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Can Mechanical Power be Used as a Safety Precaution in Pediatric Patients?

Pediyatrik Hastalarda Güvenlik Önlemi Olarak Mekanik Güç Kullanılabilir mi?

Ahmet Yuksek[1], Okkes Hakan Miniksar[2], Cevdet Yardimci[2], Aysegul Parlak Cikrikci[2]

[1]University of Health Sciences, Kocaeli Derince Education and Research Hospital, Kocaeli, Turkey
[2]Yozgat Bozok University Faculty of Medicine, Department of Anesthesiology and Reanimation, Yozgat, Turkey

ABSTRACT

Objective: Mechanical power (MP) is the amount of energy transferred to the respiratory system of patients during each breath period. After overcoming the resistances required for respiration, the remaining energy may end up by damaging the lung parenchyma. The MP limit that should not be exceeded in pediatric patients is not yet clear. The aim of this observational descriptive study is to compare the perioperative MP measurements in healthy pediatric cases with the values given in the literature.

Methods: Perioperative MP was calculated according to the simplified MP formula in pediatric patients without known lung disease and compared with the literature.

Results: The mean age of 34 patients was 68.88±31.4 months and the mean weight was 21.82±7.5 kg. The mean MP was 3.93±1.1 J min^{-1}, and the indexed MP was 0.19±0.08 J min^{-1} kg^{-1}. Both MP ($p=0.008$) and indexed MP ($p<0.001$) were significantly higher in patients with high tidal volume. In addition, we found a negative correlation between indexed MP and weight (r: -668 and $p<0.001$). Both MP and indexed MP had sufficient predictive power to predict tidal volume >10 and predictive value was significant [Auc: 0.764, 95%CI: 0.55-0.97, p: 0.026]. The value of MP>3.76 was an indicator for tidal volume >10 with 87 sensitivity and 50 specificity. Predictive value of indexed MP for tidal volume >10 mL kg^{-1} was 0.25 J kg^{-1} [AUC 0.856, 95%CI: 0.70-1.0, $p=0.003$], and indexed MP was a stronger indicator than MP.

Conclusion: This study revealed that MP threshold values calculated for adults or patients with ARDS lung are not sensitive for pediatric patients, and a new threshold value should be determined for these patients.

Keywords: Mechanical power, pediatric anesthesia, mechanical ventilation

ÖZ

Amaç: Mekanik güç (MP), her nefes döngüsünde hastaların solunum sistemine aktarılan enerji miktarıdır. Solunum için gerekli olan dirençler aşıldıktan sonra kalan enerji akciğer parankimine zarar vererek sonlanabilir. Pediatrik hastalarda aşılmaması gereken MP sınırı henüz netlik kazanmamıştır. Bu gözlemsel tanımlayıcı çalışmanın amacı, sağlıklı pediatrik olgularda perioperatif MP ölçümlerini literatürde verilen değerlerle karşılaştırmaktır.

Yöntem: Perioperatif MP, bilinen akciğer hastalığı olmayan pediatrik hastalarda basitleştirilmiş MP formülüne göre hesaplandı ve literatürle karşılaştırıldı.

Bulgular: 34 hastanın yaş ortalaması 68.88±31.4 ay ve ortalama ağırlık 21.82±7.5 kg idi. Ortalama MP 3,93±1,1 J dak^{-1} ve indekslenmiş MP 0,19±0,08 J dak^{-1} kg^{-1} idi. Hem MP ($p=0{,}008$) hem de indekslenmiş MP ($p<0{,}001$) tidal hacmi yüksek olan hastalarda anlamlı olarak daha yüksekti. Ayrıca indekslenen MP ile ağırlık (r: -668 ve $p<0.001$) arasında negatif korelasyon bulduk. Hem MP hem de indekslenmiş MP, tidal hacmi >10 tahmin etmek için yeterli tahmin gücüne sahipti ve tahmin değeri anlamlıydı [Auc: 0.764, %95 CI: 0.55-0.97, p: 0.026]. MP>3.76 değeri, 87 duyarlılık ve 50 özgüllük ile >10 tidal hacim için bir göstergeydi. >10 mL kg^{-1} tidal hacim için indekslenmiş MP'nin tahmin değeri 0.25 J kg^{-1} [AUC 0.856, %95 CI: 0.70-1.0, $p=0.003$] idi ve indekslenmiş MP, MP'den daha güçlü bir gösterge idi.

