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Research Article

Evaluation of patients who underwent invasive mechanical ventilation in a pediatric intensive care unit: A prospective study

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Abstract

Objective: To evaluate the use of invasive mechanical ventilation (MV) during a one-year period (2015–2016) in a pediatric intensive care unit (PICU), identify the most common complications and mortality rates, and compare study-period practices with more recent evidence to characterize changes in pediatric MV management over the past decade.

Method: Among 781 patients followed in the PICU of Çukurova University Faculty of Medicine between February 2015 and February 2016, 173 patients who underwent invasive MV were prospectively included. Demographic data, primary diagnoses, MV indications, PICU severity scores (Pediatric Index of Mortality [PIM II], Pediatric Risk of Mortality [PRISM III], and Pediatric Logistic Organ Dysfunction [PELOD]), ventilation modes and parameters, tracheostomy status, sedation-analgesia use, weaning, complications, and ventilator-associated pneumonia (VAP) rates were analyzed.

Result: Patient ages ranged from 2 months to 18 years (median 42 months, min-max 2-216); 57.2% were male. MV incidence was 22.1%. Neurological disease was the most common underlying condition (44.5%). Median PICU stay was 7 days (min-max 1-65) and median MV duration was 5 days (min-max 1-61). Complications occurred in 20.2% of patients; atelectasis (7.5%), VAP (6.9%), and pneumothorax (5.2%) were most frequent. VAP rate was 4.46/1,000 ventilator days. Tracheostomy was performed in 37 patients (21.4%). Mortality rate was 11%.

Conclusion: MV practices in the PICU were largely consistent with international standards. Ventilator parameters were broadly maintained within lung-protective ranges across the cohort; together with a VAP prevention bundle, this may have contributed to the comparatively low complication rate. Multicenter prospective studies are required to generate robust national data on pediatric MV practices in Turkey.

Keywords: Mechanical ventilation, indications, complications, pediatric parameters, pediatric intensive care, tracheostomy

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INTRODUCTION

Mechanical ventilation (MV) is defined as the process of maintaining respiratory function with the assistance of a device to prevent lung collapse, ensure adequate ventilation, and maintain appropriate oxygenation until the underlying pathology causing respiratory or oxygenation insufficiency is resolved. The primary objective of MV is to correct and sustain homeostasis in oxygen–carbon dioxide exchange and acid–base balance in patients with respiratory insufficiency, circulatory failure, or respiratory suppression due to central nervous system disorders (1).

Mechanical ventilation can be performed invasively or non-invasively. To provide optimal respiratory support, volume, pressure, and flow parameters must be individually tailored to each patient (2). In recent years, MV has become one of the most frequently applied life-sustaining interventions in pediatric intensive care units (PICUs), with studies reporting that more than 20% of PICU patients require invasive ventilatory support (3). With the widespread use of MV and accumulating evidence, it is now well-established that positive-pressure ventilation is not a benign process; ventilator-induced lung injury (VILI), arising from mechanisms such as volutrauma, barotrauma, atelectrauma, and biotrauma, remains a significant concern (4,5). Additional complications include pneumothorax, atelectasis, ventilator-associated pneumonia (VAP), subglottic stenosis, and oxygen toxicity.

In parallel with these developments, the approach to MV in pediatric critical care has evolved considerably. The Pediatric Mechanical Ventilation Consensus Conference (PEMVECC) has provided an internationally endorsed framework of recommendations aimed at harmonizing ventilation practices and reducing complications in critically ill children (6). Furthermore, the growing use of non-invasive modalities—particularly high-flow nasal cannula (HFNC) and bi-level positive airway pressure (BiPAP)—has increasingly deferred or averted the need for invasive MV in pediatric patients with acute respiratory failure (7).

The aim of this study was to evaluate the use of invasive MV in a tertiary PICU during a prospective one-year period (2015–2016), identify the most common complications and mortality rates, and compare these study-period practices and outcomes with more recent evidence to characterize how pediatric MV management has evolved over the past decade.

METHOD

Among 781 patients followed in the PICU of Çukurova University Faculty of Medicine between February 2015 and February 2016, 173 patients who underwent invasive MV were prospectively included in the study. Only the first MV episodes of patients with repeated applications were included. The study protocol was approved by the Ethics Committee of Çukurova University Faculty of Medicine.

