Programming Pressure Support Ventilation in Pediatric Patients in Ambulatory Surgery with a Laryngeal Mask Airway

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BACKGROUND: Anesthesia workstations with pressure support ventilation (PSV) are available, but there are few studies published on how to program flow-triggered PSV using a laryngeal mask airway (LMA) under general anesthesia in pediatric patients.

METHODS: We studied 60 ASA I and II patients, from 2 mo to 14 yr, scheduled for ambulatory surgery under combined general and regional anesthesia with a LMA. Patients were classified according to their body weight as follows: Group A ≤10 kg, Group B 11–20 kg, and Group C >20 kg. All were ventilated in PSV using the following settings: positive end-expiratory pressure of 4 cm H_2O, the minimum flow-trigger without provoking auto-triggering, and the minimum level of pressure support to obtain 10 mL/kg of tidal volume.

RESULTS: The flow-trigger most frequently used in our study was 0.4 L/min, ranging from 0.2 to 0.6 L/min. We found no correlation between the flow-trigger setting and the patient's age, weight, compliance, resistance, or respiratory rate. There was a good correlation between the level of pressure support (Group A = 15 cm H_2O, Group B = 10 cm H_2O and Group C = 9 cm H_2O) and age ($P < 0.001$), weight ($P < 0.001$), dynamic compliance ($P < 0.001$), and airway resistances ($P < 0.001$).

CONCLUSIONS: PSV with a Proseal™ LMA in outpatient pediatric anesthesia can be programmed simply using the common clinical noninvasive variables studied. However, more studies are needed to estimate the level of pressure support that may be required in other clinical situations (respiratory pathology, endotracheal tubes, or other types of surgeries) or with other anesthesia workstations.

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Pressure support ventilation (PSV) is a pressure-targeted mode which provides breath-by-breath ventilation support, always initiated by the patient and synchronized with the respiratory effort (1,2). It is the "gold standard" mode for weaning in mechanically ventilated intensive care patients (1–5).

PSV has proven to be effective in eliminating the work of breathing (WOB) (endotracheal tube, circuit, and ventilator) while also maintaining the patient's spontaneous ventilation (4,6–8). Another advantage of the use of PSV is that it requires less pressure to obtain the same target tidal volume (V_T) than controlled mechanical ventilation (1,2,5,9). This reduced pressure requirement results in less air leakage during mechanical ventilation with supraglottic airway devices like the laryngeal mask airway (LMA) (2,10,11). In addition, the resulting reduced intrathoracic pressure attenuates the effects of mechanical ventilation on hemodynamics and cardiac output especially in neonates (12,13).

Because the diameter of the airway devices used for children are always narrower, the imposed WOB is much higher than in adults (4,8). Thus, pediatric patients may further benefit from pressure support in the operating room (OR) during anesthetic procedures (5).

The aim of this study was to determine the appropriate PSV variables in pediatric patients spontaneously breathing with a LMA who were undergoing combined general and regional anesthesia. We studied the relationship of pressure support and trigger threshold as a function of age and weight. In addition, we also evaluated the influence of dynamic compliance, airway resistances, and respiratory rate on the level of pressure support programmed.

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METHODS

Sixty ASA I–II pediatric patients of both sexes were studied, ranging in age from neonate up to the age of 14 yr with a normal body mass index (between 5th and 95th percentiles). They had all been scheduled for general outpatient surgery (circumcision, inguinal hernia, cryptorchidism, hydrocele, hypospadias) under combined general and regional anesthesia between January 2005 and June 2006. The patients were classified into three groups according to their weight, Group A: up to 10 kg, Group B: from 11 to 20 kg, and Group C: 21 kg or more. Written consent was obtained from the parents or legal guardians along with the approval of our hospital's ethics committee.

A nitrous oxide/oxygen inhaled anesthetic induction was performed with sevoflurane on all patients. After IV access was obtained, atropine (0.015 mg/kg) and fentanyl (0.002 mg/kg) were administered. A Proseal™ LMA (PLMA) (LMA, Mahe, Seychelles) was used on patients weighing more than 5 kg and a Classic LMA (LMA) on those weighing <5 kg. Levobupivacaine 0.25% was used for regional blocks. Regional blocks included penile blocks, ilioinguinal, and iliohypogastric blocks, or caudal epidurals for bilateral procedures. In all patients, anesthesia was maintained with sevoflurane (1.5%–2%) and an oxygen/nitrous oxide mixture with 45% fraction of inspired oxygen (F_{IO_2}).

