A Clinical Determination of Optimal Fresh Gas Flow in a Baby EAR Circuit

Sunchai Theerapongpakdee MD*,
Thanyathorn Phanpanusit MD*, Duenpen Horatanaruang MD*,
Piyaporn Bunsangjaroen MD*, Prapapan Limpkulwathanaporn BSc (Nursing)*,
Maneerut Thananun BSc (Nursing)*, Duangthida Nonlhaopol BSc (Nursing)*

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

Objective: *Baby EAR circuit is a new modified enclosed afferent reservoir anesthetic breathing system for pediatric patients. By following His Majesty the King of Thailand's self-sufficiency philosophy, the circuit is simple and made of low-cost and easy-to-find materials found in the operating room. This present study was to investigate clinical use of the circuit and to find the optimal fresh gas flow in clinical setting.*

Material and Method: *A prospective descriptive study was conducted in pediatric patients, weighed 5-20 kg, anesthetized for surgery. The Baby EAR breathing circuit was used for general anesthesia with endotracheal tube and control ventilation. Different fresh gas flow of 3,2.5,2 and 1.5 liter per minute (LPM) was used consecutively. The authors recorded end-tidal carbon dioxide ($EtCO_2$) and mean inspiratory carbon dioxide ($ImCO_2$) while using fresh gas flow at 3, 2.5, 2, and 1.5 LPM. $EtCO_2$ of 35-45 mmHg and $ImCO_2$ of < 6 mmHg were considered clinically acceptable.*

Results: *Fifty patients were enrolled. Mean value (95% CI) of $EtCO_2$ at fresh gas flow rate of 1.5, 2, 2.5, and 3 LPM were 39.6 (39.2, 40.9), 36.7 (35.5, 37.8), 35.4 (34.3, 36.4), and 35.4 (34.3, 36.4) mmHg respectively. Mean value (95% CI) of $ImCO_2$ at fresh gas flow rate of 1.5, 2, 2.5, and 3 LPM were 4.0 (3.0, 4.9), 2.4 (1.7, 3.0), 1.8 (0.9, 2.6), and 1.3 (0.9, 1.7) mmHg respectively. Percentage of patients (95% CI) who had clinically acceptable $EtCO_2$ and $ImCO_2$ at fresh gas flow rate of 1.5, 2, 2.5, and 3 LPM were 70% (56.2, 80.9), 92% (81.2, 96.8), 98% (89.5, 99.6), and 100% (92.9, 100) respectively. No patients had serious complications.*

Conclusion: *Baby EAR circuit can be made economically and used safely for general anesthesia with control ventilation in pediatric patients weighing 5 to 20 kg at optimal fresh gas flow of 3 LPM.*

Keywords: *Anesthesia, EAR circuit, Pediatrics, Respiration, Ventilators, Mechanical*

J Med Assoc Thai 2009; 92 (5): 667-71
Full text. e-Journal: *http://www.mat.or.th/journal*

Enclosed Afferent Reservoir (EAR) is an anesthetic breathing circuit invented in 1988[1] by Miller & Miller. It is a modification of Mapleson A system, which is a type of breathing circuit without carbon dioxide (CO_2) absorber. Its advantage over Mapleson A system is the lower fresh gas flow requirement during control ventilation. It has been widely investigated for safety and effectiveness for use in both adult and pediatric patients[2-7].

Correspondence to: Theerapongpakdee S, Department of Anesthesiology, Faculty of Medicine, Khon Kaen University, Khon Kaen 40002, Thailand. Phone: 043-348-390, Fax: 043-348-390 ext 405. E-mail: Sunchai@kku.ac.th

Baby EAR (Fig. 1) is a modification of EAR circuit invented by Department of Anesthesiology, Faculty of Medicine, Khon Kaen University, Thailand for clinical use in patients weighing less than 20 kg. By applying His Majesty the King of Thailand's self-sufficiency philosophy, the circuit is made of low-cost and easy-to-find materials in the operating room. This present study was to investigate clinical use of the circuit and to find the optimal fresh gas flow in a clinical setting.