Sonuç: Bu çalışma, yetişkinler veya ARDS akciğeri olan hastalar için hesaplanan MP eşik değerlerinin çocuk hastalar için hassas olmadığını ve bu hastalar için yeni bir eşik değerinin belirlenmesi gerektiğini ortaya koymuştur.

Anahtar sözcükler: Mekanik güç, pediatrik anestezi, mekanik ventilasyon

INTRODUCTION

The energy applied to the lungs by the ventilator during mechanical ventilation (MV) is usually used to overcome resistance in the chest wall and airways. Leftover energy is consumed by temperature, inflammation, and potentially lung tissue damage. The risk of ventilation-related damage increases in lungs with impaired homogeneity and ventilation-perfusion imbalance (1). As demonstrated by experi-

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***Corresponding author:** Ahmet Yuksek • mdayuksek@hotmail.com

Ahmet Yuksek 0000-0002-7529-2971 / Okkes Hakan Miniksar 0000-0001-5645-7729
Cevdet Yardimci 0000-0001-9176-891X / Aysegul Parlak Cikrikci 0000-0001-5684-5975

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mental and clinical studies, mechanical ventilation-induced lung injury (VILI) is associated with tidal volume (TV), peak pressure, respiratory rate (RR), and airflow. The physical force applied during ventilation, TV increases exponentially with driving pressures (ΔP_{aw}), flow (exponent=2), and RR (exponent=1.4), and linearly with positive end-expiratory pressure (PEEP) (2). When the effects of these parameters are formulated, the energy applied to the lungs can be calculated. This energy has been formulated as J min^{-1} and has now taken its place as mechanical power (MP) in the literature (2). In other words, MP is the amount of power transferred to the lungs to do the work of breathing. However the residual power after breathing work will be a source of tension for the lung tissue. A benefit of the MP calculation is that it is a single, easily calculated indicator parameter that can be used for the risks of barotrauma, volutrauma or atelectotrauma associated with VILI. As shown in different publications, high MP values were associated with negative outcomes such as increased 30-day mortality in intensive care patients, increased length of stay in hospital and intensive care unit, and decreased number of ventilator free days (3,4). Although this power has been formulated by some valuable studies, threshold values and calculation methods are still being discussed in the literature. There is no definite MP limit determined. However, in some of the pioneering publications in the literature, 12 J min^{-1} MP value and 0.32±0.1 indexed MP value are recommended to be accepted as threshold values (5,6). Some other recent studies also support the conclusion that MP calculation is beneficial to predict mortality (7,8). For this reason, Gattinoni et al. suggest that MP limits and formulas should be added to the mechanical ventilator software (2). However, studies on MP have often focused on Acute Respiratory Distress Syndrome (ARDS) and have been performed on intensive care patients or experimental animal models (9). Although MP is a promising safety limit with its easy computability, there are still questions about the formula and its usefulness. The success of the MP formula in perioperative situations and especially in pediatric patients has not been adequately tested. There are not enough publications in the literature regarding MP applications in pediatric cases yet.

In this observational study, our primary aim is to calculate the MP applied in pediatric cases who undergo inguinal hernia surgery under general anesthesia and to compare them with the values presented in the literature. Our other outputs are the calculation of the MP applied per kilogram and the other transferred energies, and questioning the possible contribution of a mechanical power formula to safe mechanical ventilation in pediatric cases.

MATERIAL and METHODS

Study design and patient selection

Our study was conducted prospectively and includes elective pediatric patients who underwent laparoscopic inguinal hernia surgery. The study was conducted between January and April 2022 and informed consent was obtained from the families. All patients were intubated following neuromuscular block and MV was applied with a pediatric patient compatible mechanical ventilator (Drager Primus, Germany) in volume-controlled or pressure-controlled modes. According to the observational nature of the study, MV modes and parameters were determined according to institute practices and anesthetist preference. The groups of patients is randomised according to these preferences and there was no intervention by the study team and a control group was not used. Descriptive data of patients such as height, weight, gender, and comorbidities were recorded as demographic data. Perioperative data were recorded in two groups as pressure control group (Group P) and volume control group (Group V) according to the applied MV mode.

