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Speech effects of a speaking valve versus external PEEP in tracheostomized ventilator-dependent neuromuscular patients

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Abstract *Purpose:* Many patients with respiratory failure related to neuromuscular disease receive chronic invasive ventilation through a tracheostomy. Improving quality of life, of which speech is an important component, is a major goal in these patients. We compared the effects on breathing and speech of low-level positive end-expiratory pressure (PEEP, 5 cmH_2O) and of a Passy-Muir speaking valve (PMV) during assist-control ventilation. *Methods:* We studied ten patients with neuromuscular disorders, between December 2008 and April 2009. Flow was measured using a pneumotachograph. Microphone speech recordings were subjected to both quantitative measurements and qualitative assessments; the latter consisted of both an intelligibility score (using a French adaptation of the Frenchay Dysarthria Assessment) and a perceptual score determined by two speech therapists. *Results:* Text reading time, perceptive score, intelligibility score, speech comfort, and respiratory comfort were similar with PEEP and PMV. During speech with 5 cmH_2O PEEP, six of the ten patients had no return of expiratory gas to the expiratory line and, therefore, had the entire insufflated volume available for speech, a condition met during PMV use in all patients. During speech, the respiratory rate increased by at least 3 cycles/min above the backup rate in seven patients with PEEP and in none of the patients with PMV. *Conclusions:* Low-level PEEP is as effective as PMV in ensuring good speech quality, which might be explained by sealed expiratory line with low-level PEEP and/or respiratory rate increase during speech with PEEP observed in most of the patients.

Keywords Tracheostomy · Speech · Speaking valve · Positive end-expiratory pressure · Ventilation

Introduction

Many patients with neuromuscular respiratory failure receive chronic invasive ventilation through a tracheostomy [1–3]. Improving speech quality is a major goal, as it contributes largely to quality of life. Speech during ventilation is usually possible when using a cuffless or fenestrated tracheostomy tube creating an air leak [4]. During inspiration

(TI), part of the ventilator-delivered volume (VI) leaks toward the upper airway, elevating subglottic pressure and allowing speech [5–7]. With volume-targeted ventilation, competition may occur between the airflow needed for speech and the airflow needed to achieve sufficient tidal volume for adequate gas exchange [7].

Ventilated patients speak mainly during inspiration and a short part of expiration [5–7], whereas normal speech occurs only during expiration [8, 9]. Speech during expiration can be improved by adding positive end-expiratory pressure (PEEP) [6] or by using a Passy-Muir tracheostomy and ventilator speaking valve (PMV) (Passy-Muir Inc., Irvine, CA, USA) [10, 11]. PEEP increases airway pressure during expiration, which can be high enough to allow speech, therefore increasing speech duration throughout the respiratory cycle (Fig. 1a). Use of a speaking valve in the ventilator circuit restores speech during expiration when the device closes with expiratory flow, redirecting it towards the upper airways, thereby allowing speech (Fig. 1b).

Hoit et al. [12] showed that 4 patients, among 15, habitually used speaking valves with ventilation, and only 1 of them was among the 5 patients able to actively trigger the ventilator, allowing a respiratory rate (RR) increase when speaking. When testing high-level PEEP (15 cmH_2O) in three of these four speaking valve users, speech quality was similar with both methods. Apart from this experience performed with intensive care ventilators [12] no prospective randomized study has compared speaking valve and PEEP in a home, tracheostomized, ventilated population.

We felt that high-level PEEP could expose this population to risks of pressure-related side-effects such as hyperinflation or decrease in venous return (and its possible deleterious consequences in patients often presenting cardiac muscular dysfunction). In recent years, improvements in ventilator trigger sensitivity have allowed most patients with severe disease (vital capacity <20% predicted) to shorten the expiratory time and to increase minute ventilation delivered by the ventilator by actively increasing RR above the backup rate. PMV increases the resistance of the inspiratory circuit [13] and may therefore decrease the patient's ability to trigger the ventilator. Furthermore its use imposes that expiration occurs through the upper airways, between the tracheal wall and the tracheal tube, which can create additional resistance [14] and expose the patient to dynamic hyperinflation. Therefore, evaluation of tolerance and efficiency of such techniques is essential before considering their introduction for long-term use in a home setting away from medical monitoring.

The objective of this study is to compare the effects of low-level PEEP and of PMV on speech production during invasive assist-control ventilation (ACV), the most widely used mechanical ventilation modality at our neuromuscular disease unit.

Methods

Detailed methods are available in the Electronic Supplementary Material.

