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ORIGINAL ARTICLE

Feasibility of portable capnometer for mechanically ventilated preterm infants in the delivery room

Masashi Hotta[1] · Katsuya Hirata[1] · Masatoshi Nozaki[1] · Narutaka Mochizuki[1] · Shinya Hirano[1] · Kazuko Wada[1]

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Abstract

This study aimed to determine whether a specific portable capnometer (EMMA™) can facilitate the maintenance of an appropriate partial pressure of arterial carbon dioxide ($PaCO_2$) in intubated preterm infants in the delivery room. This study included preterm infants with a gestational age of 26 + 0 to 31 + 6 weeks who required intubation in the delivery room. We prospectively identified 40 infants who underwent the EMMA™ monitoring intervention group and 43 infants who did not undergo monitoring (historical control group). $PaCO_2$ was evaluated either at admission in the neonatal intensive care unit or at 2 h after birth. The proportion of infants with an appropriate $PaCO_2$ (35–60 mmHg) was greater in the intervention group than in the control group (80% vs. 42%; $p = 0.001$). There were no significant differences in the rate of accidental extubation (5.0% vs. 7.0%, $p = 1.00$) or in the proportion of infants with an appropriate $PaCO_2$ among infants whose birth weight was < 1000 g (54% vs. 40%, $p = 0.49$). However, among infants whose birth weight was ≥ 1000 g, the $PaCO_2$ tended to be more appropriate in the intervention group than in the control group (93% vs. 44%; $p < 0.001$).

Conclusion: The EMMA™ facilitated the maintenance of an appropriate $PaCO_2$ for mechanically ventilated preterm infants, especially infants with birth weight ≥1000 g, in the delivery room.

What is Known:

- *An inappropriate partial pressure of arterial carbon dioxide has been associated with intraventricular hemorrhage in preterm infants.*
- *There is a need to appropriately control the partial pressure of arterial carbon dioxide in preterm infants.*

What is New:

- *This is the first report regarding the feasibility of a portable capnometer, the EMMA™, in the delivery room.*
- *The EMMA™ may be considered a feasible monitoring device in the delivery room for intubated preterm infants, especially infants with birth weight ≥1000 g.*

Keywords Capnometry · Carbon dioxide · Intubation · Neonatal resuscitation · Premature infants

Abbreviations

BPD	Bronchopulmonary dysplasia
CI	Confidence interval

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✉ Masashi Hotta
spyf88d9@yahoo.co.jp

Katsuya Hirata
khirata0513@gmail.com

Masatoshi Nozaki
m.nozaki@wch.opho.jp

Narutaka Mochizuki
narutaka@wch.opho.jp

Shinya Hirano
shirano@wch.opho.jp

Kazuko Wada
kwada@wch.opho.jp

[1] Department of Neonatal Medicine, Osaka Women's and Children's Hospital, 840 Murodo-cho, Izumi, Osaka 594-1101, Japan

CO_2	Carbon dioxide
$EtCO_2$	End tidal carbon dioxide
HFO	High-frequency oscillation
IVH	Intraventricular hemorrhage
NICU	Neonatal intensive care unit
$PaCO_2$	Partial pressure of arterial carbon dioxide
PVL	Periventricular leukomalacia
RDS	Respiratory distress syndrome

Introduction

An inappropriate range of the partial pressure of arterial carbon dioxide ($PaCO_2$) is associated with intraventricular hemorrhage (IVH) [1]. Some reports in the 1990s showed that an inappropriate $PaCO_2$ was associated with periventricular leukomalacia (PVL) [2, 3] and bronchopulmonary dysplasia (BPD) [4]. Additionally, neurocognitive dysfunction could be associated with blood gas derangements, including changes in $PaCO_2$ [5]. Neonatologists have attempted various methods to estimate and thus control the $PaCO_2$ in preterm infants, such as observing chest elevation, tidal volume, transcutaneous carbon dioxide (CO_2), end-tidal CO_2 ($EtCO_2$), and blood sampling.

$EtCO_2$ monitoring is noninvasive and associated with fewer complications, compared with blood gas sampling. However, $EtCO_2$ monitoring in preterm infants is limited by the dead space of the device. A small portable mainstream capnometer (EMMA™; Masimo, Irvine, CA, USA) was recently developed to resolve this problem. This capnometer may be useful for preterm infants during resuscitation after birth because of its portability (length of 69 mm) and a small amount of dead space (1 mL). Most importantly, a correlation between the $EtCO_2$ values monitored by the EMMA™ and the $PaCO_2$ in preterm infants has been reported [6], and this device will presumably be useful in clinical situations.