Patients in both groups were excluded if they had congenital heart disease, pre-existing lung or airway disease, conditions that may decrease chest wall compliance, chronic respiratory failure requiring long term MV, pulmonary hypertension or conditions where nitrous oxide is contraindicated and patients with tracheostomy. Approval was obtained from the institutional ethics committee. Standard anesthesia monitoring including non-invasive blood pressure, pulse oximetry, 3-channel electrocardiography and heart rate monitoring and intraoperative end tidal carbon dioxide monitoring were applied to all patients. General anesthesia was administered to all patients and no spontaneous breathing activity was observed in any of them. Anesthesia was initiated with sevoflurane, propofol, fentanyl, and rocuronium bromide was used as muscle relaxant. Oxygen mixed with nitrous oxide and 1 minumum alveolar concentration (MAC) sevoflurane were used for anesthesia maintenance. Due to the observational nature of our study, no study specific changes were made in the ventilation mode and parameters applied to the patients.

Data collecting

In Group V patients, MP was calculated with the simplified formula applied by Gattinoni et al.;

MP_{vcv}= RR x TV x (PIP-[(P_{plat}-PEEP) x 0.5]) x 0.098 (1,2). ($MP_{vcv;}$ MP for volume controlled ventilation, P_{plat}; plateau pressure)

In pressure-controlled ventilation (PCV), the simplified MP formula of Becher et al. was used;

MP_{pcv}= RR x TV x (ΔP_{insp}+PEEP) x 0.098 (11). (MP_{pcv}; MP for pressure controlled ventilation, (ΔP_{insp};P_{plato} –tPEEP))

The MP calculated from the above formulas of Gattinoni et al and Becher et al are consistent with the calculated MP by computer or on a volume pressure graph (2,11). For this reason, both formulas are widely accepted methods in the literature. Expressions used in formulas, where 0.098 is a conversion factor to J min^{-1}, RR is the respiratory rate in beats min^{-1}, TV is the tidal volume in L, PEEP is the positive end-expiratory pressure in cmH_2O, ΔP_{insp} is the driving inspiratory pressure in cmH_2O, T_{insp} is the inspiratory time in seconds, P_{plato} is the plateau pressure in cmH_2O.

Respiratory mechanics were registered within 30 min after intubation. Baseline settings for PCV were as follows: P_{plato} limit=13 cm H_2O, PEEP=0–5 cm H_2O; Inspiratory Expiratory ratio (I/E) 1:2 and RR were adjusted according to respiratory system mechanics and to achieve an end-tidal CO_2 40±5 mmHg and the TV was taken as the average value of the volumes formed at the minute the measurements were made. Adjustments were made as follows in patients who underwent volume-controlled ventilation (VCV): Patients ventilated with a constant flow. Tidal Volume: 6-8 mL kg^{-1}, PEEP: 0-5 cmH_2O, I/E: 1/2 and RR adjusted according to respiratory system mechanics and to achieve an end-tidal CO_2 40±5 mmHg, FiO_2 40-50%. Peak inspiratory pressure (PIP), plateau pressure (P_{plato}), extrinsic (set) positive end-expiratory pressure (PEEP), total PEEP (tPEEP), intrinsic PEEP (tPEEP–PEEP), ΔP (P_{plato} –tPEEP), delivered VT (mL kg^{-1}), I/E, RR, and maximum inspiratory flow (QI L^{-1}) and expiratory flow (L min^{-1}) recorded as variables.

Other formulas used in calculations were; Indexed MP(MP kg^{-1}, calculated MP according to ideal body weight), Dynamic power (TV x RR x [(Pplato + tPEEP) x 0.5), force applied to the lungs in each inspiration in mJ min^{-1}), Driving Power (TV x RR x [(P_{plato} – tPEEP) x 0.5], for the driver power that provides the gas flow in mJ min^{-1}), and Mechanical Energy (0.098 (TV kg) (PIP - [(P_{plato} - PEEP) x 0.5], Calculated mechanical energy in mJ kg^{-1}).

Statistical Analysis

The adequacy of the number of patients was decided by power analysis (G*power, version 3.1.9.4 software). In our reference by Francesca Collino et al, the effects of high and low PEEP values on MP were examined (10). Accordingly, when the alpha was 0.05, the power was 80%, and the effect size was 0.9922, it was seen that groups of at least 14 people were sufficient. The number of patients was determined by the data obtained at the end of the study period.

The Shapiro-Wilk Normality test was used to assess whether the data were normally distributed. Normally distributed data were given as mean±standard deviation, and non-normally distributed data were given as median±IQR. Independent samples t-test was used to compare Group V and Group P patients. The Pearson correlation analysis was used for correlation analysis. ROC analysis was used to measure the power of MP and indexed MP values to predict patients with high TV (>10mL kg^{-1}).