Material and Method

This present study is a prospective descriptive study, conducted at Srinagarind Hospital, Faculty of

Medicine, Khon Kaen University, Thailand. After approval from the institutional Ethics Committee, 50 ASA I-II (American Society of Anesthesiologists physical status I or II) pediatric patients weighing 5-20 kg scheduled for elective surgery and general anesthesia with endotracheal intubation were recruited. Patients with cardiovascular and respiratory diseases were excluded. Informed consent was obtained from the parents.

All patients received standard care for general anesthesia. The Baby EAR breathing circuit was used for general anesthesia with an endotracheal tube and control ventilation. After premedication with fentanyl 1-2 mcg/kg and midazolam 0.05-0.1 mg/kg intravenously, anesthesia was then induced with propofol 1-2 mg/kg. Atracurium 0.4-0.6 mg/kg was used for intubation. Anesthesia was maintained with N_2O: O_2 (1:1) and Isoflurane at the concentration of 1-2%. Ventilation was controlled to achieve peak airway pressure of 15-20 cmH_2O and respiratory rate of 20-24 breath per minute (bpm). Different fresh gas flow of 3, 2.5, 2, and 1.5 liter per minute (LPM) was used consecutively. The authors recorded end-tidal carbon dioxide ($EtCO_2$) and mean inspiratory carbon dioxide ($ImCO_2$) while using fresh gas flow at 3, 2.5, 2 and 1.5 LPM for at least 15 minutes for each flow rate. $EtCO_2$ of 35-45 mmHg and $ImCO_2$ of < 6 mmHg were considered clinically acceptable. Body temperature was controlled within 36-37°C. Vital signs and respiratory parameters were recorded. Data was presented and analyzed using descriptive statistics, namely percentage, mean ± SD, 95% CI (95% confidence interval).

Results

Table 1 shows $EtCO_2$ and $ImCO_2$ at different fresh gas flow rate in fifty patients with mean age of 2 years and average weight of 11.28 kg. $EtCO_2$ and $ImCO_2$ are shown in Table 1. Percentage of patients (95% CI) who had clinically acceptable $EtCO_2$ and $ImCO_2$ at fresh gas flow rate 1.5, 2, 2.5, and 3 LPM were 70% (56.2, 80.9), 92% (81.2, 96.8), 98% (89.5, 99.6), and 100% (92.9, 100) respectively (Table 2). The value of $EtCO_2$ and $ImCO_2$ when patients are divided into 3 groups according to their weight (5-10 kg, 11-15 kg, 16-20 kg) is shown in Table 3. No patients had serious complications.

Discussion

Mapleson A breathing system is a type of non-absorber anesthetic breathing system which can be used with controlled ventilation but in the expense of high fresh gas flow rate required to eliminate rebreathing (2-3 times of minute ventilation). To use with pediatric patients, fresh gas flow of 6-8 LPM is required. This can increase cost of anesthesia and increase air pollution in the operating room. Miller & Miller[1] (1988) have introduced the enclosed afferent reservoir (EAR) breathing systems, which is a modification of Mapleson A system and evaluated its use in clinical setting. Droppert et al[7] (1991) has suggested that fresh gas flow of 70 ml/kg should be used for controlled ventilation in adult patients. For pediatric use in controlled ventilation mode, Meakin et al[6] (1992) concluded in their study that the formula for fresh gas flow is 0.6 x $weight^{0.5}$ (kg), this fresh gas

Table 1. $EtCO_2$ and $ImCO_2$ at different fresh gas flow (n = 50)

	FGF 1.5 LPM	FGF 2 LPM	FGF 2.5 LPM	FGF 3 LPM
$EtCO_2$ (mmHg) (95%CI)	39.6 ± 4.5 (39.2, 40.9)	36.7 ± 4.1 (35.5, 37.8)	35.4 ± 3.8 (34.3, 36.4)	35.4 ± 3.7 (34.3, 36.4)
$ImCO_2$ (mmHg) (95%CI)	4.0 ± 3.3 (3.0, 4.9)	2.4 ± 2.2 (1.7, 3.0)	1.8 ± 2.9 (0.9, 2.6)	1.3 ± 1.5 (0.9, 1.7)