Patients

Ten neuromuscular ventilator-dependent patients were studied during their usual respiratory follow-up at the

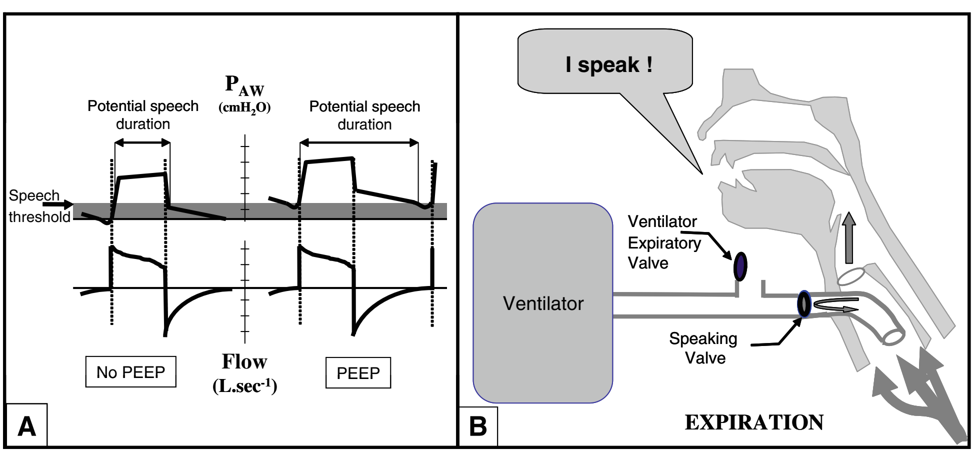

Fig. 1 Methods of speech improvement during expiration. **a** Use of PEEP can maintain during expiration a pressure level in the airways high enough to allow speech during part or sometimes all of the expiration time; speech duration can increase throughout expiration. **b** The phonation valve is placed in the ventilator circuit close to the tracheostomy tube. During inspiration it opens, allowing inflow for ventilation. At the end of inspiration, the expiratory valve of the ventilator opens and the expiratory flow closes the phonation valve, therefore directing the rest of the expiratory flow towards the upper airways and allowing the patient to speak. P_{AW} airway pressure, *PEEP* positive end-expiratory pressure

R. Poincaré Teaching Hospital (Garches, France), after obtaining written informed consent. Protocol was approved by our institutional review board.

Experimental setup

Ventilator-delivered flow and tracheal pressure were measured at the proximal end of the tracheostomy tube. Oxygen saturation (SpO_2) was estimated using pulse oximetry (Ohmeda Biox; BOC Healthcare, Boulder, CO, USA).

Acoustic speech signals were recorded using three methods: (1) on a microcomputer with an AD converter (MP150® and Acqknowledge®; Biopac System, Goleta, CA, USA) that synchronized respiratory data (ventilator flow and tracheal pressure) and acoustic data, using a microphone (DM202, MDE; Pierron, Sarreguemines, France) positioned 20 cm from the patient's lips; (2) using the Dragon NaturallySpeaking 10® speech recognition system (Nuance; Burlington, MA, USA), with its specific microphone and a laptop computer containing its speech recognition software; and (3) on a digital recorder (DS55; Olympus®, Herodphot, Manage, France) for subsequent assessment of fundamental frequency and qualitative analysis.

Experimental protocol

All patients were usually ventilated in ACV mode via cuffless tracheostomy. VI, TI, backup rate, and inspiratory trigger sensitivity were unchanged. Before testing, patients were familiarized with the use of 5 cmH_2O PEEP and of PMV. After 20 min to adjust to each technique, patients were tested in each condition in random order. They successively: used the Dragon NaturallySpeaking 10® voice-training menu, uttered the [a] sound as long as possible, read a list of words, performed a glissando from high to low pitch then from low to high pitch, and read a text.

Data analysis

RR, TI, VI, the volume expired through the tracheostomy tube (VE), and the difference between VI and VE (considered as an approximation of the volume expired through the upper airway) were measured. Patient's ventilator triggering was considered significant when RR exceeded backup rate by at least 3 cycles/min.

Speech was evaluated by measuring the mean speaking time during respiratory cycle, text reading time, and ability to use Dragon NaturallySpeaking 10®. The number of grammatical and phonological errors made by Dragon NaturallySpeaking 10® during text reading were recorded. Two speech therapists, with no direct experience with ventilator-supported patients and blinded to speech condition, performed perceptual analyses. Intelligibility was evaluated with a French adaptation of the Frenchay Dysarthria Assessment (0–8 scale) [15] and a French perceptual score (0–128 scale) [16].