After the LMA was placed and the patient had started to breathe spontaneously, the anesthesia circuit was connected to the anesthesia workstation with the PSV mode (Avance, Datex-Ohmeda, GE healthcare, Helsinki, Finland). The variables were programmed so that the minimum pressure support above positive end-expiratory pressure (PEEP) level that would obtain a V_T of 10 mL/kg. The trigger was set with the following clinical criteria: we started at the minimum flow-trigger that the machine would provide (0.2 L/min) and increased it while checking that each trigger activation was provoked by the patient's respiratory movement as observed in the abdominal region (between the navel and the xifoid process), so as to avoid an auto-triggering or self-triggering situation. Auto-triggering or self-triggering is defined as auto-cycling that occurs when something activates the ventilator's trigger without any inspiratory effort by the patient. However, although flow-trigger activation does not have to affect anything on the pressure curve, one can usually see that the pressure curve presents a small decrease or depression in the PEEP level just before the pressure support curve begins to rise. This decrease usually does not occur in an auto-triggering situation (Fig. 1). The level of pressure support and trigger sensitivity could be modified during the surgery in order to maintain the above-specified ventilation objectives. The apnea or backup time was set with a 4 cm H_2O of PEEP (10 s for Groups A and B and 15 s for Group C). The length of the breathing time (end of the breathing) was set to 20% of the peak inspiratory flow (7). All patients were managed with weight-appropriate heat and moisture exchanging filters (HMEF), which were placed in the patients' mouth between the LMA and the spirometer (Clear-Therm mini pediatric HMEF for ≥10 kg children and Clear-Therm micro HMEF for <10 kg children) (Intersurgical, Workingham, Berkshire, UK). The respiratory mechanics (pulmonary dynamic compliance and airway resistances) were monitored using an anesthesia monitoring S/5 side stream spirometry module with Pedi-lite for patients <10 kg, and a D-lite in patients >10 kg (Datex-Ohmeda).

The following variables were recorded: level of pressure support, trigger, dynamic pulmonary compliance, airway resistance, inhaled and exhaled V_T, end-tidal carbon dioxide ($ETco_2$), peripheral oxygen saturation, respiratory rate, heart rate, arterial blood pressure, age, and weight. The data were collected using the S5 Collect software package (Datex-Ohmeda) from the time of anesthetic induction until the LMA was removed.

Patients with LMA had leaks >15% (expired V_T was 15% less than inspired V_T) 11, those requiring larger fentanyl doses that lead to apnea and required (Synchronized Intermittent Mandatory Ventilation) mode for more than 10 min after anesthetic induction, or those with an $ETco_2$ > 45 mm Hg were excluded from the study.

Statistical analysis was preformed using SPSS for Windows (Release 9.0). Quantitative (Categorical) variables are expressed as follows: mean, mode, standard deviation, minimum-maximum values, and qualitative data as counts and percentages. Quantitative data were tested by one way analysis of variance. *Post hoc* comparison was tested using the Student–Newman–Keuls test. Correlation between the quantitative data was tested by the Pearson's correlation. Two-sided tests were used and a P value of <0.05 was considered statistically significant. We used the mode instead of the mean for airway resistance, dynamic compliance, pressure support, and programmed trigger obtained from the data recorded during the time in which mechanical ventilation was active in each patient. The power analysis for the studied parameters for each group showed an observed power >90% in all cases.

