Comparison of Minimal Fresh Gas Requirements of Baby Enclosed Afferent Reservoir and Jackson Rees Anesthetic Circuit for General Anesthesia in Spontaneously Breathing Children

Sunchai Theerapongpakdee MD*,
Thepakorn Sathitkarnmanee MD*, Sirirat Tribuddharat MD, PhD*, Nonthida Rojanapithayakorn MD*,
Kanchana Uppan BN*, Cattleya Thongrong MD*, Piyaporn Bunsangcharoen MD*

** Department of Anesthesiology, Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand*

Objective: *The authors compared the baby enclosed afferent reservoir (Baby EAR) with the Jackson-Rees (JR) anesthesia circuit for the minimal fresh gas flow (FGF) requirement with no and clinically acceptable rebreathing in spontaneous breathing anesthesia among pediatric patients.*

Material and Method: *The present study was a randomized crossover study. Twenty patients, weighing 5 to 20 kg with ASA physical status I-II were enrolled. They were allocated to group 1 (EAR-JR) starting with Baby EAR then switching to JR or group 2 (JR-EAR), reversed pattern. After induction and intubation, anesthesia was maintained with a N_2O/O_2 combination with sevoflurane 1 to 3% and fentanyl. Starting with the first circuit, all patients were spontaneously ventilated with FGF 500 mL/kg/min for 10 minutes, and then gradually decreased by 50 mL/kg/min every five minutes. End-tidal CO_2 ($ETCO_2$) and inspired minimum CO_2 ($imCO_2$) were recorded until rebreathing ($imCO_2$ >2 mmHg) occurred and continued until rebreathing was not clinically acceptable ($imCO_2$ >6 mmHg). The anesthesia breathing circuit was switched and the procedure repeated.*

Results: *The minimal FGF at no rebreathing of Baby EAR and JR were 192.5±76.6 and 347.5±108.2 mL/kg/min; p<0.001. At acceptable rebreathing, the values were 117.5±46.7 and 227.6±90.6 mL/kg/min; p<0.001.*

Conclusion: *Baby EAR can be used safely, effectively, and requires less FGF than JR in pediatric anesthesia in patients weighing 5 to 20 kg.*

Keywords: *Enclosed afferent reservoir (EAR), Jackson Rees system (JR), Anesthesia breathing circuit, Spontaneous breathing, Pediatric anesthesia*

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Jackson-Rees anesthesia circuit (JR), or the Mapleson F system, is the most commonly used breathing system in pediatric anesthesia. It is compact, lightweight, and portable, but requires a high fresh gas flow (FGF), two to three times per minute ventilation in patients with spontaneous breathing and 1 time in patients with controlled breathing to prevent rebreathing[1]. The main disadvantages of a high FGF are (a) loss of body heat and humidity, making mucus thick and dry, (b) wasted anesthetic gas, and (c) pollution in the operating room[2,3].

The Enclosed Afferent Reservoir anesthesia circuit (EAR) is an anesthesia breathing circuit introduced by Miller and Miller, modified from the Magill or Mapleson A circuit[4,5]. The advantages are (a) high efficiency, (b) low gas flow usage in both controlled and spontaneous respiration[6], (c) nominal heat loss, (d) conserved moisture, (e) reduced pollution in the operating room, and (f) low anesthetic cost[2,3].

Theerapongpakdee et al invented a modified EAR anesthesia circuit called a Baby EAR to use at Srinagarind Hospital among pediatric patients <20 kg. The Baby EAR is made from inexpensive and readily available materials in the operating room: 1.25 L plastic beverage bottles, rubber gloves, bacterial filters, endotracheal tubes, plastic syringes, 15-mm diameter corrugated tubes, and yellow hollow latex rubber tubes[7-9]. The difference from other breathing circuits is that the Baby EAR has a KKU one-way valve in the expiratory limb (Fig. 1).