During daily follow-ups, patient observation forms and medical records were reviewed to collect and record the following data: demographic information, primary diagnoses, indications for invasive MV, pediatric intensive care severity scores (Pediatric Index of Mortality [PIM II], Pediatric Risk of Mortality [PRISM III], and Pediatric Logistic Organ Dysfunction [PELOD]), type and method of ventilation, endotracheal tube or tracheostomy status, duration of PICU stay and intubation, sedation-analgesia and neuromuscular blocker use, weaning and extubation methods, complications, VAP rates,

and other outcomes. Pediatric intensive care scores were calculated using a computer-based system according to the original methodology, based on the worst physiological values recorded at PICU admission and within the first 24 hours, in line with the standard scoring windows for these instruments. Mechanical ventilator parameters were recorded daily; minimum and maximum values were used during the evaluation.

Ventilator weaning protocol

Patients were evaluated on daily clinical rounds three times per day. Blood gas analysis was performed 1–2 times daily to guide ventilator adjustments. Sedation was interrupted daily to allow clinical reassessment. Peak inspiratory pressure (PIP) and positive end-expiratory pressure (PEEP) were kept within protective limits and were not routinely escalated beyond these thresholds; weaning was achieved through stepwise reduction of pressure support as respiratory mechanics and gas exchange allowed. A spontaneous breathing trial was performed as part of extubation readiness assessment, and the decision to extubate was made at the end of clinical rounds based on the patient's respiratory status, oxygenation, and ventilator requirements.

The diagnosis of VAP was confirmed at least 48 hours after initiation of MV, based on the appearance of new progressive infiltrates on chest radiography, along with at least two of the following criteria: hyperthermia (>38°C) or hypothermia (<36°C), leukocytosis (>12,000/mm³) or leukopenia (<4,000/mm³), purulent tracheal secretions, hypoxemia (≥15% decrease in the ratio of partial pressure of arterial oxygen to fraction of inspired oxygen [PaO_2/FiO_2]), increased oxygen requirement, or increased ventilation requirement (3). All VAP diagnoses were confirmed by the hospital's infectious diseases committee. The VAP prevention bundle applied in this unit included daily weaning assessments, hand hygiene, head-of-bed elevation to 30°–45°, aseptic suctioning technique, use of closed-system suctioning, and adherence to oral care recommendations.

Statistical analysis

Data were analyzed using IBM SPSS Statistics version 20.0. Normality of distribution for continuous variables was assessed using the Shapiro-Wilk test. As age, MV duration, PICU length of stay, PIM II, PRISM III, and PELOD were not normally distributed and markedly right-skewed (Shapiro-Wilk $p<0.001$ for all), the Mann-Whitney U test was used for two-group comparisons of these variables, and they are reported as median (min-max) rather than mean ± standard deviation (SD) throughout the manuscript. The chi-square test, or Fisher's exact test when expected cell counts were <5, was used to compare categorical variables such as mortality, sex, MV indication, and primary disease. A p-value of <0.05 was considered statistically significant. To assess the association between PICU severity scores and mortality, PIM II, PRISM III, and PELOD were each entered as continuous predictors in separate univariable logistic regression models with in-hospital mortality as the outcome; results are reported as odds ratios (OR) with 95% confidence intervals (CI) and p-values. A multivariable model was not fitted given the limited number of mortality events (n=19); these findings are hypothesis-generating.

RESULTS

Patient characteristics

A total of 173 patients requiring invasive MV between February 2015 and February 2016 were prospectively analyzed. Patient ages ranged

from 2 months to 18 years (median 42 months, min-max 2-216); 99 (57.2%) were male and 74 (42.8%) were female. The incidence of MV in the study PICU was 22.1%. Neurological disease was the most common underlying condition (n=77, 44.5%), followed by metabolic disease (n=21, 12.1%), congenital cardiovascular disease (n=20, 11.5%), and oncological disease (n=11, 6.3%). The most frequent indication for MV was hypoxemic respiratory failure (n=88, 51%), followed by postoperative care (n=36, 20%), hypercapnic respiratory failure (n=20, 11%), Glasgow Coma Scale ≤8 (n=19, 11%), and shock (n=10, 6%) (**Table 1**).