RESULTS

The mean age of 34 patients was 68.8±31.4 months and the mean weight was 21.8±7.5 kg. Fourteen of the patients were ventilated in volume control mode (Group V) and 20 patients were ventilated in pressure control mode (Group P). Mean minute ventilation was 3.99±1.1 L and TV was 183.8±64.1 mL. The demographic data of the patients and the measured values due to mechanical ventilation are shown in Table I. No hemodynamic complications (hypotension, bradycardia, etc.) were observed in the period between the induction of anesthesia and the collection of measurements, which would necessitate changing the mechanical ventilation mode or the adjusted parameters. The late hemodynamic side effects of the applied mechanical ventilation were not followed up since they were not included in the study. Postoperative respiratory distress and complications were not observed in any of our study patients. In terms of late effects, the patients were not followed up for study purposes.

Mean MP, indexed MP, Delivered TV, Mechanical Energy, Dynamic Power, Driving Power were calculated for all patients. Values calculated from mechanical ventilation parameters are presented in Table II.

When the volume control and pressure control modes were compared, the weight and age of the patients in Group P were significantly lower (p=0.001), and the respiratory rate was significantly higher (p=0.021). Although the MP in Group P and V were comparable, the indexed MP was significantly higher in Group P (p=0.001) (Figure 1). Although the PIP were significantly higher in Group V (p=0.044), the peak pressures were below 15 cmH_2O in both groups. While total TV administered in Group V were higher (p=0.001), a delivered TV (TV kg^{-1}) was higher in Group P (p=0.027).

In Group V, TV was found to be >10mL kg^{-1} in 2 patients and 6 patients in Group P. However, MP was not above 6 J min^{-1} in any of these 8 patients. In other words, the MP calculation did not give a warning against high tidal volume in these patients. Although we applied a high tidal volume, the MP value was below the recommended limit for adults. Mean MP was 4.82±1.0 and indexed MP was 0.28±0.1 in 8 patients with TV>10 mL kg^{-1}, mean MP was calculated as 3.65±1.0 and indexed MP was calculated as 0.17±0.05 in patients with TV<10 mL kg^{-1}. Both MP (p=0.008) and indexed MP (p<0.001) were significantly higher in patients with high TV. In addition, while there is no correlation between MP and weight (r:0.273 and p:0.118), we found that higher indexed MP was applied at lower weights for all study patients, and this negative correlation was significant (r:-668 and p<0.001)

Predictive value of MP for TV>10 mL kg^{-1} was significant [Auc: 0.764, 95%CI: 0.55-0.97, p: 0.026]. The value of MP>3.76 was an indicator for TV>10 mL kg^{-1} with 87% sensitivity and 50% specificity. The predictive value of indexed MP for TV>10 mL kg^{-1} was [AUC 0.856, 95%CI: 0.70-1.0, p=0.003], sensitivity 0.25 J kg^{-1} was indicative for TV>10 mL kg^{-1} with 75% sensitivity

Table I. Height, Weight, Adjusted Mechanical Ventilator Parameters and Measured Ventilation Values of the Patients

Characteristic	Mean±SD (n=34)	Group V (n=14)	Group P (n=20)	p
Weight (kg)	21.8±7.5	28.7±5.0	17.0±4.8	**0.001**
Age (months)	68.8±31.4	86.2±23.1	56.7±31.1	**0.005**
Tidal volume (mL)	180± 64.1	227.07±67.1	153.60±41.3	**0.001**
Delivered tidal volume (mL kg^{-1})	8.45±1.7	7.84±1.4	9.17±1.7	**0.027**
Minute volume (L min^{-1})	3.99±1.1	4.77±1.7	3.44±0.7	**0.001**
PEEP (cmH$_2$O)	2.61±1.3	3.14±1.1	2.25±1.4	0.065
Peak pressure (cmH$_2$O)	11.61±1.4	12.21±1.3	11.20±1.3	**0.044**
Plateau pressure (cmH$_2$O)	11.20±1.2	11.71±1.3	10.85±1.1	0.050
Driving Pressure (cmH$_2$O)	8.58±1.6	8.57±1.5	8.60±1.7	0.961
Respiratory rate (Respiration min^{-1})	23.17±2.9	21.78±2.3	24.15±3.0	**0.021**

SD: Standard deviation, **PEEP:** Positive End-Expiratory Pressure, **Group V:** Volume, **Group P:** Pressure controlled ventilation.