Values are mean ± SD, 95% confidence interval. FGF = fresh gas flow, LPM = liter per minute

Table 2. Patients who had clinically acceptable $EtCO_2$ and $ImCO_2$ at different fresh gas flow

n = 50	FGF 1.5 LPM	FGF 2 LPM	FGF 2.5 LPM	FGF 3 LPM
Patients who had clinically acceptable $EtCO_2$ and $ImCO_2$ (95% CI)	35 (70%) (56.2, 80.9)	46 (92%) (81.2, 96.8)	49 (98%) (89.5, 99.6)	50 (100%) (92.9, 100)

Values are number of patients (percentage). FGF = fresh gas flow, LPM = liter per minute

Table 3. $EtCO_2$ and $ImCO_2$ at different fresh gas flow grouped by their weights

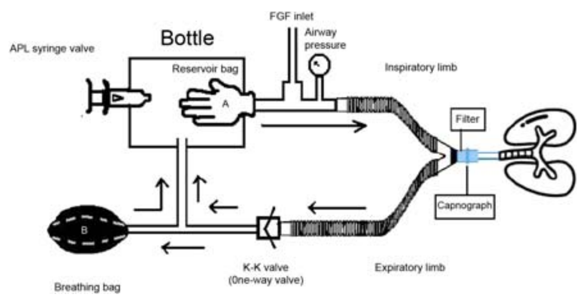
	FGF 1.5 LPM	FGF 2 LPM	FGF 2.5 LPM	FGF 3 LPM
5-10 kg, n = 23				
$EtCO_2$ (mmHg) (95% CI)	38.4 ± 4.4 (36.5, 40.3)	35.9 ± 3.3 (34.5, 37.4)	34.8 ± 3.7 (33.2, 36.5)	34.6 ± 3.5 (33.0, 36.1)
$ImCO_2$ (mmHg) (95% CI)	3.3 ± 2.7 (2.2, 4.5)	2.2 ± 2.0 (1.3, 3.0)	1.6 ± 1.8 (0.8, 2.4)	1.3 ± 1.5 (0.6, 1.9)
11-15 kg, n = 22				
$EtCO_2$ (mmHg) (95% CI)	39.9 ± 4.7 (37.8, 42.0)	36.8 ± 4.3 (34.8, 38.7)	35.4 ± 3.9 (33.7, 37.1)	35.5 ± 3.9 (33.8, 37.3)
$ImCO_2$ (mmHg) (95% CI)	4.1 ± 3.5 (2.5, 5.6)	2.4 ± 2.6 (1.2, 3.6)	1.8 ± 2.1 (0.8, 2.7)	1.4 ± 1.6 (0.6, 2.1)
16-20 kg, n = 5				
$EtCO_2$ (mmHg) (95% CI)	43.6 ± 2.0 (41.0, 46.1)	39.8 ± 3.1 (35.9, 43.6)	37.6 ± 3.3 (33.4, 41.7)	38.4 ± 3.0 (34.6, 42.1)
$ImCO_2$ (mmHg) (95% CI)	6.4 ± 4.9 (0.3, 1.2)	3.0 ± 2.1 (0.3, 5.6)	2.4 ± 1.8 (0.1, 4.6)	1.2 ± 0.8 (0.1, 2.2)

Values are mean ± SD, 95% confidence interval. FGF = fresh gas flow, LPM = liter per minute

flow rate will produce normocapnia to mild hypocapnia in children who weighed 10-70 kg.

Baby EAR pediatric breathing system is the newest innovation of the non-absorber breathing system with character of Mapleson A system in pediatric anesthesia, developed by the team of anesthesiologists at Srinagarind Hospital, Faculty of Medicine, Khon Kaen University for use in small children. It was simply made of disposable materials in the operating room such as 1-liter plastic bottle of intravenous fluid, surgical gloves, bacterial filter, endotracheal tube, 10-ml and 20-ml disposable plastic syringes, plastic corrugated hoses (15-mm internal diameter), yellow latex rubber tube, pediatric Y connector (Fig. 1, 2). The difference of this new breathing system from others is that after installing a one-way valve (KK one-way valve) in the expiratory hose before pouring the expired gas into the enclosed plastic bottle, it can be used in controlled breathing mode with fresh gas flow as low as 2-3 LPM in pediatric patients who weighed less than 20 kg.