Correspondence to:
Sathitkarnmanee T, Department of Anesthesiology, Faculty of Medicine, Khon Kaen University, Khon Kaen, 40002, Thailand.
Phone & Fax: 043-348-390
E-mail: thepakorns@gmail.com

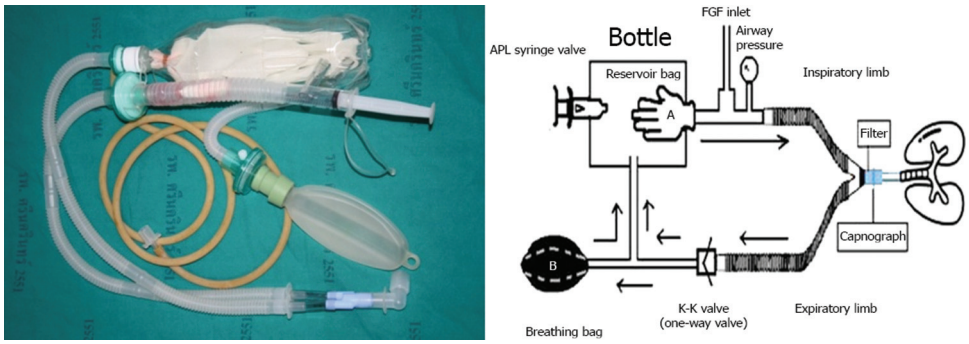

Fig. 1 Baby enclosed afferent reservoir circuit (Baby EAR): actual circuit and diagram.

Theerapongpakdee et al studied the clinical use of the Baby EAR and found it could be used safely in children between 5 and 20 kg, using a fresh gas flow of 2.5 and 3 L/min in the spontaneous breathing and controlled breathing, respectively[7,9]. There has been no study comparing the minimal fresh gas flow between the Baby EAR and JR.

Objective

The aim of this clinical trial was to compare the Baby EAR with the JR vis-à-vis the minimal FGF requirement with no and clinically acceptable rebreathing in spontaneous breathing anesthesia among pediatric patients weigh 5 to 20 kg.

Material and Method

The present study was approved by the Institutional Review Board of Khon Kaen University (HE531147) and registered at ClinicalTrilas.gov (NCT02167269). Written informed consent was obtained from all the parents.

The present study was a randomized, crossover study conducted at Srinagarind Hospital, Faculty of Medicine, Khon Kaen University, Thailand. The inclusion criteria were patients with a between 5 and 20 kg, having an ASA physical status I or II, and being scheduled for general anesthesia. The authors excluded patients who (a) had respiratory or cardiovascular disease, (b) could not breathe spontaneously during anesthesia, and (c) for patient the caudal block could not be done. The combined anesthetic machine and gas analyzer used in the present study was the Dräger Primus (Dräger AG, Lübeck, Germany).

Rebreathing was defined according to Humphrey's criteria as the partial or complete inhalation of previously exhaled gases; that is, >2 mmHg of inspired minimum CO_2 ($imCO_2$)[10]. Whereas Fresh Gas Flow (FGF) is the total volume of oxygen and nitrous oxide delivered from the flow meters of the anesthetic machine to the circuit per minute, the minimal FGF is the lowest FGF used while patient developed no rebreathing.

Immediately after entering the operating room, the eligible patients were randomly assigned to one of the two groups, group 1 started with the Baby EAR then switched to the JR (EAR-JR), and group 2 started with the JR then switched to the Baby EAR (JR-EAR).

Baseline blood pressure, pulse rate, and oxygen saturation were obtained using standard monitors. All patients were pre-medicated intravenously with fentanyl 0.5 to 1 µg/kg and atropine 0.01 mg/kg IV. Anesthesia was induced with propofol (2-3 mg/kg IV) or sevoflurane then intubation performed with deep sevoflurane or succinylcholine 1 mg/kg IV, using an uncuffed endotracheal tube of a size appropriate for each patient. An allowable leakage of airway pressure is 15 to 20 cmH_2O; if it exceeded this, the endotracheal tube was changed to a more appropriate size.

After intubation, a caudal block with 0.25% bupivacaine with adrenaline 1:200,000 0.5 to 1 mL/kg was done. Anesthesia was maintained with a 50% N_2O/O_2 combination with sevoflurane 1 to 3%, adjusted to ensure a proper anesthetic level to achieve normal vital signs and to keep the end-tidal CO_2 ($ETCO_2$) <60 mmHg. Fentanyl 1 µg/kg/h was infused during the procedure. All patients were spontaneously ventilated with FGF 500 mL/kg/min at the start of each anesthesia breathing circuit, waiting for the depth of anesthesia to be maintained and the patient to spontaneously breathe for at least 10 minutes. Baseline $ETCO_2$ and $imCO_2$ were then measured. The pulse rate, blood pressure and respiratory rate were recorded every five minutes and body temperature recorded every 15 minutes.