Table II. Values Calculated according to Mechanical Power Formulas

Characteristic	Mean±SD	Group V (n=14)	Group P (n=20)	p
MP (n=34) (J min^{-1})	3.93±1.1	3.78±1.0	4.03±1.2	0.537
Indexed MP (J min^{-1} kg^{-1})	0.19±0.08	0.13±0.03	0.24±0.07	**0.001**
Driving power	17.63±5.0	20.40±4.16	15.68±4.8	**0.006**
Mechanical energy	6.19±1.7	6.12±1.6	6.25±1.8	0.836
Dynamic power	29.12±10.7	36.36±10.5	24.05±7.6	**0.001**

Note: SD: Standard deviation, **MP:** Mechanical Power, **Group V:** Volume, **Group P:** Pressure controlled ventilation.

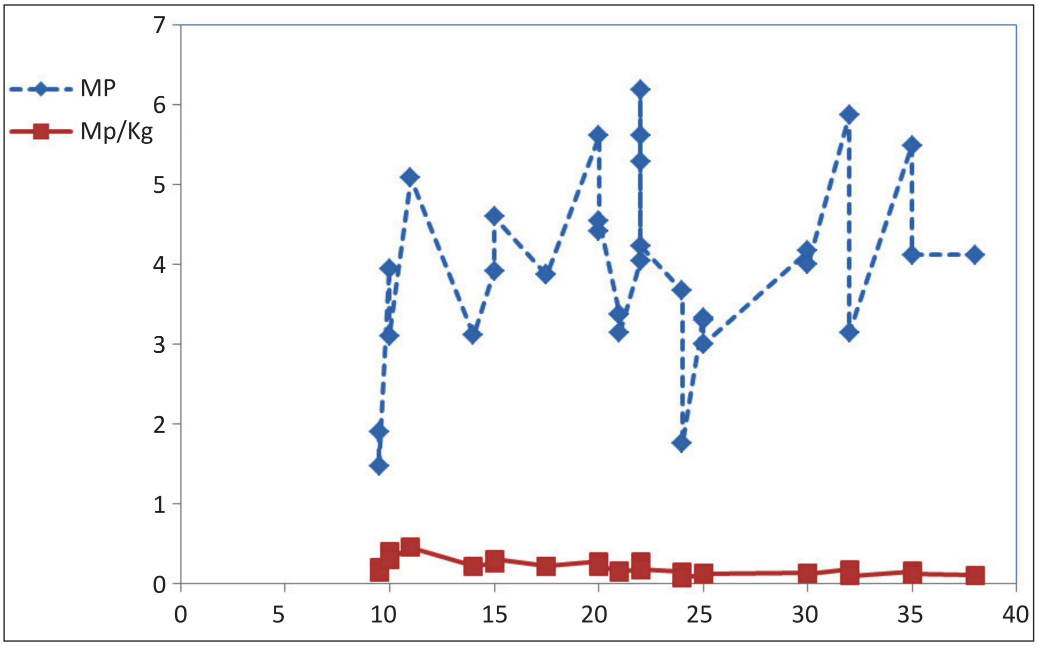
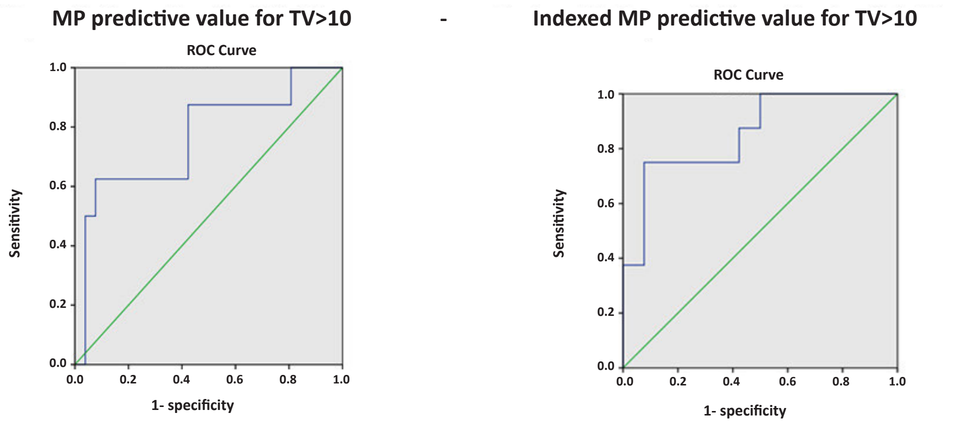


Figure 1. MP and indexed MP changes according to patients weight.