Preterm infants have a risk of $PaCO_2$ fluctuation, especially immediately after birth, because of the shift from fetal circulation to neonatal circulation. This can result in respiratory disturbances such as respiratory distress syndrome (RDS), which may require intubation and surfactant. Some reports have shown that $EtCO_2$ monitoring is useful in patients undergoing mechanical ventilation during hospitalization in the neonatal intensive care unit (NICU) [7–9]. Although some studies have addressed the feasibility of $EtCO_2$ monitoring immediately after birth in both intubated and non-intubated infants [10–13] or in only non-intubated infants [14], none has involved such assessment only in intubated preterm infants.

The present study was performed to determine whether a specific portable capnometer (EMMA™) can feasibly maintain an appropriate $PaCO_2$ in intubated preterm infants immediately after birth.

Materials and methods

Setting and patients

This study included a prospective intervention group and a historical control group. All patients were preterm infants born at ≥26 to <32 weeks' gestation at the Osaka Women's and Children's Hospital in Osaka, Japan, and were intubated in the delivery room. Patients who were born from 1 April 2019 to 15 January 2021 and underwent intubation with the use of the EMMA™ in the delivery room were prospectively enrolled for inclusion in the intervention group. The EMMA™ and its adapter for neonates (1 mL of dead space) were connected to the distal side of the endotracheal tube when monitoring mainstream $EtCO_2$. The EMMA™ was set to display $EtCO_2$ values until evaluation of the $PaCO_2$ value as the primary outcome. Assessments of $EtCO_2$ values and management of resuscitation were performed at the discretion of the resuscitators. The historical control group (without EMMA™ monitoring) comprised patients born from 1 April 2017 to 1 September 2018. In both groups, no sedatives or muscle relaxants were administered to infants during resuscitation. All intubations were emergently decided by the resuscitator, depending on each infant's respiratory condition. An endotracheal tube size of 2.0 to 3.0 mm was selected, depending on each infant's birth weight. After the initiation of mechanical ventilation, we used pressure control and a synchronized intermittent mandatory ventilation mode. Detailed ventilator settings were determined in accordance with each infant's condition. Tidal volume was monitored using a flow sensor connected to the distal side of the endotracheal tube or the EMMA™ adapter. In both groups, we excluded patients with incomplete medical records, patients with congenital disorders that may influence the respiratory or circulatory systems, and patients who were extubated during evaluation of the $PaCO_2$ value as the primary outcome. We also excluded patients who needed high-frequency oscillation (HFO) ventilation because the $EtCO_2$ values monitored by the EMMA™ were not accurate under HFO ventilation. Data were collected from eligible patients' medical records. This study was approved by the Ethics Committee of Osaka Women's and Children's Hospital (No. 1165). Written informed consent was retrospectively obtained from the parents of all patients in the intervention group, after admission to the NICU. The need for informed consent in the control group was waived because of the historical nature of the data assessment.

Outcomes

The primary outcome was the $PaCO_2$ value either at admission to the NICU or at 2 h after birth. For patients with several arterial blood gas analyses, we chose the analysis