RESULTS

Nine patients were excluded from the study because of the following factors: 1) four from an excessive LMA leakage, all of them weighed <5 kg and were managed with a classic LMA (No. 1) (Group A), 2) two patients had a regional block failure that required additional fentanyl administration that resulted in a >10 min apnea (Group C), and 3) three patients had $ETco_2$ levels > 45 mm Hg even with a V_T of 10 mL/kg (2 in Group B, and 1 in Group C). Ventilator settings and respiratory mechanics of all

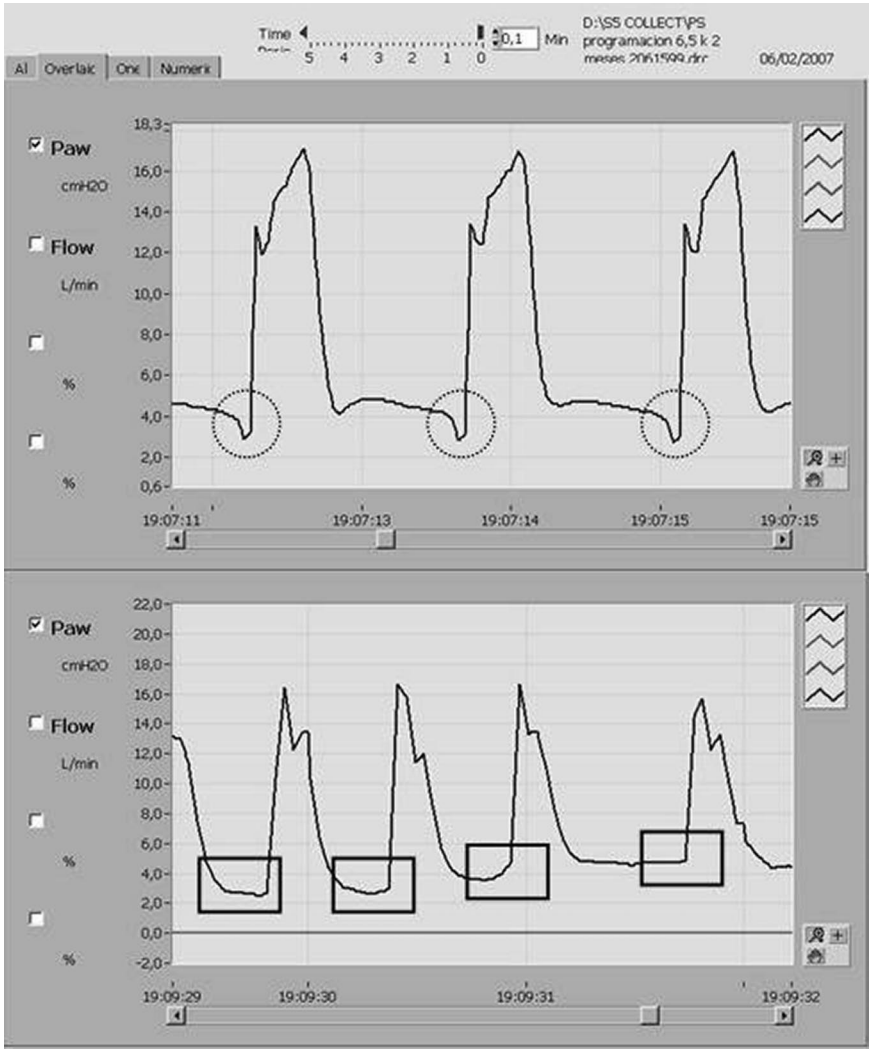

Figure 1. Setting the inspiratory trigger: Auto-cycling occurs when non-respiratory airflow, pressure oscillations or leaks, mimic an inspiratory effort. These tracings show two different airway pressure-time curves. The upper panel shows normal trigger activation by the patient in which a small negative deflection in the pressure tracing just before the start of inspiration (circles) is clearly seen. The lower panel shows an example of auto-triggering or auto-cycling. Note that no respiratory efforts, evidenced by the absence of any pressure decrease are detected before the inspiratory cycles (rectangles).

patients are shown in Table 1. There were no statistically significant differences in the levels of $ETco_2$ among the different groups.

Pressure Support

The pressure support showed a negative correlation with weight, age, and dynamic compliance in this population of pediatric patients ($r = -0.718$ $P < 0.001$; $r = -0.766$ $P < 0.001$; and $r = -0.789$ $P < 0.001$ respectively; Figs. 2 and 3) and a positive correlation with airway resistances ($r = 0.945$ $P < 0.001$ Fig. 4). A positive correlation was also observed between the level of pressure support used and the respiratory rate both within each group and among the three groups of patients ($r = 0.829$ $P < 0.05$ and $r = 0.814$ $P < 0.001$ respectively). On the contrary, the level of pressure support showed no correlation with the flow-trigger used.