Subjective respiratory and speech comfort was evaluated on a horizontal visual analog scale (VAS) [17, 18].

Statistical analysis

Results are expressed as median and interquartile range (25–75%). As sample sizes were too small for assessment of normality, differences between the two conditions were assessed using nonparametric tests (Wilcoxon). P values <0.05 were considered statistically significant.

Results

Patients

Table 1 shows the characteristics of the ten study participants. Median age was 28.0 (24.2–35.5) years. All patients had severe neuromuscular respiratory failure [vital capacity, 8.5% (4.7–13.5%) of predicted] with marked ventilator dependency [24 (21–24) h per day]. Median duration of ventilation was 13 (11–19) years. All patients were ventilated in ACV mode, using a cuffless nonfenestrated tracheostomy tube. Only one patient (patient 6) was unable to trigger the ventilator. All patients were naive regarding the Passy-Muir valve but none expressed any apprehension concerning its use. Three patients (patients 1, 5, and 10) used PEEP with their usual ventilation settings.

Ventilator parameters

Table 2 presents resting ventilatory parameters under both conditions. The only significant difference was higher mean inspiratory pressure with PEEP than with PMV. VI − VE was not different between the two conditions. However, no gas was expired through the tracheostomy tube in all patients with PMV and in five patients (patients 2, 4, 7, 9, and 10) with PEEP. Although RR was similar in both conditions, significantly increased RR was seen in three patients (patients 3, 9, and 10) with PEEP and in none of the patients with PMV.

During speech (reading), absence of expired gas exit through the tracheostomy tube was noted in all patients with PMV and in six patients (patients 2, 3, 4, 7, 9, and 10) with PEEP; in the four other patients, part of the expired volume (128−202 mL) exited through the tracheostomy

Table 1 Characteristics of the ten study patients

	Sex/age (years)	Diagnosis	Weight (kg)	Height (cm)	Duration of invasive ventilation (years)	Time on ventilator per day (h)	VCL (% predicted)	Pi_{max} (cmH_2O)	Pe_{max} (cmH_2O)	Type of tracheostomy tube	Type of ventilator	Adjusted VI (mL)	Backup rate (min^{-1})
1	M/36	DMD	38	159	24	24	0.330 (8)	6	7	Rusch #8	Eole 3	420	17
2	M/24	Nm	32	144	14	24	0.510 (11)	17	25	Shiley #5.5	Eole 3	620	20
3	M/25	DMD	33	145	5	20	0.400 (12)	14	13	Tracoe #6	Eole 3	470	18
4	M/31	SMA	23	150	18	24	0.450 (12)	35	16	Tracoe #7	Eole 3	600	18
5	M/26	Nm	43	173	24	24	0.140 (3)	8	14	Rusch #6	Eole 3	450	22
6	M/49	A-C S	84	173	21	24	0.810 (18)	22	12	Tracoe #10	Legendair	700	15
7	F/23	Multi. m	37	165	12	20	0.360 (9)	11	22	Bivona #6	Eole 3	610	15
8	M/27	DMD	24	158	6	24	0.310 (7)	9	9	Tracheoflex #7	Legendair	420	15
9	M/34	DMD	49	160	17	24	0.150 (4)	4	7	Tracheoflex #10	Eole 3	750	16
10	F/37	FSHD	59	165	10	24	0.490 (14)	11	13	Tracoe #8	Legendair	500	14

Rusch unfenestrated/uncuffed tracheostomy tube (Rusch Europe Medical, France), *Bivona* unfenestrated/uncuffed tracheostomy tube (Smiths Medical, Rungis, France), *Shiley* unfenestrated/uncuffed tracheostomy tube (Covidien, Pau, France), *Tracheoflex* unfenestrated/uncuffed tracheostomy tube (Teleflex Medical, Le Faget, France), *Eole3* Eole ventilator (Resmed, Saint Priest, France), *Legendair* Legendair ventilator (Airox-Covidien, Pau, France), *Tracoe* unfenestrated/uncuffed tracheostomy tube (Pouret Medical, France)

M male, *F* female, *VC* vital capacity, *% pred* percentage of predicted value, Pi_{max} maximal inspiratory pressure, Pe_{max} maximal expiratory pressure, *VI* ventilator-delivered volume, *DMD* Duchenne muscular dystrophy, *Nm* nemaline myopathy, *SMA* spinal muscular atrophy, *A-C S* Arnold-Chiari syndrome, *Multi m.* multicore myopathy, *FSHD* facioscapulohumeral dystrophy