The present study has shown that the Baby EAR circuit can be used safely in all patients with fresh gas flow of 3 LPM. If fresh gas flow of 2 or 2.5 LPM were used, a small number of patients had high $EtCO_2$ and $ImCO_2$ but not to a harmful level (Table 1, 2). By categorizing patients into groups by body weight (Table 3), $EtCO_2$ and $ImCO_2$ tended to be lower when using the same fresh gas flow in lighter than heavier children, corresponding with alveolar ventilation which



FGF = fresh gas flow, APL = adjustable pressure limiting

Fig. 1 Diagram of Baby EAR circuit (→ shows direction of gas flow)

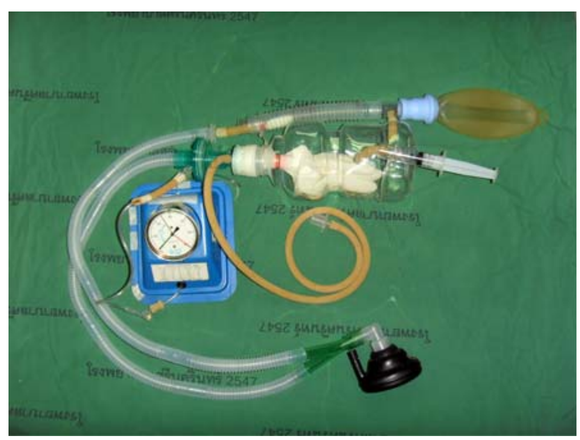


Fig. 2 Baby EAR circuit

varies depending on body weight. Therefore, the authors suggest the fresh gas flow of $\geq$ 2 LPM in patients who weighed 5-20 kg. The use of capnography will increase safety of patients if the lower fresh gas flow is to be used with full understanding of the structure and function of the system.

Conclusion

Baby EAR circuit is a new non-absorber pediatric anesthetic breathing system that is simple and made of disposable material in the operating room. It can be used safely for general anesthesia with control ventilation in pediatric patients weighed 5-20 kg at optimal fresh gas flow of 3 LPM.

References

1. Miller DM, Miller JC. Enclosed afferent reservoir breathing systems. Description and clinical evaluation. Br J Anaesth 1988; 60: 469-75.
2. Barrie JR, Beatty PC, Campbell IT, Healy TE. Determination of the onset of rebreathing in an enclosed afferent reservoir breathing system in anaesthetized, spontaneously breathing adults: a comparison of three methods. Eur J Anaesthesiol 1994; 11: 187-91.
3. Theerapongpakdee S, Sermdamrongsak U. A comparative study between EAR and coaxial circle breathing system. Thai J Anesthesiol 1992; 18: 140-4.
4. Barrie JR, Beatty PC, Campbell IT, Meakin G, Healy TE. Fresh gas requirements of an enclosed afferent reservoir breathing system in anaesthetized, spontaneously breathing adults. Br J Anaesth 1993; 70: 468-70.
5. Meakin G, Jennings AD, Beatty PC, Healy TE. Fresh gas requirements of an enclosed afferent reservoir breathing system in anaesthetized, spontaneously ventilating children. Br J Anaesth 1992; 68: 333-7.
6. Meakin G, Jennings AD, Beatty PC, Healy TE. Fresh gas requirements of an enclosed afferent reservoir breathing system during controlled ventilation in children. Br J Anaesth 1992; 68: 43-7.
7. Droppert PM, Meakin G, Beatty PC, Mortimer AJ, Healy TE. Efficiency of an enclosed afferent reservoir breathing system during controlled ventilation. Br J Anaesth 1991; 66: 638-42.