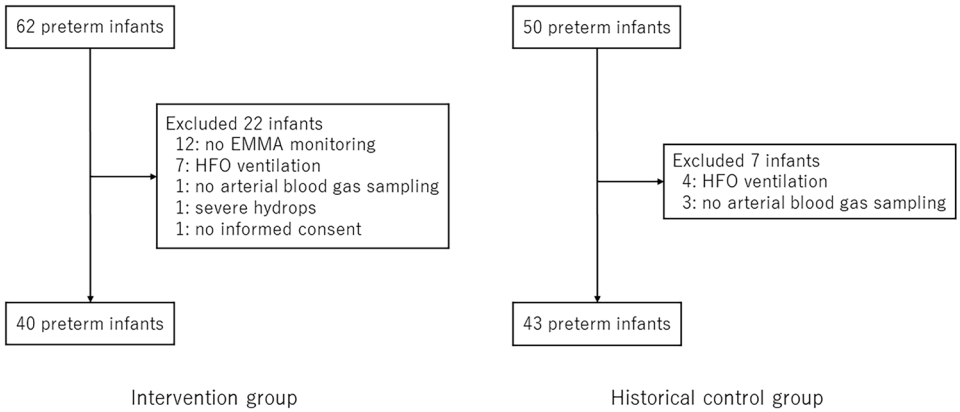

Fig. 1 Flow chart of the study participants

nearest to admission to the NICU or at 2 h after birth as the primary outcome. We chose one analysis per patient. In our hospital, intubation, mechanical ventilation, catheter insertion (peripheral venous catheter, peripherally inserted central catheter, arterial catheter, and umbilical catheter), and skin-to-skin communication with the mother were performed in the resuscitation room or delivery room as needed. This strategy was used to stabilize patients as soon as possible in the delivery room for subsequent admission to the NICU. Because the use of this strategy led some infants to stay in the delivery room for a few hours, we set the $PaCO_2$ value either at admission to the NICU or at 2 h after birth as the primary outcome. The secondary outcome was the incidence of adverse events. The exposure was to monitor $EtCO_2$ in the delivery room by using EMMA™. In both groups, $PaCO_2$ was analyzed by a blood gas analyzer (ABL800 FLEX PLUS or ABL90 FLEX PLUS; Radiometer, Copenhagen, Denmark). We defined an appropriate range of $PaCO_2$ as 35 to 60 mmHg, in accordance with previous reports [1–5, 11, 15–19]. We stratified the patients according to birth weight for the data analysis.

Sample size calculation

The historical control group comprised 43 patients, 18 (42%) of whom had a $PaCO_2$ within the appropriate range either at admission to the NICU or at 2 h after birth. We hypothesized that the proportion of patients who had a $PaCO_2$ within the normal range would be ≥ 75% using the EMMA™. In accordance with this hypothesis, we calculated the required

Table 1 Patient characteristics

	Intervention group $N=40$	Control group $N=43$	*p*-value
Antenatal steroids	21 (53)	19 (44)	0.51
Caesarean delivery	34 (85)	31 (72)	0.19
Chorioamnionitis	10 (25)	22 (51)	0.023
Gestational age, weeks	28.4 [27.7–30.4]	28.4 [26.9–29.9]	0.47
Birth weight, g	1112.0 [922.5–1288.0]	1084.0 [817.0–1288.0]	0.63
Male sex	14 (35)	21 (49)	0.27
Multiple birth	18 (45)	9 (21)	0.034
Cord blood lactate, mg/dL	30.0 [20.0–47.0]	35.0 [24.0–60.5]	0.14
5-min Apgar score	8.0 [7.0–8.0]	8.0 [7.0–8.0]	0.85
CRIB-II score	8.0 [6.0–10.0]	9.0 [7.0–11.0]	0.083
Intubation time, minutes	6.0 [4.0–13.1]	10.0 [4.0–20.0]	0.27
Endotracheal tube size			
2.0 mm	2 (5.0)	5 (12)	0.39
2.5 mm	31 (78)	34 (79)	
3.0 mm	7 (18)	4 (9.3)	
Surfactant administration[a]	27 (68)	32 (74)	0.63
Nitric oxide administration[a]	3 (7.5)	4 (9.3)	1.00

Data are expressed as median [interquartile range] or number (%)

CRIB Clinical Risk Index for Babies

[a]Before admission to the neonatal intensive care unit or 2 h after birth

Table 2 Main outcomes

	Intervention group $N=40$	Control group $N=43$	p-value
Appropriate range of $PaCO_2$	32 (80)	18 (42)	0.001
$PaCO_2$, mmHg	42.0 [36.7–46.3]	38.8 [31.8–48.8]	0.41
Examining $PaCO_2$ time after birth, minutes	117.5 [96.5–137.3]	117.0 [101.0–137.0]	0.53
Examining $PaCO_2$ time after intubation, minutes	107.8 [89.0–123.5]	104.0 [89.0–124.0]	0.94
Number of blood gas analyses[a]	1.0 [1.0–2.0]	1.0 [1.0–2.0]	0.85
Accidental extubation[a]	2 (5.0)	3 (7.0)	1.00

Data are expressed as median [interquartile range] or number (%)

$PaCO_2$ partial pressure of arterial carbon dioxide

[a]Before admission to the neonatal intensive care unit or 2 h after birth

sample size to be 40 patients in each group based upon 80% power and a two-tailed significance level of 0.05. The sample size calculation was performed with the power and sample size program [20].