Flow-Trigger

The mean flow-trigger sensitivity used was 0.35 ± 0.13 L/min (range 0.2 and 0.6 L/min) with a mode of 0.4 L/min for all three groups. There was no significant statistical correlation between the actual flow-trigger used, the programmed pressure support and the patient's age, weight, dynamic compliance, airway resistance, and respiratory rate.

DISCUSSION

Our study shows that PSV incorporated into an anesthesia workstation with a circular circuit and flow-trigger can be used with children, aged 2 mo to 14 yr and weighing 4–56 kg undergoing outpatient general surgical procedures. Furthermore, it is an easy ventilation mode to program as only two variables, trigger sensitivity and inspiratory pressure support level, need to be set. The flow-trigger sensitivity used for most of the children in our study was 0.4 L/min, with a very narrow range (0.2–0.6 L/min). Programming the sensitivity of the flow-trigger in children is simple as it is not influenced by changes in the child's age, weight, dynamic compliance, or airway resistance.

Ventilatory management of children during ambulatory pediatric anesthesia has traditionally used any of the various Mapleson circuits in order to maintain the patient's spontaneous respiration and thus avoid the use of mechanical ventilation and muscle relaxants (14–16). Maintaining spontaneous ventilation during pediatric ambulatory anesthesia may facilitate early

Table 1. Level of Pressure Support, Compliance, Airway Resistance, Flow-Trigger, End-Tidal Carbon Dioxide ($ETco_2$), and Respiratory Rate in the Three Groups of Patients: Group A (< 10 kg), Group B (11–20 kg), and Group C (> 20 kg)

	Weight (kg)	Mean	SD	Mode	Minimum	Maximum
Pressure support (cm H_2O)	<10	14.4	0.97	15	13	15
	11–20	10.6	1.28	10	9	15
	>20	8.6	1.12	9	7	11
	Total	10.7	2.36	10	7	15
Dynamic compliance (mL/cm H_2O)	<10	6.7	3.16	5.5	4	12
	11–20	16.5	4.05	17	7	23
	>20	31.7	9.32	30	18	50
	Total	19.7	11.17	18	4	50
Airway resistance (cm $H_2O \cdot L^{-1} \cdot s^{-1}$)	<10	50.7	11.92	54	28	64
	11–20	21.1	8.55	18.5	11	57
	>20	12.1	5.56	12	6	26
	Total	23.9	16.27	18	6	64
Flow-trigger (L/min)	<10	0.36	0.08	0.4	0.2	0.4
	11–20	0.30	0.11	0.2	0.2	0.6
	>20	0.41	0.14	0.4	0.2	0.6
	Total	0.35	0.13	0.4	0.2	0.6
$ETco_2$ (mm Hg)	<10	42.8	1.14	42.5	41	44
	11–20	43.3	1.09	44	40	45
	>20	42.9	2.03	44	37	45
	Total	43.1	1.47	44	37	45
Respiratory rate (bpm)	<10	23.5	2.51	24	18	26
	11–20	17.5	1.86	18	13	21
	>20	12.2	2	11	10	16
	Total	16.9	4.52	17	10	26

Data are expressed as mean, standard deviation, mode, and the maximum and minimum of the values obtained.