MP predictive value for TV>10 - **Indexed MP predictive value for TV>10**

*[Auc: 0.764, 95%CI: 0.55-0.97, p:0.026]. The value of MP>3.76 was indicator for TV>10 with 87 sensitivity and 50 specificity.

* [AUC 0.856, 95%CI: 0.70-1.0, p=0.003], sensitivity 0.25 J/kg was indicative for TV >10 with 75% sensitivity and 93% specificity.

Figure 2. Roc curve of MP and Indexed MP predictive value for TV>10
*[Auc: 0.764, 95%CI: 0.55-0.97, p: 0.026]. The value of MP>3.76 was an indicator for TV>10 with 87 sensitivity and 50 specificity.
* [AUC 0.856, 95%CI: 0.70-1.0, p=0.003], sensitivity 0.25 J kg^{-1} was indicative for TV >10 with 75% sensitivity and 93% specificity.

and 93% specificity and indexed MP was a stronger indicator than MP (Figure 2).

DISCUSSION

In our study, MP for 34 healthy pediatric patients who underwent volume control and pressure-controlled MV was calculated with suitable formulas for these modes. The mean MP in both ventilation modes was similar between groups (p=0.537). Mean MP for all patients was calculated as 3.93±1.0 J min^{-1}. Mechanical power could be easily calculated in cases where both volume control and pressure control ventilation were applied.

The mean age (p=0.005) and weight (p=0.001) of the patients in Group V were higher than the Group P, and their respiratory rate (p=0.021) was significantly lower. For this reason, MP applied per kilogram was found to be significantly higher in Group P (p=0.001). However, it may be due to the fact that TV was already adjusted for kilograms in Group V patients (227.07±67.1 vs 153.60±41.3), and formed according to the pressure limit in Group P patients. It should be taken into account that pediatric patients have high compliance and all patients are healthy pediatric cases without lung problems. Pressure control modes, therefore, provided higher TV per kilogram.

Mechanical Power is the amount of energy transferred to the respiratory system per minute during MV. The power dissipated here is used to overcome the elastic forces of the lung and the resistance to the airflow (11,12). A portion of the applied energy is reflected in the tissues as excessive stretching, volume or pressure damage, and heat. Both resistance and elastance of pediatric patients are different from adults (13). In these patients, airway resistance is high, and narrowing of the airway results in a greater increase in resistance. In pediatric cases, applying force above the energy required for ventilation may result in anchoring epithelial and endothelial cells. However, adequate or excessive power and energy limits are not clear for these patients. Becher et al. calculated the amount of force applied due to MV in 42 patients with and without ARDS as 15.6±6.9 J min^{-1}, and Meidjen et al. calculated the mean MP value as 13.34 (IQR:11.40–17.82) in the same patients with different calculations (11,12). Among these patients, the mean MP was calculated as 24.31 (IQR:17.52–26.18) J min^{-1} in patients with ARDS and 11.49 (IQR:10.83–13.13) J min^{-1} in healthy adults without ARDS under PCV.

In our study questioning the mechanical power applied intraoperatively in pediatric patients, applied average mechanical power was lower than the values applied for adult patients in the literature (our mean MP 3.9±1.1 J min^{-1}). These two important findings show that it actually reaches the pressure or volume limits we set with a lower MP but a higher indexed MP than the limits in the literature. The reason for the divergence of the indexed MP value is that as the patients' weight (28.7±5.0 vs 17.0±4.8) and age (86.2±23.1 vs 56.7±31.1) decrease, the airway resistance increases, and some of the applied force is used to overcome this resistance. Besides, indexed MP was 0.19±0.08 J min^{-1} kg^{-1}. In a study by Diaz et al., the median indexed MP was 1.36 (IQR:0.97–1.77) in non-ARDS children heavier than 15 kg and 0.98 (0.65–1.36) in children less than 15 kg. Regardless of ARDS presence, indexed Mp value was more sensitive in patients weighing less than 15 kg compared to patients more than 15 kg (13). This finding showed us that the median MP and indexed MP values applied in healthy pediatric cases will be different from adults and therefore different alarm limits should be set.