Statistical analysis

Fisher's exact test or the chi-squared test were used to evaluate categorical variables, and the Mann–Whitney *U* test was used to evaluate continuous variables. We used Pearson's correlation test to evaluate correlations between variables. We used the Jonckheere–Terpstra test for analysis of trends. Missing data were excluded from the analysis. Statistical significance was defined using a p-value of <0.05. All statistical analyses were performed with EZR (developed by Saitama Medical Center, Jichi Medical University, Saitama, Japan) [21], which is a graphical user interface for R software (The R Foundation for Statistical Computing, Vienna, Austria); specifically, it comprises a modified version of R commander with the addition of statistical functions frequently used in biostatistics.

Results

In total, 62 preterm infants in the intervention group and 50 preterm infants in the control group were eligible for inclusion in this study. We excluded 22 infants from the intervention group and seven infants from the historical control group. Thus, 40 infants in the intervention group and 43 infants in the control group were included in this analysis (Fig. 1). The diseases that caused respiratory failure were RDS ($n=29$), transient tachypnea of the newborn ($n=8$), and apnea ($n=3$) in the intervention group; they were RDS ($n=35$), transient tachypnea of the newborn ($n=5$), and apnea ($n=3$) in the control group. The characteristics of these infants are presented in Table 1. Cord blood lactate data were missing for one infant in the intervention group and four infants in the historical control group. There were no significant differences between groups except that the incidence of chorioamnionitis was significantly lower ($n=10$ [25%] vs. $n=22$ [51%]; $p=0.023$), and the incidence of multiple births was significantly higher ($n=18$ [45%] vs. $n=6$ [14%]; $p=0.003$) in the intervention group than in the control group.

Table 2 shows the main outcomes of this study. The proportion of infants whose $PaCO_2$ was within the appropriate range was significantly greater in the intervention group than in the control group ($n=32$ [80%] vs. $n=18$ [42%]; $p=0.001$). The difference in $PaCO_2$ values between groups was not statistically significant (Fig. 2). Furthermore, there was no significant difference in the rate of accidental extubation ($n=2$ [5.0%] vs. $n=3$ [7.0%], $p=1.00$). The correlation coefficient between the $PaCO_2$ value and sampling time from birth was −0.18 (95% confidence interval (CI), −0.38–0.042; $p=0.11$). The correlation coefficient between the $PaCO_2$ value and sampling time from intubation was −0.10 (95% CI, −0.31–0.12; $p=0.37$).

Table 3 shows the results of the analysis stratified according to birth weight (< 1000 vs. ≥ 1000 g). Among