Table 2 Ventilation characteristics at rest

	PEEP	PMV	PEEP versus PMV, Wilcoxon
VI (mL)	526 (414–596)	510 (382–583)	0.59
VI − VE (mL)	464 (259–572)	499 (380–584)	0.11
RR (min^{-1})	18 (17–19)	17 (15–18)	0.83
TI (s)	1.27 (1.16–1.38)	1.28 (1.19–1.38)	0.67
Te (s)	2.08 (1.99–2.12)	2.18 (2.03–2.34)	0.28
TI/TTOT	0.38 (0.37–0.40)	0.38 (0.35–0.39)	0.59
Peak IP (cmH_2O)	17.5 (14.6–23.3)	18.0 (13.5–21.4)	0.72
Mean IP (cmH_2O)	13.1 (11.3–15.4)	11.7 (9.8–13.5)	0.05
Mean EP (cmH_2O)	3.8 (1.6–5.2)	2.2 (1.9–5.1)	0.85
SpO_2 (%)	97.5 (97.0–100.0)	98.5 (97.2–99.0)	0.86

PEEP positive end-expiratory pressure, *PMV* Passy-Muir speaking valve, *VI* ventilator-delivered volume, *VI − VE* ventilator-delivered volume minus volume expired through the tracheostomy tube (an approximation of the volume expired through the upper airways), *TI* inspiratory time, *TTOT* total respiratory time, *RR* respiratory rate, *Peak IP* peak inspiratory pressure, *Mean IP* mean inspiratory pressure, *Mean EP* mean expiratory pressure, SpO_2 oxygen saturation

tube with PEEP. Both VI and VI − VE were lower with PEEP than with PMV. In contrast, RR was higher with PEEP than with PMV, and seven patients had significantly increased RR with PEEP (patients 1, 2, 3, 5, 8, 9, and 10). RR values at least 3 cycles/min higher than at rest were noted in four (patients 1, 2, 5, and 8) of these seven patients with PEEP and in none of the patients with PMV. Finally, minute ventilation expired through the upper airways and therefore available for speech [i.e., (VI − VE) × RR] was similar in both conditions [PEEP versus PMV: 9.1 (6.5–10.1) L/min versus 9.2 (8.0–10.0) L/min, $P = 0.51$]. Of the four patients partially expiring though the ventilator circuit during PEEP, three had RR increases that failed to compensate for the volume lost for speaking (Table 3).

Speech

Sustained [a] duration was similar with PEEP and PMV [1.76 (1.31–2.48) s versus 1.98 (1.68–2.58) s, respectively; $P = 0.65$], and expiration duration was also similar [0.92 (0.53–1.74) s versus 1.18 (0.74–1.58) s, $P = 0.65$].

During the glissando test, no difference was found between the two conditions for minimal fundamental frequency [PEEP versus PMV, 89 (84–94) Hz versus 92 (88–94) Hz, $P = 0.26$] or maximal fundamental frequency [PEEP versus PMV, 197 (190–199) Hz versus 196 (188–199) Hz, $P = 0.67$].

Five patients succeeded in using Dragon Naturally-Speaking 10® system in both conditions (patients 2, 3, 4,

Table 3 Ventilation characteristics during speech

	PEEP	PMV	PEEP versus PMV, Wilcoxon
VI (mL)	493 (389–558)	548 (420–575)	0.03
VI − VE (mL)	493 (261–558)	548 (418–576)	0.017
RR (min^{-1})	21 (18–24)	17 (15–18)	0.017
TI (s)	1.31 (1.14–1.36)	1.35 (1.26–1.50)	0.012
Te (s)	1.38 (0.99–1.88)	2.05 (1.62–2.28)	0.037
TI/TTOT	0.48 (0.42–0.53)	0.38 (0.37–0.41)	0.14
Peak IP (cmH_2O)	17.0 (14.0–20.5)	16.5 (12.2–20.0)	0.96
Mean IP (cmH_2O)	12.0 (9.5–15.0)	12.0 (10.2–14.0)	0.81
Mean EP (cmH_2O)	5.1 (2.8–5.9)	5.3 (2.9–5.8)	0.95
SpO_2 (%)	97.7 (97.0–98.9)	97.5 (97.3–98.3)	0.68

7, and 10). They showed no difference between the two conditions regarding number of grammatical errors [PEEP versus PMV, 3 (3–6) versus 3 (3–5), $P = 0.28$] or phonological errors [PEEP versus PMV, 37 (33–38) versus 34 (29–47), $P = 0.89$] while reading the text. Another patient (no. 1) succeeded in using Dragon NaturallySpeaking 10® system with PMV but not with PEEP; the numbers of grammatical and phonological errors while reading the text with PMV were 9 and 37, respectively.