การหาปริมาณก๊าซที่เหมาะสมต่อการใช้งานทางคลินิกสำหรับวงจรวางยาสลบเด็ก ชนิด Baby EAR

สรรชัย ธีรพงศ์ภักดี, ธัญธรณ์ พันธ์ภานุสิทธิ์, เดือนเพ็ญ ห่อรัตนาเรือง, ปิยะพร บุญแสงเจริญ, มณีรัตน์ ธนานันต์, ดวงธิดา นนท์เหล่าพล, ประภาพรรณ ลิมป์กุลวัฒนพร

วัตถุประสงค์*: Baby EAR เป็นวงจรวางยาสลบแบบใหม่ที่ประดิษฐ์เพื่อใช้ในผู้ป่วยเด็ก ทำขึ้นจากวัสดุที่หาง่าย ราคาถูก สอดคล้องกับแนวพระราชดำริเรื่องเศรษฐกิจแบบพอเพียง สามารถช่วยลดงบประมาณในการซื้อวงจรวางยาสลบที่มีราคาแพงจากต่างประเทศได้ ผู้นิพนธ์จึงต้องการศึกษาการใช้วงจร Baby EAR ในการวางยาสลบผู้ป่วยเด็ก เพื่อดูประสิทธิภาพในการใช้งานทางคลินิกและศึกษาหาปริมาณ fresh gas flow ที่เหมาะสม*

วัสดุและวิธีการ*: เป็นการศึกษาแบบพรรณนา โดยใช้วงจร Baby EAR วางยาสลบแบบควบคุมการหายใจในผู้ป่วยเด็กน้ำหนักตัว 5-20 กก. บันทึกค่า end-tidal carbon dioxide($EtCO_2$) และ mean inspiratory carbon dioxide ($ImCO_2$) ขณะใช้ fresh gas flow ขนาด 3, 2.5, 2, 1.5 ลิตรต่อนาที ค่า $EtCO_2$ และ $ImCO_2$ ที่ยอมรับได้ทางคลินิก คือ 35-45 มม.ปรอท และ < 6 มม.ปรอท ตามลำดับ คำนวณค่าทางสถิติและนำเสนอในรูป ค่าเฉลี่ย ร้อยละ และ 95% CI (95% confidence interval)*

ผลการศึกษา*: ผู้ป่วยเข้าร่วมการศึกษาจำนวน 50 ราย พบว่าค่าเฉลี่ย (95% CI) ของ $EtCO_2$ เมื่อใช้ fresh gas flow 1.5, 2, 2.5 และ 3 ลิตรต่อนาที เท่ากับ 39.6 (39.2, 40.9), 36.7 (35.5, 37.8), 35.4 (34.3, 36.4) และ 35.4 (34.3, 36.4) มม.ปรอท ตามลำดับ และค่าเฉลี่ย (95% CI) ของ $ImCO_2$ เมื่อใช้ fresh gas flow 1.5, 2, 2.5 และ 3 ลิตรต่อนาที เท่ากับ 4.0 (3.0, 4.9), 2.4 (1.7, 3.0), 1.8 (0.9, 2.6) และ 1.3 (0.9, 1.7) มม.ปรอท ตามลำดับ โดยร้อยละ(95% CI) ของผู้ป่วยที่มีค่า $EtCO_2$ และ $ImCO_2$ อยู่ในค่าที่ยอมรับได้เมื่อใช้ fresh gas flow 1.5, 2, 2.5 และ 3 ลิตรต่อนาที ได้แก่ 70% (56.2, 80.9), 92% (81.2, 96.8), 98% (89.5, 99.6) และ 100% (92.9, 100) ตามลำดับ และไม่มีผู้ป่วยเกิดภาวะแทรกซ้อนจากการใช้วงจรดังกล่าว*

สรุป*: วงจร Baby EAR เป็นนวัตกรรมตามแนวเศรษฐกิจแบบพอเพียงและสามารถใช้ในการวางยาสลบแบบควบคุมการหายใจในผู้ป่วยเด็กที่น้ำหนักตัวระหว่าง 5 ถึง 20 กก. ได้อย่างปลอดภัย โดยค่า fresh gas flow ที่เหมาะสม คือ 3 ลิตรต่อนาที*