Severity scores at admission ranged as follows: PIM II median 24.3% (4.5–100%), PRISM III median 20 (5–67), and PELOD median 1.3% (0.1–100%). In patients who died, the requirement for multiple inotropic agents was significantly more frequent and strongly associated with mortality. Among non-survivors, median PIM II was 100, median PRISM III was 45, and median PELOD was 76%. Each one-unit increase in PIM II was associated with a 1.11-fold increase in mortality risk (OR 1.11, 95% CI: 1.053–1.167, p<0.001); each one-unit increase in PRISM III increased mortality risk by 1.19-fold (OR 1.19, 95% CI: 1.114–1.275, p<0.001); and each one-unit increase in PELOD was associated with a 1.04-fold increase in mortality risk (OR 1.04, 95% CI: 1.026–1.062, p<0.001). No statistically significant difference was found between sexes in their effect on mortality.

Among patients on MV, the most commonly used device was the Dräger Evita-2, used in 91 patients (52.6%). Pressure-controlled ventilation was utilized in all patients; the predominant mode was synchronized intermittent mandatory ventilation with pressure support (SIMV+PS).

Table 1. Epidemiological and demographic characteristics of the cases

Variable	N	%
Age (months)		
Median (min-max)	42(2-216)	
Gender		
Female	74	42.8
Male	99	57.2
Underlying Condition		
Congenital cardiovascular diseases	20	11.5
Neurological diseases	77	44.5
Metabolic diseases	21	12.1
Oncological diseases	11	6.3
Infectious diseases	5	2.9
Nephrological diseases	11	6.3
Immunological diseases	2	1.1
Other	26	15.0
Indication for MV		
Hypoxemic respiratory failure	88	51.0
Hypercapnic respiratory failure	20	11.0
Postoperative care	36	20.0
Glasgow Coma Scale ≤8	19	11.0
Shock	10	6.0
Incidence of MV	173	22.1
Mortality	19	11.0

MV: Mechanical ventilation

Endotracheal tubes were cuffed in 110 patients (63.6%) and uncuffed in 63 patients (36.4%). The median PICU length of stay was 7 days (min-max 1-65) and median MV duration was 5 days (min-max 1-61) **(Table 2)**.

Sedation and vasoactive support

Sedation and analgesia were administered to 126 patients (72.8%). Benzodiazepines and opioids were the first-line agents; midazolam and fentanyl were the most commonly used drugs. Vasoactive or inotropic support was required in 55 patients (31.8%). The most commonly

Table 2. Pediatric Intensive Care Unit and mechanical ventilation parameters

Parameter	Mean ± SD	Median (Min-Max)
Max PIP (cmH_2O)	22.95 ± 5.25	22 (11-44)
Min PIP (cmH_2O)	18.18 ± 3.10	18 (10-28)
Max PEEP (cmH_2O)	6.28 ± 1.54	6 (5-13)
Min PEEP (cmH_2O)	5.41 ± 0.75	5 (4-9)
Max MAP (cmH_2O)	10.20 ± 1.90	9 (8-20)
Min MAP (cmH_2O)	8.45 ± 1.07	8 (7-17)
Max RR (breaths/min)	25.60 ± 6.20	25 (12-45)
Min RR (breaths/min)	19.57 ± 5.10	20 (10-35)
Max TV/kg (mL/kg)	8.16 ± 1.15	8 (6-12)
Min TV/kg (mL/kg)	6.83 ± 0.81	7 (6-10)
Max FiO_2 (%)	55.75 ± 14.30	60 (33-100)
Min FiO_2 (%)	38.39 ± 4.88	40 (30-65)
Max Ti (s)	0.92 ± 0.69	0.8 (0.7-0.9)
Min Ti (s)	0.81 ± 0.49	0.8 (0.6-0.7)
Max Trigger	1.20 ± 0.47	1.0 (0.7-2.0)
Min Trigger	1.20 ± 0.45	1.0 (0.6-2.0)
Max PS (cmH_2O)	8.65 ± 3.30	8 (5-19)
Min PS (cmH_2O)	6.31 ± 4.10	6 (0-19)
PICU LOS (days)	—	7 (1-65)
MV duration (days)	—	5 (1-61)
PIM II score	—	24.3 (4.5-100)
PRISM III score	—	20 (5-67)
PELOD score	—	1.3 (0.1-100)