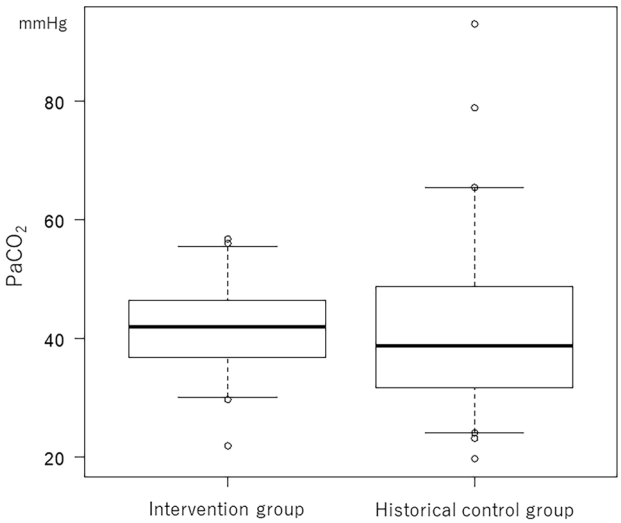

Fig. 2 Distribution of $PaCO_2$ values

Table 3 Comparison outcomes stratified by birth weight

Birth weight < 1000 g	Intervention group $N=13$	Control group $N=20$	*p*-value
Appropriate range of $PaCO_2$	7 (54)	8 (40)	0.49
$PaCO_2$, mmHg	36.2 [32.9–43.4]	35.6 [32.5–50.1]	0.71
Examining $PaCO_2$ time after birth, minutes	120.0 [103.0–149.0]	110.0 [97.0–132.0]	0.84
Examining $PaCO_2$ time after intubation, minutes	108.5 [95.0–128.0]	104.8 [90.0–122.9]	0.69
Number of blood gas analyses[a]	1.0 [1.0–2.0]	2.0 [1.0–2.0]	0.40
Accidental extubation[a]	2 (15)	2 (10)	1.00
Birth weight ≥ 1000 g	Intervention group $N=27$	Control group $N=23$	*p*-value
Appropriate range of $PaCO_2$	25 (93)	10 (44)	< 0.001
$PaCO_2$, mmHg	42.5 [39.4–46.4]	40.1 [31.4–47.8]	0.21
Examining $PaCO_2$ time after birth, minutes	116.0 [95.0–133.0]	125.0 [104.0–141.5]	0.22
Examining $PaCO_2$ time after intubation, minutes	102.0 [89.0–122.5]	104.0 [89.0–128.0]	0.73
Number of blood gas analyses[a]	1.0 [1.0–2.0]	1.0 [1.0–1.0]	0.16
Accidental extubation[a]	0 (0.0)	1 (4.3)	0.46

P*aCO*$_2$ partial pressure of arterial carbon dioxide

Data are expressed as median [interquartile range] or number (%)

[a]Before admission to the neonatal intensive care unit or 2 h after birth

infants whose birth weight was < 1000 g, the proportion of infants with an appropriate $PaCO_2$ did not significantly differ between the intervention and control groups ($n=7$ [54%] vs. $n=8$ [40%]; $p=0.49$). Among infants whose birth weight was ≥ 1000 g, however, the rate of normocapnia was significantly higher in the intervention group than in the control group ($n=25$ [93%] vs. $n=10$ [44%]; $p<0.001$).

Table 4 Comparison between infants with and without an appropriate range of $PaCO_2$ during the intervention period

	With appropriate $PaCO_2$ $N=32$	Without appropriate $PaCO_2$ $N=8$	*p* value
$PaCO_2$, mmHg	42.9 [40.8–47.5]	31.4 [29.9–33.1]	< 0.001
Examining $PaCO_2$ time after birth, minutes	116.0 [91.5–137.3]	121.5 [109.0–129.3]	0.66
Examining $PaCO_2$ time after intubation, minutes	99.8 [87.8–123.1]	113.3 [105.0–126.1]	0.35
Number of blood gas analyses[a]	1.0 [1.0–2.0]	1.0 [1.0–2.0]	0.89
Accidental extubation[a]	2 (6.2)	0 (0.0)	1.00
Antenatal steroids	16 (50)	5 (63)	0.70
Cesarean delivery	28 (88)	6 (75)	0.58
Chorioamnionitis	9 (28)	1 (13)	0.65
Gestational age, weeks	28.6 [28.0–30.6]	27.9 [27.3–29.3]	0.078
Birth weight, g	1182.0 [1003.5–1390.0]	799.0 [590.5–1005.0]	0.005
Male sex	12 (38)	2 (25)	0.69
Multiple birth	16 (50)	2 (25)	0.26
Cord blood lactate, mg/dL	30.0 [20.0–38.5]	30.5 [25.0–56.3]	0.72
5-min Apgar score	8.0 [7.0–8.0]	7.5 [6.8–9.0]	0.58
Intubation time, minutes	7.0 [4.0–15.5]	4.0 [2.9–7.0]	0.070
Endotracheal tube size			
2.0 mm	0 (0.0)	2 (25)	0.026
2.5 mm	25 (78)	6 (75)	
3.0 mm	7 (22)	0 (0.0)	
Surfactant administration[a]	22 (69)	5 (63)	1.00
Nitric oxide administration[a]	2 (6.2)	1 (13)	0.50

Data are expressed as median [interquartile range] or number (%)

CRIB Clinical Risk Index for Babies, *PaCO*$_2$ partial pressure of arterial carbon dioxide

[a]Before admission to the neonatal intensive care unit or 2 h after birth

Table 4 shows the comparison between infants who did and did not have a $PaCO_2$ within the appropriate range in the intervention group. There were significant differences in the $PaCO_2$ (42.9 [40.8–47.5] vs. 31.4 [29.9–33.1] mmHg, $p < 0.001$), birth weight (1182.0 [1003.5–1390.0] vs. 799.0 [590.5–1005.0] g, $p = 0.005$), and endotracheal tube size (2.0 mm: $n = 0$ [0.0%] vs. $n = 2$ [25%]; 2.5 mm: $n = 25$ [78%] vs. $n = 6$ [75%]; 3.0 mm: $n = 7$ [22%] vs. $n = 0$ [0.0%]; $p = 0.026$). Additionally, larger endotracheal tubes tended to be used by infants with higher birth weights ($p < 0.001$) in the intervention group.