No differences were found in the text reading task between PEEP and PMV for reading time [114 (77–156) s versus 108 (81–182) s, respectively; $P = 0.33$], number of syllables per minute [114 (82–166) versus 123 (67–160), respectively; $P = 0.38$], perceptive score [34 (23–38) versus 28 (15–44), respectively; $P = 0.26$] or intelligibility score [4.6 (3.5–5.5) versus 4.2 (3.4–5.5), respectively; $P = 0.76$].

Tolerance

All patients tolerated PEEP throughout the trial, whereas two patients (nos. 8 and 10) needed to disconnect the PMV periodically between tasks. Nevertheless, VAS scores at the end of both conditions showed no difference in speech comfort [PEEP versus PMV, 4.7 (3.6–7.9) versus 3.5 (2.3–6.1), $P = 0.58$] or respiratory comfort [PEEP versus PMV, 5.1 (3.5–6.5) versus 3.3 (2.6–6.8), $P = 0.92$].

Subpopulations

In the seven patients who increased their RR by at least 3 cycles/min above the backup rate with PEEP (patients 1, 2, 3, 5, 8, 9, and 10), time needed to read the text passage was shorter with PEEP compared with PMV, and the difference was nearly statistically significant [79 (70–131) s versus 87 (75–177) s, respectively; Wilcoxon $P = 0.06$]. There were no significant differences between the two conditions in this subgroup regarding speech comfort [PEEP versus PMV, 4.4 (3.6–8.4) versus 3.2 (1.5–4.8), respectively; Wilcoxon $P = 0.18$] or respiratory comfort [PEEP versus PMV, 4.0 (2.8–6.5) versus 3.2 (2.2–4.9), respectively; Wilcoxon $P = 0.93$].

In the four patients (nos. 1, 5, 6, and 8) partially expiring through the ventilator circuit during speech with PEEP, sustained [a] duration on expiration ranged from 0.50 to 1.54 s with PEEP and from 0.30 to 1.33 s with PMV. Moreover, in the three patients (nos. 1, 5, and 8) of this subgroup whose RR increased by at least 3 cycles/min during speech with PEEP, time needed to read the text was shorter and speech comfort was better with PEEP than with PMV.

In three patients (nos. 4, 5, and 10), detailed analysis during PMV use showed abrupt pressure drops of 0.4–1 cmH_2O, synchronized with expiratory flow decreases, without any microphone signal variation, which were not followed by an inspiration.

Discussion

Speech quality was not significantly different between PEEP and PMV conditions in our patients with advanced neuromuscular disease. During speech with 5 cmH_2O PEEP, six of the ten patients expired exclusively through the upper airways so that the entire insufflated volume was available for speech, as with PMV. Significantly increased RR occurred in seven patients with PEEP and in none of the patients with PMV. These two factors may explain that low-level PEEP produced similar speech quality to PMV.

Technological and methodological issues

The ventilator used in our previous study of PEEP improving speech in tracheostomized ventilated patients [17] was capable of delivering a high flow during expiration and maintaining PEEP level despite the leak induced by speech (see Fig. 1 in [17]). Thus, the flow feeding speech during expiration came from both the patient and the ventilator. Unfortunately, this ventilator is no longer available and current ventilators cannot provide expiratory flows greater than 6 L/min. To adjust PEEP, currently available home volumetric ventilators use an adjustable pressure-threshold occlusion valve in the expiratory line that acts as a one-way inspiratory valve for speaking when the tracheostomy tube pressure is below PEEP level during expiration. This technological characteristic limits the advantage of PEEP compared with PMV. Hopefully, in the future, systems efficient in maintaining PEEP levels will again become available for home ventilators.

Among our patients, six out of ten did not reach 5 cmH_2O PEEP during speech, as no expiratory gas returned to the ventilator expiratory line. Therefore, in these six patients, increasing the set level of PEEP, i.e., the pressure threshold for valve occlusion in the expiratory line, should not affect speech. In the four remaining patients, raising the PEEP level could result in exclusive expiration through the upper airway during speech. However, except for patient 6, who was not able to trigger the ventilator, these patients increased their RR during speech with PEEP and had shorter reading task durations and better speech comfort with PEEP than with the PMV.