The FGF was reduced by 50 mL/kg/min every five minutes, waiting for the $imCO_2$ to be regularly maintained at least 60 sec. The $ETCO_2$ and $imCO_2$ values were recorded until rebreathing occurred ($imCO_2$ >2 mmHg) and measurements continued until rebreathing was not clinically acceptable ($imCO_2$ >6 mmHg). The minimal FGF before rebreathing occurred (FGF of $imCO_2$ ≤2 mmHg) is the amount of gas that does not cause rebreathing. The minimal FGF for which rebreathing was still acceptable (FGF of $imCO_2$ ≤6 mmHg) is the amount of gas that was clinically acceptable. After switching the anesthesia breathing circuit, the FGF was increased to 500 mL/kg/min for 10 minutes and the procedure was repeated. The minimal FGF before the rebreathing occurred and the FGF at which rebreathing was still clinically acceptable were recorded. After extubation, all of the patients were observed in the PACU and relevant factors recorded until there was good recovery from anesthesia before sending the patient back to the ward.

Statistical analysis

A minimum of 15 patients was needed to detect a clinically relevant reduction in FGF of 20%, with a power of 0.90 and a level of significance of 5%. Twenty patients were recruited to cover a potential dropout rate of 20%. Randomization was achieved using a computer-generated list (kept in sealed envelopes). Statistical analyses were performed with Statistical Package for the Social Sciences (SPSS) for Windows version 17.0 (SPSS, Chicago, IL). Continuous data were expressed as mean (SD) and compared using the paired Student's t-test or Mann-Whitney U test where applicable. Categorical data were expressed by number (%) and comparison was made by the Chi-square test. A p-value <0.05 was considered statistically significant.

Results

Twenty eligible patients completed the study and their data were included in the final analysis. Both EAR-JR and JR-EAR were comparable with respect to age, body weight, height, ASA physical status, and anesthetic data (Table 1).

At no rebreathing and acceptable rebreathing, the $ETCO_2$ levels were significantly higher for the Baby EAR (p = 0.009). There was no difference in $imCO_2$ values between both groups. The minimal FGF without

Table 1. Demographic and clinical data of the patients in the EAR-JR and JR-EAR groups

Variables	EAR-JR (n = 10)	JR-EAR (n = 10)	p-value
Demographic measure			
Age (year-month)	1-9 (1-2)	3-1 (1-9)	0.056
Sex: male (%)	8 (80)	9 (90)	0.531
BW (kg)	9.9 (3.0)	12.4 (3.5)	0.109
Height (cm)	111.5 (16.3)	88.8 (25.2)	0.323
Type of surgery (n)			
Lower abdomen	4 (40)	1 (10)	0.165
External genitalia	5 (50)	5 (50)	
Lower extremities	1 (10)	4 (40)	
Vital signs			
RR (tpm)	23 (2.4)	23.3 (4.8)	0.899
HR (bpm)	118 (23.6)	108.3 (23.2)	0.394
SBP (mmHg)	99.8 (16.0)	97.6 (12.5)	0.776
DBP (mmHg)	54.4 (14.8)	50.1 (11.8)	0.555
ASA classification (n)			
I	7 (70)	8 (80)	0.606
II	3 (30)	2 (20)	
Anesthesia data			
Total fentanyl (µg/kg/hour)	1.7 (1)	1.2 (0.5)	0.219
Total 0.25% bupivacaine (mL/kg)	0.63 (0.15)	0.59 (0.13)	0.619
Anesthesia duration (minute)	94.5 (38.6)	109 (56.3)	0.510

EAR = enclosed afferent reservoir; JR = Jackson-Rees anesthesia circuit; BW = body weight; RR = respiratory rate; HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; ASA = American Society of Anesthesiologists
Values are presented as mean (SD) or number (%)

Table 2. $ETCO_2$, $imCO_2$, minimal FGF at no and acceptable rebreathing and vital signs of patients in the Baby EAR and JR groups