SD: Standard deviation; PIP: Peak inspiratory pressure; PEEP: Positive end-expiratory pressure; MAP: Mean airway pressure; RR: Respiratory rate; TV: Tidal volume; FiO_2: Fraction of inspired oxygen; Ti: Inspiratory time; PS: Pressure support; PICU: Pediatric intensive care unit; LOS: Length of stay; PIM: Pediatric Index of Mortality; PRISM: Pediatric Risk of Mortality; PELOD: Pediatric Logistic Organ Dysfunction

used agents were dopamine (32.9%), adrenaline (24.3%), dobutamine (17.9%), noradrenaline (13.3%), and milrinone (6.9%). Neuromuscular blocking agents were required in 57 patients (32.9%).

Tracheostomy

Tracheostomy was present in 92 patients at some point during follow-up. Acute/temporary tracheostomy was performed in 4 patients (2.3%) and subsequently closed. In 88 patients, the indication for tracheostomy was chronic respiratory failure; 55 patients (31.8%) had tracheostomy at the time of admission. In 33 patients (19.1%), chronic respiratory failure was diagnosed during hospitalization, necessitating permanent tracheostomy. A total of 79 patients (45.7%) were discharged with home ventilators.

Complications and VAP

Complications were observed in 35 patients (20.2%). The most common complication was atelectasis (n=13, 7.5%), followed by VAP (n=12, 6.9%), pneumothorax (n=9, 5.2%), and decubitus ulcer (n=2, 1.2%) **(Table 3)**. The VAP rate was 4.46 per 1,000 ventilator days.

Table 3. Complications associated with mechanical ventilation

Complication	N	%
Atelectasis	13	7.5
Ventilator-associated pneumonia (VAP)	12	6.9
Pneumothorax	9	5.2
Decubitus ulcer	2	1.2
Total patients with ≥1 complication	35	20.2

Note: one patient had concurrent pneumothorax and VAP.

Mortality and factors associated with mortality

The overall PICU mortality rate was 2.43% (n=19 of all admissions). Among mechanically ventilated patients, the mortality rate was 11% (n=19/173). In univariate analysis, PIM II, PRISM III, and PELOD scores, the presence of neurological disease, need for invotropic support, and presence of tracheostomy were significantly associated with mortality **(Table 4)**. Longer MV duration was also associated with mortality (median 7 vs. 5 days, p=0.019), whereas age, sex,

PICU length of stay, neuromuscular blocker use, and weaning-onset day did not reach statistical significance. All 19 non-survivors had required inotropic/vasoactive support, and none of the 77 patients with neurological disease as the primary diagnosis died, suggesting a comparatively favorable mortality profile for this subgroup. These associations are univariate and hypothesis-generating; a multivariable model was not fitted given the limited number of events (n=19).

Table 4. Univariate comparison of survivors and non-survivors

Variable	Survivors (n=154)	Non-survivors (n=19)	p-value
PIM II, median (min-max)	23.4 (4.5-100)	100 (66.8-100)	<0.001
PRISM III, median (min-max)	17 (5-56)	45 (32-67)	<0.001
PELOD %, median (min-max)	1.3 (0.1-100)	76 (32-99)	<0.001
MV duration, days, median (min-max)	5 (1-61)	7 (2-61)	0.019
Age, months, median (min-max)	45 (1.8-216)	24 (2.4-180)	0.374
Sex, male, n (%)	87/154 (56.5%)	12/19 (63.2%)	0.758
Neurological disease, n (%)	77/154 (50.0%)	0/19 (0%)	<0.001
Inotropic/ vasoactive support, n (%)	36/154 (23.4%)	19/19 (100%)	<0.001
Tracheostomy, n (%)	91/154 (59.1%)	1/19 (5.3%)	<0.001
Neuromuscular blocker use, n (%)	48/154 (31.2%)	9/19 (47.4%)	0.247

DISCUSSION

The frequency of invasive MV use has steadily increased in PICUs worldwide. Contemporary studies report that over 20% of PICU patients require invasive ventilatory support (3), and up to 63% of patients admitted with acute respiratory or cardiorespiratory illness may ultimately require some form of MV (7). In the present study, the rate of MV application was 22.1%, which is consistent with figures reported in more recent single-center studies from Turkey, including Durak and Boydag who found an MV rate of 30.5% in a tertiary PICU (8), and with earlier domestic data from Robinder et al. (9) (30%), Kendirli et al. (10) (18.1%), and Poyrazoğlu et al. (11) (24.1%).