Interpretation of results

Several hypotheses can explain higher RR during speech with PEEP. First, when no expiratory activity is present, intrinsic PEEP ($PEEP_i$) can be described by a single-exponential time function, $PEEP = (V_T/C)e^{-T_e/RC}$, where V_T is tidal volume, T_e is expiratory time, and R, C, and RC are, respectively, the resistance, compliance, and time constant of the respiratory system [19, 20]. When part of the expiration passes through the ventilator expiratory line with PEEP, the resistance of the respiratory system during expiration is lower than with PMV. Therefore, when the patient wants to shorten T_e, the risk of $PEEP_i$, which increases the effort needed to trigger the ventilator, is higher with PMV than with PEEP. Second, in an earlier study we found that the resistance of PMV was about 3.8 cmH_2O/L/s [13]; PMV use may increase the inspiratory effort needed to trigger the ventilator, which explains the decrease of trigger use. We did not record inspiratory effort, as this would have required recording esophageal and transdiaphragmatic pressures in order to be sure whether pressure variations were due to inspiratory muscles activation; the presence of esophageal catheter would have been a much more invasive procedure, which could moreover interfere with speech production as the pressure balloons are positioned through the upper airways. However, we observed in a few patients abrupt pressure drops of 0.4−1 cmH_2O, synchronized with decreases of expiratory flow, which strongly suggested the presence of ineffective breaths, as previously described [21, 22]. Furthermore, the patients may have felt no need to trigger the ventilator during speech with PMV. However, the higher RR observed with PEEP was not associated with decrease in respiratory comfort during speech. Thus, RR increase during speech may be a physiological behavior in this population, as with healthy, nontracheostomized individuals [9]. It is unlikely to be secondary to a rise of $PaCO_2$, as Shea et al. [7] measured the mouth air leakage during inspiration, which ranged from 15 to 38 mL. Moreover, alveolar volume loss was probably less than the leaked volume, considering that it could partially wash out the instrumental dead space (circuitry from the Y ventilator circuit to the distal part of tracheostomy tube). Last, end-tidal CO_2 measured in nine patients, with and without PEEP, just before and just after speech in order not to be altered by leaks, showed no change despite RR increase [17].

Tidal volumes and TI values during speech differed between the two conditions, but we previously demonstrated that home ventilators failed to maintain tidal volume constant when system impedance changed [23].

Clinical implications

As suggested by Hoit et al. [12], the advantage of PEEP compared with one-way speaking valves is greater safety in the event of tracheostomy tube cuff inflation or upper airway occlusion. In both situations, severe hypoventilation or barotrauma can occur, depending on whether or not the ventilator has a pressure safety system. Using PEEP instead of PMV decreases these risks, and the lower the PEEP level, the lower the risk. For these reasons, we were reluctant, until now, to use PMV, and we have limited PEEP level to 5 cmH_2O in our population ventilated at home without continuous monitoring by healthcare professionals. The use of higher PEEP levels could be considered if patients could switch it on when needed. Some current ventilators have two preprogrammed ventilation settings, one of which could be used to set a higher PEEP level for a given period of time (for example, a nighttime program and a daytime program), but switching programs requires the intervention of a third party, as most of these neuromuscular patients are too disabled to perform such a task themselves. Ideally, to be autonomous, patients would need a remote-control device with an adapted interface to switch between PEEP levels when starting or stopping to speak. Studies are needed to evaluate the feasibility of such a technique. In the meantime, we demonstrated that speech with 5 cmH_2O PEEP was as good as speech produced with a one-way valve during ACV. However, as evaluation duration was short, it is necessary first to evaluate immediate tolerance under close medical supervision before considering using these techniques at home and to closely re-evaluate long-term tolerance over time.

In conclusion, low-level PEEP is as effective as PMV in ensuring good speech quality. Low-level PEEP seems safer than PMV, as it reduces the risk of hyperinflation-related side-effects since, in case of pressure rise in the airways, expiration through the ventilator circuit is still possible as soon as pressure reaches PEEP level, contrary to the situation when using PMV. Therefore, in tracheostomized neuromuscular patients receiving long-term assist-control mechanical ventilation, we suggest that low-level PEEP can be used at home. We regret the discontinuation of home ventilators capable of delivering large flows during expiration to maintain PEEP despite leaks induced by speech, but we are confident that, in the future, manufacturers will improve ventilators' PEEP performance.

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