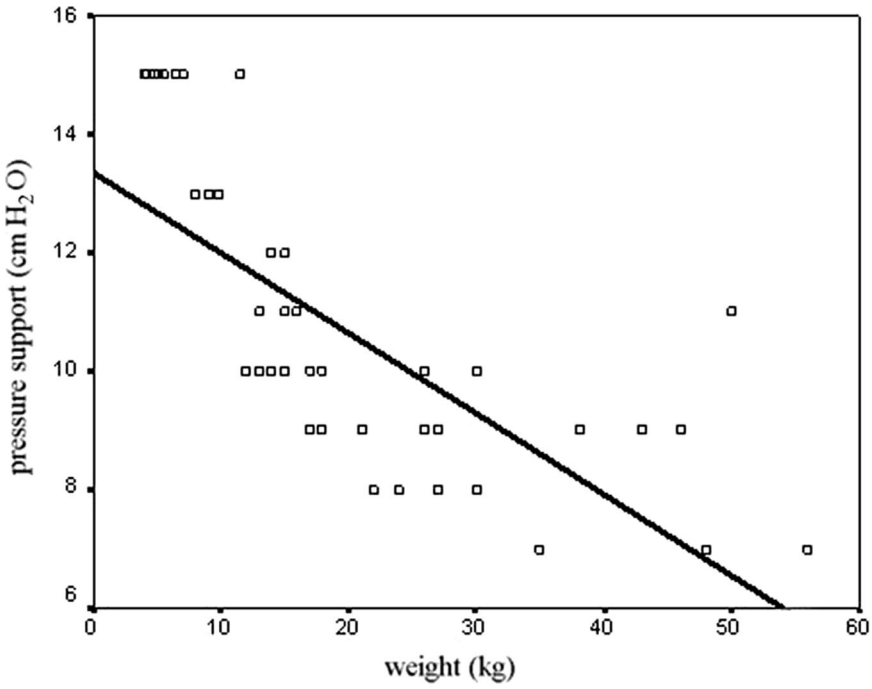

Figure 2. Correlation between the programmed level of pressure support (cm H_2O) and children's weight (kg): A negative correlation was found between the programmed pressure support and the weight of the child ($r = -0.718$), which is statistically significant ($P < 0.001$). A higher level of pressure support is needed in smaller children to compensate for their increased airway resistance and work of breathing.

tracheal extubation and minimizes air leaks with supraglottic devices or uncuffed endotracheal tubes, as compared to mandatory positive-pressure ventilation. However, mechanical ventilation is often required because of the anesthetic-induced respiratory depression. PSV can offer the advantages of mechanical ventilation, while retaining the advantages of spontaneous breathing (15,17).

Children between 11 and 20 kg needed a pressure support of 10 cm H_2O above PEEP, with maximum and minimum readings of 9 and 15 cm H_2O. The pressure support used in this group of patients is similar to that used in the studies by Tokioka et al. and Von Goedecke et al. (7,15). Our study differs from these previous studies in that we used a circular circuit anesthesia workstation and not an intensive care ventilator. The peak flow of an anesthesia workstation is usually much lower than that of an intensive care ventilator and the time delay in delivering the flow is usually longer with anesthesia workstations

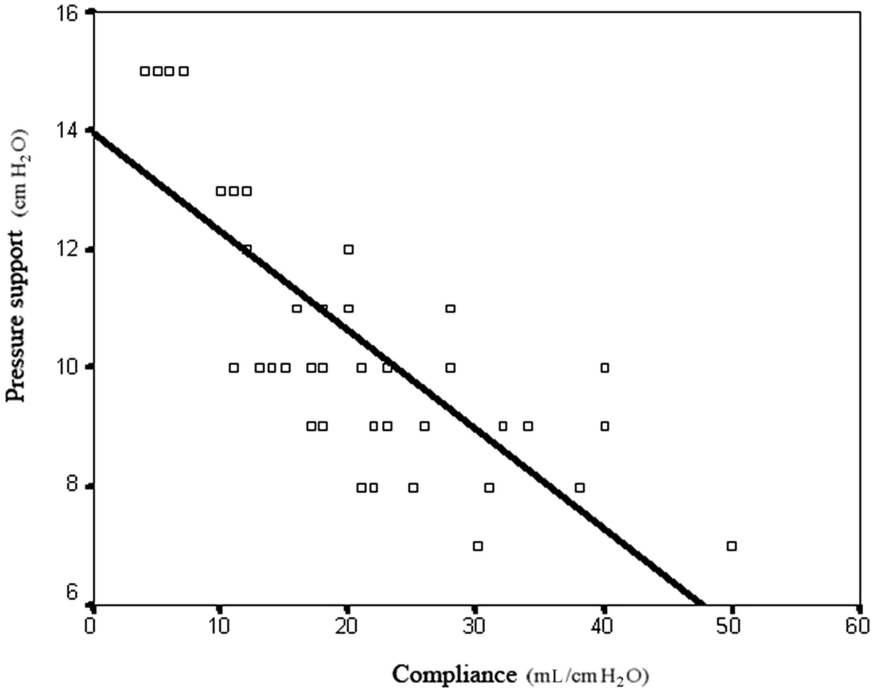

Figure 3. Correlation between the programmed level of pressure support (cm H_2O) and dynamic compliance (mL/cm H_2O) in children: A negative correlation was found between the programmed pressure support and the measured compliance ($r = -0.789$), which is statistically significant ($P < 0.001$).