The pressure applied to the lungs should be titrated with caution in order to avoid adverse events in safe mechanical ventilation. As shown in two pioneering studies in ARDS about 24 years ago, excessively high tidal volumes increase mortality in intensive care patients, and patients benefit from adjusting pressure and volumes (14,15). The most well known biochemical mechanisms for lung injury are volutrauma, barotrauma and atelectotraumas (16). Chemical and inflammatory causes of damage are difficult to manage because they cannot be easily measured during mechanical ventilation. An important publication by Putersen et al., showed that low TV increase survival in ARDS patients reinforced the concept of lung-protective ventilation (17). The relationship between TV and VILI has also been demonstrated previously in the ARDS Network study, called the 'ARMA trial' (15). Here, it has been shown that reducing TV from 12 to 6 mL kg^{-1} reduces mortality by 22%. In another study, a decrease in pulmonary cytokine concentration was observed as a result of TV reduction from 6 to 4 mL kg^{-1} (18). Another way to reduce VILI is to reduce barotrauma. As Diaz et al stated, peak pressures above 30 cmH_2O are related with barotrauma (13). Mean peak airway pressures in our study were calculated as 11.50±1.4 cmH_2O. Although the peak pressures in the VCV group were 12.21±1.3 cmH_2O and significantly ($p=0.044$) higher than the PCV group, they were within acceptable limits for barotrauma. Another cause of lung injury is atelectotrauma. Stress on lung tissue caused by cyclic opening and closing is a cause of VILI (19,20). Although the Alveolar Recruitment for Acute Respiratory Distress Syndrome Trial (ART) investigators stated that high PEEP is not superior to the recruitment maneuver in reducing mortality in moderate and severe ARDS, it is essential to open the lungs and keep them open in both methods (21). The most effective way to keep the lung open in perioperative conditions and intensive care is to apply a PEEP (16,22). In our patients, an average of 3.0±1.3 cmH_2O PEEP was applied and there was no difference between the two groups. In addition to the conventional VILI prevention strategies many novel calculations and strategies such as low driving pressure or individualized ventilation have recently adopted the clinical practice (4,23,24). Mechanical power calculations seem to be a promising strategy because they can be obtained with non-invasive methods and requires no experience. Gattinoni et al. proposed a useful formula for calculating the MP applied to the lungs in volume-controlled ventilation (2). Cressoni et al., in an animal study, showed that MP administered over 12 J min^{-1} was associated with VILI and suggested that this value be considered as an alarm limit (5). In addition, Costa et al found that 0.32±0.1 J min^{-1} kg^{-1} indexed MP (MP kg^{-1}) was associated with increased mortality in ARDS patients (6). Although the method of this study in the proof of VILI part was criticized, it is clear that high MP application should be avoided.

After the MP calculation formula applied by Gattinoni et al. for VCV, Becher et al. showed the MP calculation formula for PCV. However, studies have been carried out mostly in adult and intensive care patients. Due to different respiratory system compliance and resistance of pediatric patients, different threshold values should be calculated. There are a limited number of studies in the literature trying to determine the MP threshold in pediatric patients (5,12). In this respect, we think that our study will contribute to the literature. One of the limited numbers of studies conducted in pediatric patients was conducted by Diaz et al (13). Intensive care patients with and without ARDS were included. In our study, otherwise healthy children undergoing surgery were included. Both the mean MP value of 3.93±1.1 J min^{-1} in our study and the median MP values in the patients with ARDS (median 2.87+IQR: 2.10–3.92) and without ARDS (median 2.60+IQR: 1.58–3.11) in the Diaz study are much lower than the 12 J min^{-1} which is considered as a threshold value for lung injury. The mean weight of the cases included in our study was 21.8±7.5 kg. These values were calculated as 28.7±5.0 in Group V and 17.0±4.8 in Group P, which was also significantly lighter. This shows that it is important to calculate indexed MP in addition to MP in pediatric patients with low weight. Diaz et al. stated in their study that their results could not be generalized to situations other than VCV mode. Similarly, in our study group, indexed MP was higher in lower-weight patients and it was shown that low weight was associated with high indexed MP in PCV mode as well (r:-668 and $p<0.001$).