Regarding indications for MV, respiratory failure continues to be the most frequently reported indication across the literature (12,13). Farias et al. (12) reported respiratory failure in 75% of children, Ramirez et al. (13) in 46.5%, and Kendirli et al. (10) in 64%. In the present study, the frequency of MV due to respiratory failure was 62.4%, consistent with these reports. Neurological disease was the most prevalent underlying condition (44.5%), a finding also echoed in recent literature; Durak and Boydag similarly identified neurological diseases as the predominant diagnostic category among mechanically ventilated children (8).

Regarding ventilation modes, pressure-controlled ventilation remains the dominant strategy in pediatric practice. SIMV ± PS continues to be widely utilized, although the field has progressively moved toward volume-targeted modes to minimize VILI. The PEMVECC consensus recommends lung-protective strategies with tidal volumes of 5–8 mL/kg and plateau pressures below 28 cmH_2O (6). Şık reported SIMV ± PS use in 76.6% of cases in a Turkish PICU (14). In the present study, all patients were managed with pressure-controlled ventilation in SIMV+PS mode. The median tidal volume was 8 mL/kg (range 6-12), median PIP was 22 cmH_2O (range 11-44), and median PEEP was 6 cmH_2O — values broadly within the lung-protective range. Although volume-targeted modes have

been increasingly introduced in PICUs, their adoption remains limited in many centers.

MV complications remain a major source of morbidity in PICUs. Despite the use of lung-protective ventilation modes, complications occur frequently. Ramirez et al. (13) reported pneumothorax in 8.1% and VAP in 17.4% of patients; Kendirli et al. (10) found atelectasis in 26.3%, VAP in 17.5%, and pneumothorax in 13.1%; and Şık (14) reported an MV-related complication rate of 38.9%. In a recent retrospective study covering 2021–2023, 24.1% of patients experienced at least one adverse event, with VAP being the most common consequence (13%), followed by post-extubation stridor (7.9%) and air-leak syndrome (6%) (15). In the present study, complications were observed in 20.2% of patients; atelectasis was the most common complication (7.5%), followed by VAP (6.9%) and pneumothorax (5.2%). Ventilator parameters were largely maintained within lung-protective ranges across the cohort (median tidal volume 8 mL/kg, median PIP 22 cmH_2O, median PEEP 6 $cmH_{2v}O$). The comparatively low overall complication rate observed in this cohort is therefore likely attributable to a combination of generally protective ventilator settings and the VAP prevention bundle applied in this unit (see Methods), consistent with evidence that bundle-based prevention strategies significantly reduce VAP rates across settings (16); the VAP rate of 4.46 per 1,000 ventilator days observed here compares favorably with published benchmarks.

Sedation and analgesia protocols are fundamental to the management of mechanically ventilated children. In the present study, sedation was provided with midazolam in 126 patients (72.8%) and fentanyl in 87 patients (50.3%), representing the most frequently used agents — consistent with published pediatric sedation practices in which midazolam–opioid combinations remain the most common approach (6). Neuromuscular blocking agents were required in 57 patients (32.9%). Vasoactive support was required in 31.8% of patients, with dopamine and adrenaline being the most commonly used agents, consistent with standard practice for septic shock and low cardiac output states.

Mortality rates in PICUs vary considerably depending on institutional resources, patient case-mix, and underlying comorbidities. In PICUs, mortality rates have been reported to range from 4.7% to 19% (9,13). The mortality rate for patients receiving MV was reported as 47% by Tullu et al. (17), 58.3% by Kendirli et al. (10), and 36.4% by Şık (14). In a recent Turkish single-center study, a 19.4% mortality rate was observed among mechanically ventilated children with a statistically significant association with sepsis (8). In the present study, the overall PICU mortality rate was 2.43%, while mortality among mechanically ventilated patients was 11% — substantially lower than many comparative series. This favorable outcome likely reflects standardized care protocols, the relatively lower prevalence of sepsis-driven admissions, and the high proportion of neurological diagnoses, which may carry a different mortality profile.