We compared the included infants in the intervention period with infants who were excluded because EMMA™ monitoring had not been performed during the intervention period (Online Resource). There were no significant differences between the two groups, except that cord blood lactate (30.0 [20.0–47.0] vs. 46.5 [39.8–66.8] mg/dL, $p = 0.007$) and Clinical Risk Index for Babies-II score [22] (2.5 [2.5–2.6] vs. 8.0 [7.0–9.0] , $p < 0.001$) were significantly lower in the included infants than in the excluded infants.

Furthermore, there were no significant differences in the proportion of infants with normocapnia between infants in the control group and infants who were excluded because EMMA™ monitoring had not been performed during the intervention period ($n = 18$ [42%] vs. $n = 7$ [58%], $p = 0.58$).

Discussion

In this study, we investigated the feasibility of using a portable capnometer to maintain the $PaCO_2$ within the appropriate range for mechanically ventilated preterm infants immediately after birth. Utilization of the EMMA™ in the delivery room from immediately after intubation significantly increased the proportion of infants with an appropriate $PaCO_2$ at admission to the NICU or at 2 h after birth. To our knowledge, this is the first study to evaluate the feasibility and safety of using a portable capnometer, the EMMA™, for mechanically ventilated preterm infants in the delivery room.

The main strength of this study is that we collected intervention data prospectively and showed the feasibility of using a portable capnometer during resuscitation of intubated preterm infants. The findings of this study suggest that $EtCO_2$ monitoring with a portable capnometer, the EMMA™, immediately after birth may facilitate the maintenance of an appropriate range of $PaCO_2$ in intubated preterm infants. Some reports have revealed that $EtCO_2$ monitoring is useful for neonates in the NICU [7–9]. Several previous studies have investigated the feasibility of $EtCO_2$ monitoring in preterm infants in the delivery room. A randomized controlled study showed that $EtCO_2$ monitoring was feasible for infants receiving facemask ventilation [14]. Another randomized controlled study of preterm infants (in which most patients were non-intubated) showed that $EtCO_2$ monitoring did not reduce the occurrence of inappropriate $PaCO_2$ [13]. The present study aimed to evaluate the efficacy of $EtCO_2$ monitoring for intubated preterm infants who had a greater risk of inappropriate $PaCO_2$; it showed the feasibility of a portable $EtCO_2$ monitor with a small amount of dead space.

During the first few days after birth, the respiratory and circulatory conditions of neonates undergo considerable changes. Some studies have shown that inappropriate $EtCO_2$ within a few days after birth in preterm infants is associated with PVL [2, 3], IVH [1, 11, 12], and BPD [4]. Therefore, it is important to monitor CO_2 and control the $PaCO_2$ appropriately in preterm infants immediately after birth to reduce the risks of these diseases. Controlling the $EtCO_2$ immediately after birth can prevent a cumulative abnormal $PaCO_2$ state. The EMMA™, the availability, and safety of which were evaluated in the present study could be an effective device for preterm infants immediately after birth.

A previous study showed that the $EtCO_2$ value monitored by the EMMA™ was correlated with the $PaCO_2$ value in preterm infants [6]. In that study, the $EtCO_2$ value monitored by the EMMA™ was more accurate in heavier infants. In our study, stratified analysis and intervention group analysis showed that $EtCO_2$ monitoring was more effective in heavier infants. The lack of statistical significance in infants whose birth weight was < 1000 g in the stratified analysis may have been related to the small sample size. However, $EtCO_2$ monitoring might be less accurate in infants with extremely low birth weights because their respiratory and circulatory dynamics are more unstable, especially immediately after birth. Additionally, smaller preterm infants require greater tidal volume, with respect to body weight, to overcome the additional dead space caused by $EtCO_2$ monitoring; this may increase the risk of volutrauma-induced lung injury. The EMMA™ should be used for preterm infants in the higher body weight stratum. Nevertheless, the accuracy of measurement with the EMMA™ could facilitate an appropriate $PaCO_2$ range in a large proportion of infants. In addition to monitoring $EtCO_2$, the dead space of the $EtCO_2$ monitor might have contributed to CO_2 retention in intubated preterm infants, who had a greater tendency to shift to hypocapnia because of improvement in their respiratory status immediately after birth by intubation, mechanical ventilation, or surfactant administration. Notably, 1 mL of dead space could be sufficient for preterm infants to pool CO_2 and maintain an appropriate $PaCO_2$.