Although Diaz stated in their study that the ΔP value better discriminates ARDS than all formulas including MP, Rauf et al. stated in their study that the driving pressure value in pediatric patients was most effective factor for MV-related days and pediatric intensive care unit (PICU) length of stay, but not for mortality (13,25). In our patients, the driving pressures were below 15 cmH_2O in both Group V and Group P. However, there are multiple risk factors for VILI, and considering driving pressures alone would only be looking at risks from one angle. Mechanical power offers a perspective on the different parameters. Although a relationship between high driving pressure and mortality has been defined in previous studies, the relationship between MP and driving pressure has not been adequately investigated. Mechanical power makes an important contribution in terms of taking into account some other parameters that are not used in the calculation of driving pressure. Tonna et al. investigated the relationship between MP and driving pressure from a similar point of view, and found that using these two indicators together was significantly more predictive than using them alone, according to the model they used (26). In our study, the average dynamic power was calculated as 29.12 (IQR:20.50-35.49) and driving pressure 8.58±1.6

cmH_2O. Pressure-controlled ventilation was applied in 20 of 34 patients with healthy lungs. For this reason, our patients remained within the driving pressure limits. In the study of Parhar et al. in ARDS patients, the average driving pressure was calculated as 15.0 cmH_2O and found to be associated with 28-day mortality. In the same study, TV>8 mL kg^{-1} was not associated with mortality (8). In our patients, the mean TV was 8.45 (IQR:7.42-9.27) mL kg^{-1}. In patients in Group P, TV was calculated as 9.17±1.7 mL kg^{-1} and was higher than Group V (7.84±1.4 ml kg^{-1}) (p=0.027). An important point is that TV>10mL kg^{-1} was found in 2 patients in Group V and 6 patients in Group P. However, MP was not above 6 J min^{-1} (Less than half of the 12 J min^{-1} alarm limit) in any of these 8 patients. In other words, the MP calculation did not warn against high tidal volume in these patients. On the other hand, both MP and indexed MP were significantly higher in patients with TV>10 mL kg^{-1}. According to our ROC analysis, 0.25 J min^{-1} kg^{-1} indexed MP was indicative for TV>10 with 75% sensitivity and 93% specificity. Although the calculation of delivered TV (TV kg^{-1}) is easier than the calculation of indexed MP, our findings show that a new threshold is required for both MP and indexed MP in pediatric patients and this is a more comprehensive indicator than delivered TV.

Mechanical power is an easy monitoring that does not require additional costs or experience As noted by Gattinoni, et al., these parameters can be easily adapted to MV software (27). In a study comparing MP and lung ultrasonography (LUS), MP was as useful as LUS in predicting mortality in ARDS patients. While experience is required for LUS, no experience needed for calculating MP there is no need for experience (28). Therefore, further studies on MP and indexed MP and further adaptation to our clinical practice seem beneficial.

Our study has some limitations; firstly, MP was not a continuous monitoring parameter. Therefore, measurements were taken at the 30th minute of the operation in all cases for standardization, MP changes in longer surgeries were not recorded. Although lung protective ventilation was used as a criterion in the method of our study, high tidal volume measurements were observed in some patients. Measuring tidal volumes within one minute, not a continuous variable, may have produced this result. These patients were not excluded from the study. Because, due to its observational nature, our primary outcome was to observe perioperative MP values in healthy lungs. In addition, volume-controlled mode was preferred more frequently in pediatric cases of older ages and pressure-controlled mode in younger children in our study. It would be appropriate to make a randomization based on the age factor, which is an important variable, or to compare the effects of different modes on MP in similar age groups. However, these points may be the subject of new studies. Our study is not an outcome-based analysis. We did not have a different group such as adult patients. Postoperative complications were not followed for a long time. The small number of patients might lead to type II error although the data are very consistent in our description. Considering the literature, the number of patients was similarly low in similar studies. However, it was observed that there were not enough studies on MP measurements in healthy pediatric lungs. For this reason, we believe that this study will contribute to the field.

CONCLUSION

This study revealed that MP threshold values calculated for adults or patients with ARDS lung are not suitable for pediatric patients, the indexed MP value is more significant than MP, and a new threshold value should be determined for MP and indexed MP in pediatric patients. Adding this easy-to-measure safety scale to the mechanical ventilator software will contribute to patient safety.

AUTHOR CONTRIBUTIONS

Conception or design of the work: AY

Data collection: APC, HM, CY

Data analysis and interpretation: AY, HM

Drafting the article: AY, HM

Critical revision of the article: AY, HM, CY

All authors (AY, HM, CY, APC) reviewed the results and approved the final version of the manuscript.

DATA AVAILABILITY STATEMENT

The research raw data are not publicly available due to ethical reasons. The data are available with the corresponding author and can be made available upon receiving a formal and reasonable request.

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