36 or 37 or 38 or 39 or 40
43. 41 and 42
44. limit 43 to (humans and yr = “1979–2022”)