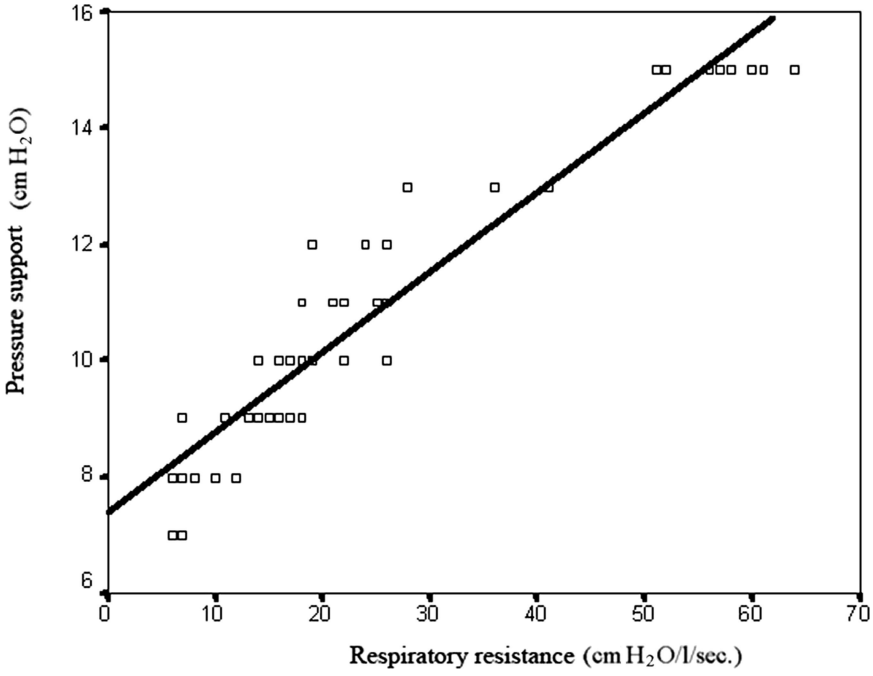

Figure 4. Correlation between the programmed level of pressure support (cm H_2O) and airway respiratory resistance (cm $H_2O \cdot L^{-1} \cdot s^{-1}$). A positive correlation was observed between the programmed pressure support and the airway resistance measured ($r = 0.945$), which is statistically significant ($P < 0.001$).

than with intensive care ventilators. Therefore, it is necessary to confirm that the ventilatory modes that work with intensive care ventilators also provide adequate ventilatory support when used with anesthesia workstations and this is especially important when ventilating pediatric patients (18).

The pressure support mode for children ≤10 kg in our study was 15 cm H_2O above PEEP, with maximum and minimum values that ranged between 13 and 15 cm H_2O. The need for more pressure support in children weighing <10 kg is thought to be secondary to the greater airway resistance and increased WOB. Larger children (>20 kg) needed less pressure support at 9 cm H_2O above PEEP, ranging between 7 and 11 cm H_2O.

Our study shows that pressure support was inversely proportional to the weight, age, and dynamic compliance of our pediatric patients and directly proportional to airway resistance, however, not all these variables are independent of each other. Age and weight, with a normal body mass index, similarly indicate the airway physiological changes during the growing process in children. All these variables are physiologically interdependent, hence higher airway resistances are encountered in smaller children.

According to our results, an easy way to program the level of pressure support inside the OR is to start with 15 cm H_2O in children under 10 kg (<1 yr old) and to start with 10 cm H_2O in children more than 10

kg (>1 yr old), and readjust this level according to the V_T obtained (the lower the V_T the more pressure is needed and vice versa).