In recent years, the prolonged need for MV has been reported as the most common indication for tracheostomy in children (18,19). In the present study, 21.4% (n=37) of patients underwent tracheostomy during hospitalization. Neurological diseases (76.1%) and metabolic diseases (12.5%) were the most common indications, consistent with reports by Jardine et

al. (20), Lawrason et al. (21), Mete et al. (19), and Karapınar et al. (22). A recent multicenter analysis further confirmed that tracheostomy rates are significantly associated with prolonged MV duration and that patients requiring MV for more than 30 days face considerably higher tracheostomy rates, VAP rates, and mortality (23). These findings reinforce the importance of early and systematic weaning assessment.

An important consideration when interpreting these findings is that the study period (February 2015–February 2016) preceded several major developments in pediatric respiratory support. Most notably, the Second Pediatric Acute Lung Injury Consensus Conference (PALICC-2), published in 2023, established the first internationally endorsed, evidence-graded definition and management bundle for pediatric acute respiratory distress syndrome (PARDS), with explicit targets for tidal volume, plateau pressure, driving pressure, and permissive hypercapnia (24). At the time of the present study, lung-protective ventilation was applied according to general physiological principles rather than a codified PARDS-specific protocol; the ventilator parameters recorded in this cohort nonetheless fell within the ranges now recommended by PALICC-2, suggesting that core lung-protective practices were already present in this unit before their formal consensus articulation.

The management of hypoxemic respiratory failure — the leading indication for MV in this cohort (51%) — has also evolved substantially over the past decade. High-flow nasal cannula (HFNC) therapy has become markedly more widely adopted as a first-line intervention to avert or delay invasive ventilation (25), but was not systematically used in the study PICU during data collection. Its subsequent adoption may have shifted the invasively ventilated population toward higher-severity cases in contemporary practice, a consideration when extrapolating these findings to current populations.

These historical figures find support in a recently published Swedish PICU cohort study covering a similarly dated period (2008–2016), which reported mortality within a comparable range despite being published in 2024 (26), and recent reviews confirm that prolonged MV remains the leading driver of pediatric tracheostomy, reinforcing the continued relevance of these findings to current practice (27).

Limitations of the study

An important limitation of this study is that the data were collected approximately 10 years ago (February 2015–February 2016). Over the past decade, MV practices have evolved substantially, particularly with the increased use of non-invasive modalities, standardization of lung-protective strategies, and advances in ventilator technology. Therefore, the findings may not fully reflect current clinical practice. Nevertheless, the study provides valuable historical insight and may serve as a benchmark for evaluating temporal changes in pediatric MV in Turkey. The single-center design and the one-year observation window additionally limit the generalizability of findings. In addition, cuff leak testing prior to extubation was not systematically recorded during the study period; therefore, its relationship with post-extubation stridor could not be evaluated, and this remains an area for prospective assessment in future studies.

CONCLUSION

The pediatric severity scores PIM II, PRISM III, and PELOD were each strongly and independently associated with in-hospital mortality, supporting their continued use as prognostic tools in PICU practice. Ventilator management and outcomes

were broadly comparable to contemporary series, despite the data predating several subsequent advances in pediatric respiratory support. Multicenter prospective studies incorporating contemporary practices are needed to validate these findings and generate robust national data on pediatric MV outcomes in Turkey.

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Conflict of Interest

The authors declare that they have no conflict of interests regarding content of this article.

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Ethical Declaration

Ethical permission was obtained from the Çukurova University, Medical Faculty Clinical / Human Research Ethics Committee for this study with date 5 February 2016 and number 50/28, and Helsinki Declaration rules were followed to conduct this study.

Is derived from thesis?

This study was prepared by rearrangement of the specialty thesis by Sıdıka Canan Atasoy, entitled as "Çukurova Üniversitesi Tıp Fakültesi Çocuk Yoğun Bakım Ünitesi'nde Bir Yıl Süresince İnvaziv Mekanik Ventilasyon Uygulanan Hastaların Değerlendirilmesi".

Previous Presentation

Some part of this study was presented as oral/poster presentation at " XIII. Congress of Pediatric Emergency Medicine and Intensive Care" held in İzmir, entitled as "P-159 Çukurova Üniversitesi Tıp Fakültesi Çocuk Yoğun Bakım Ünitesinde Bir Yıl Süresince İnvaziv Mekanik Ventilasyon Hastaların Değerlendirilmesi"

Author Contributions

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