This study had several limitations. First, this was a single-center, non-randomized, single-arm (historical control) study; the study design may limit the generalizability of the results. We could not sufficiently eliminate the influences of changes in staff or methods, nor could we eliminate the

influences of changes in the quality of resuscitation over time. The outcomes may have been affected by using the historical control group for comparison. Notably, however, there was no significant difference in the proportion of infants with an appropriate $PaCO_2$ between the control group and infants who were excluded because EMMA™ monitoring had not been performed. Additionally, the use of an $EtCO_2$ monitor itself might have increased the medical staff's awareness of CO_2 values in preterm infants during resuscitation in the intervention group. However, the ability of the EMMA™ to increase awareness of CO_2 values implies that the portable capnometer is an effective monitoring device. Furthermore, this study included infants at 26 to 31 weeks' gestation for safety reasons; in particular, the EMMA™ was a new device for our hospital. The EMMA™ may be useful for infants at < 26 weeks' gestation; such infants may be more vulnerable to fluctuations of CO_2. Additionally, during the study period, no infants had been extubated at the primary outcome measurement, leading to exclusion from the analysis, despite efforts to achieve extubation as soon as each patient's respiratory condition permitted. Therefore, the infants in this study might have had more severe conditions than infants in other hospitals. Second, we could not evaluate the correlation between $EtCO_2$ and $PaCO_2$ in this study, and we could not assess the tube leakage incidence and the respiratory rate, which may have led to reduced accuracy regarding $EtCO_2$ in preterm infants. Very few patients < 3 kg have used cuffed endotracheal tubes, although such tubes might be safe in these infants [23]. No infants used cuffed endotracheal tubes in our study. In the intervention group, the endotracheal tubes were smaller in infants with a $PaCO_2$ outside the appropriate range. When tube leakage increases, $EtCO_2$ values become less accurate. However, tube leakage was not necessarily related to tube size in our study because larger endotracheal tubes tended to be used in infants with higher birth weights. Thus, an appropriate endotracheal tube size might be selected based on birth weight. Additionally, gestational age, birth weight, and endotracheal tube size were not significantly different between patients with and without EMMA™ monitoring. Furthermore, the accuracy of the EMMA™ in premature infants has been previously reported [6], although caution is needed regarding underestimation of $EtCO_2$, which is inversely proportional to birth weight. Third, we did not evaluate long-term outcomes. An inappropriate $PaCO_2$ is associated with PVL, IVH, and BPD [1–4, 11]. These diseases are also associated with long-term outcomes [24–28]. Further studies are required to reveal the importance of controlling the $PaCO_2$ immediately after birth via $EtCO_2$ monitoring, with respect to long-term outcomes.

In conclusion, our study suggests that the use of a portable capnometer, the EMMA™, is feasible for mechanically ventilated preterm infants immediately after birth to maintain an appropriate range of $PaCO_2$, especially among infants with birth weight ≥ 1000 g. The EMMA™ may be considered an effective monitoring device for these infants.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00431-021-04246-1.

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Authors' contributions MH conceptualized and designed this study, contributed to the data analysis, and drafted the article. KH, MN, NM, SH, and KW reviewed the study results and gave conceptual suggestions. All authors reviewed the draft article and approved the final article for publication.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Ethical approval This study was approved by the Ethics Committee of Osaka Women's and Children's Hospital (No. 1165).

Consent to participate Written informed consent was retrospectively obtained from the parents of all patients in the intervention group after admission to the neonatal intensive care unit. The need for informed consent in the control group was waived because of the historical nature of the data assessment.

Consent for publication Written informed consent was retrospectively obtained from the parents of all patients in the intervention group after admission to the neonatal intensive care unit. The need for informed consent in the control group was waived because of the historical nature of the data assessment.

Conflict of interest The authors declare no competing interests.

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