Variables	Baby EAR (n = 20)	JR (n = 20)	*p*-value
FGF with no rebreathing (mL/kg/min)	192.5 (76.6)	347.5 (108.2)	<0.001
FGF with acceptable rebreathing (mL/kg/min)	117.5 (46.7)	227.6 (90.6)	<0.001
$ETCO_2$ at $imCO_2$ ≤2 (mmHg)	48.1 (7.5)	44.0 (9.9)	0.009
$ETCO_2$ at $imCO_2$ ≤6 (mmHg)	48.5 (7.4)	45.6 (10.2)	0.041
$imCO_2$			
$imCO_2$ with no rebreathing (mmHg)	1.5 (0.6)	1.35 (0.7)	0.481
$imCO_2$ with clinical acceptable (mmHg)	5.2 (1.7)	5.25 (1.40)	0.917
BT (Celsius)	36.1 (0.6)	36.2 (0.5)	0.080
HR (bpm)	138.3 (15.4)	137.2 (13.4)	0.402
RR (tpm)	28.5 (6.8)	27.9 (6.9)	0.317
SBP (mmHg)	89 (10.7)	88.7 (9.1)	0.703
DBP (mmHg)	40.2 (9.5)	41.5 (8.0)	0.386

FGF = fresh gas flow; $ETCO_2$ = end tidal carbon dioxide level; $imCO_2$ = inspired minimum CO_2 level; BT = body temperature; HR = heart rate; RR = respiratory rate; SBP = systolic blood pressure; DBP = diastolic blood pressure
Values are presented as mean (SD)

and with acceptable rebreathing were significantly lower in the Baby EAR compared to the JR (p<0.001) (Table 2). The FGF requirement in the Baby EAR decreased by 44.6% and 48.4% for no rebreathing and acceptable rebreathing comparing with the JR. Blood pressure, heart rate, and respiratory rate did not differ between the two groups at any of the measured time intervals.

Discussion

The present study revealed that the Baby EAR required about 45% less FGF than JR both without and with acceptable rebreathing.

The anesthesia breathing circuit commonly used in pediatric patients is the JR. The FGF requirement needs two to three times more gases per minute of ventilation for spontaneous breathing. This results in a loss of body heat and moisture in the expired gases, excessive waste gas and produces pollution in the operating room[2,3].

EAR, a modification of the Mapleson A system, was invented by Miller & Miller for use in both controlled ventilation and spontaneous breathing mode among pediatric patients[4]. Meakin et al[5] concluded in their study that the optimal FGF (L/min) is 0.6 x weight1/2 (kg) or the formula: Quantities of gas (mL/min) = 1,000 + [weight (kg) x 100]

Theerapongpakdee et al devised the Baby EAR system for use in pediatric patients, using materials readily available in the operating room[7-9]. Various studies found that the Baby EAR could be safely used in pediatric patients in both controlled and spontaneous breathing mode[5,7-9]. The advantages of this circuit are its (a) high efficiency, (b) lower FGF requirement for preventing rebreathing, (c) reduced loss of heat and humidity, and (d) less pollution in the operating room.

A previous study of the Baby EAR vs. the JR in general anesthesia with controlled ventilation showed no difference in the amount of FGF required with $imCO_2$ ≤6 mmHg (1.83±0.53 vs. 2.25±0.81 L/min, p>0.05); thus it was concluded that the Baby EAR can be effectively and safely used instead of the JR[8].

The minimal FGF that caused no rebreathing in the Baby EAR in the present report was significantly less than that of the JR (192.5±76.6 vs. 347.5±108.2 mL/kg/min, p<0.001), which contrasted with the comparative study in controlled breathing[8]. This reduction in FGF may be due to the presence of a one-way valve in the expiratory limb of the Baby EAR system. The $ETCO_2$ in the Baby EAR was slightly, but significantly, higher because they received higher dose of fentanyl as shown in Table 1; however, there was no significant difference in clinical practice because the value for both systems was within clinically acceptable levels. The body temperatures of both groups were comparable because all patients received hot air warmer to prevent hypothermia.

Conclusion

The Baby EAR anesthesia breathing circuit can be used safely, effectively and with a lower fresh gas flow than the Jackson-Rees circuit in pediatric patients weigh 5 to 20 kg. The minimal fresh gas flow requirement for the Baby EAR circuit for preventing rebreathing is 192.5±76.6 mL/kg/min but can be as low as 117.5±46.7 mL/kg/min with clinically acceptable rebreathing in the spontaneous breathing mode.

What is already known on this topic?