In general, flow-triggers are much more sensitive than classic pressure-triggers making them especially useful for pediatric patients; in particular, they never let the patient breathe against a closed circuit, although they have the inconvenience of easily going into auto-triggering due to patient or circuit leaks. To take advantage of these new triggers, patient or circuit leaks must be avoided and we recommend starting with the lowest and most sensitive setting that the anesthesia machine provides and increasing the setting until any clinical situation of auto-triggering disappears. One must check that each trigger activation is preceded by a patient's inspiratory effort that is visible in the region between the navel and the xifoid process. If the trigger is activated in the absence of a respiratory effort, the trigger sensitivity must be reduced by increasing the liters per minute to activation. Particularly inside the OR and with pediatric patients, the trigger must be set as low as possible in order to increase the synchronicity between patient and machine. With the anesthesia workstation that we used in our study, the most frequently used trigger was 0.4 L/min, and it varied very little (±0.2 L/min), independently of age, weight, dynamic compliance, or the patient's airway resistances.

Although the side stream spirometry module with Pedi-lite or D-lite has the advantages of noninvasively measuring inspiratory and expiratory flows as well as pressure at the mouth of the patient, these measurements can be altered by flow turbulence and may become unreliable (19). To avoid this, a HMEF should be placed between the LMA and the spirometer (19,20). In addition, it is prudent to consider that a single isolated measurement may be affected by several factors including surgical abdominal manipulation, patient coughing or sighing, kinks in the tube or other devices, creating outliers (19). As the statistical processing of each of the measurements calculates the mean with the standard deviation, an outlying sample measurement could substantially alter the final reading and not correspond to the actual respiratory condition of the patient. Nevertheless, because numerous measurements are taken in the course of an anesthetic procedure, one at each breath, if instead of using the statistical mean, one uses the mode (the reading most often repeated in the series of values of a variable), the interference caused by the outliers could thus be eliminated, increasing the reliability of measurements obtained with the spirometers.

Although our study does not compare PLMA efficacy to that of a Classic LMA in the same patient population, our study shows that the PLMA (sizes 1.5–3) is an effective tool for mechanical ventilation with pressure support in pediatric patients. No major leaks occurred with the PLMA (in all cases <15% of the inspired V_T), consistent with other current studies (10,17,21) whereas the No. 1 Classic LMA (<5 kg) frequently has considerable leaks during positive pressure ventilation. In our study, 4 of 13 patients weighing <5 kg were excluded from the study because they had leaks of more than 15% of inspired V_T. The No. 1 Classic LMA was used in all four, as reported in other studies (10,17,21–23). Therefore, it may be advisable to use an endotracheal tube for positive pressure mechanical ventilation until an effective PLMA is available for children weighing <5 kg.

The $ETco_2$ values were close to the upper physiological limit (mean 43.1 mm Hg), and three patients were excluded because they had an $ETco_2$ > 45 mm Hg despite a V_T of 10 mL/kg. The high $ETco_2$ was probably the result of the larger artificial ventilatory dead space obtained when adding the LMA, humidifier and spirometer in contrast to the dead space that could be found with an endotracheal tube alone. The analysis of the respiratory rate in the three groups showed a small decrease when compared to physiological values, probably as an effect of the anesthetics on the respiratory center; in particular, opiates often produce bradypnea. Our use of fentanyl in the induction period could also have caused this high $ETco_2$ (24,25). This may explain why we found a decrease in the minute volume at the beginning of anesthesia, which can be compensated for by increasing the pressure support to increase V_T, until the respiratory rate normalizes itself.

Our study has several limitations. The studied children were ASA I and II and therefore our results cannot be extended to patients with previous respiratory disease or obesity. Pressure support has not been studied comparing endotracheal tubes with LMAs, because the imposed WOB for the two airway devices is unlikely to be the same, and therefore the required pressure support would probably also differ. Other limitations are that we did not measure the imposed WOB or the effects of other anesthetics.

We conclude that PSV with a PLMA provided by an anesthesia workstation with a trigger-flow is effective and an easy ventilation mode for ASA I-II pediatric patients, aged 2 mo to 14 yr, in ambulatory surgery with a combined general and regional anesthesia. A flow-trigger of 0.4 L/min is usually sufficient for all children. The pressure support can be easily adjusted according to the child's age, dynamic compliance, and airway resistance.

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