The Enclosed Afferent Reservoir anesthesia circuit (EAR) is an anesthesia breathing circuit that has the following advantages, (a) high efficiency, (b) low gas flow usage in both controlled and spontaneous respiration, (c) nominal heat loss, (d) conserved moisture, (e) reduced pollution in the operating room, and (f) low anesthetic cost. The Baby EAR is the modification for use in pediatric patients <20 kg. It can be used safely in children weigh 5 to 20 kg, using a fresh gas flow of 2.5 and 3 L/min in the spontaneous breathing and controlled breathing, respectively.

What this study adds?

There has been no study comparing the minimal fresh gas flow between the Baby EAR and JR. This study showed that the Baby EAR require less fresh gas flow in spontaneous breathing mode comparing with the JR. The minimal fresh gas flow requirement for the Baby EAR circuit for preventing rebreathing was 192.5±76.6 mL/kg/min but could be as low as 117.5±46.7 mL/kg/min with clinically acceptable rebreathing in the spontaneous breathing mode.

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Potential conflicts of interest

None.

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การศึกษาเปรียบเทียบปริมาณก๊าซน้อยที่สุดที่ใช้ในการดมยาสลบเด็ก ด้วยวงจรดมยาสลบชนิด baby enclosed afferent reservoir และ Jackson Rees ในแบบหายใจเอง

สรรชัย ธีรพงศ์ภักดี, เทพกร สาธิตการมณี, สิริรัตน์ ตรีพุทธรัตน์, นนทิดา โรจนพิทยากร, กาญจนา อุปปัญ, คัทลียา ทองรอง, ปิยะพร บุญแสงเจริญ

วัตถุประสงค์: เพื่อศึกษาเปรียบเทียบปริมาณก๊าซน้อยที่สุดที่ใช้ในการดมยาสลบผู้ป่วยเด็กที่มารับการผ่าตัดแบบหายใจเอง โดยไม่เกิดภาวะคาร์บอนไดออกไซด์คั่ง ระหว่างวงจร baby enclosed afferent reservoir (Baby EAR) และ Jacksonn Rees (JR)

วัสดุและวิธีการ: เป็นการศึกษาแบบ randomized crossover ผู้ป่วยเด็ก 20 ราย น้ำหนักตัว 5 ถึง 20 กิโลกรัม ASA physical status 1-2 ได้รับการแบ่งออกเป็นสองกลุ่ม กลุ่มแรก (EAR-JR) ได้รับวงจร Baby EAR แล้วจึงสลับเป็น JR หรือ กลุ่มที่สอง (JR-EAR) ได้รับวงจรตรงกันข้ามโดยเริ่มจาก JR หลังดมยาสลบและใส่ท่อช่วยหายใจ ควบคุมความลึกของการสลบด้วย N_2O/O_2 และ sevoflurane 1-3% เมื่อเริ่มต้นใช้วงจรแรก ให้ผู้ป่วยหายใจเองด้วยก๊าซที่ 500 มล./กก./นาที 10 นาที ลดปริมาณก๊าซลงครั้งละ 50 มล./กก./นาที ทุก 5 นาที จนกระทั่งเกิดภาวะคาร์บอนไดออกไซด์คั่ง และคาร์บอนไดออกไซด์คั่งที่ยอมรับได้ทางคลินิก โดยค่าคาร์บอนไดออกไซด์ในลมหายใจเข้า >2 และ >6 มิลลิเมตรปรอท แล้วจึงสลับวงจรดมยาสลบ

ผลการศึกษา: ปริมาณก๊าซน้อยที่สุดที่ใช้ในวงจร Baby EAR และ JR เมื่อเกิดภาวะคาร์บอนไดออกไซด์คั่งมีค่าเฉลี่ยเท่ากับ 192.5±76.6 และ 347.5±108.2 มล./กก./นาที ($p<0.001$) และเท่ากับ 117.5±46.7 และ 227.6±90.6 มล./กก./นาที ($p<0.001$) เมื่อเกิดภาวะคาร์บอนไดออกไซด์คั่งที่ยอมรับได้ทางคลินิก

สรุป: วงจรดมยาสลบเด็ก Baby EAR สามารถใช้ดมยาสลบได้อย่างปลอดภัย มีความต้องการก๊าซน้อยกว่าวงจร Jackson Rees ในการดมยาสลบเด็กน้ำหนักตัว 5 ถึง 20 กิโลกรัม แบบหายใจเอง