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

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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 (EtCO2) and mean inspiratory carbon dioxide (ImCO2) while using fresh gas flow at 3, 2.5, 2, and 1.5 LPM. EtCO2 of 35-45 mmHg and ImCO2 of < 6 mmHg were considered clinically acceptable.

Results: Fifty patients were enrolled. Mean value (95% CI) of EtCO2 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 ImCO2 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 EtCO2 and ImCO2 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

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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 (CO2) 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).

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 N₂O: O₂ (1:1) and Isoflurane at the concentration of 1-2%. Ventilation was controlled to achieve peak airway pressure of 15-20 cmH₂O 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 (EtCO₂) and mean inspiratory carbon dioxide (ImCO₂) while using fresh gas flow at 3, 2.5, 2, and 1.5 LPM for at least 15 minutes for each flow rate. EtCO₂ of 35-45 mmHg and ImCO₂ 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 EtCO₂ and ImCO₂ at different fresh gas flow rate in fifty patients with mean age of 2 years and average weight of 11.28 kg. EtCO₂ and ImCO₂ are shown in Table 1. Percentage of patients (95% CI) who had clinically acceptable EtCO₂ and ImCO₂ 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 EtCO₂ and ImCO₂ 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 weight⁰.₅ (kg), this fresh gas flow rate is expected to produce EtCO₂ and ImCO₂ within target limits.

### Table 1. EtCO₂ and ImCO₂ at different fresh gas flow (n = 50)

<table>
<thead>
<tr>
<th>Fresh Gas Flow (LPM)</th>
<th>EtCO₂ (mmHg) (95% CI)</th>
<th>ImCO₂ (mmHg) (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>39.6 ± 4.5 (39.2, 40.9)</td>
<td>4.0 ± 3.3 (3.0, 4.9)</td>
</tr>
<tr>
<td>2</td>
<td>36.7 ± 4.1 (35.5, 37.8)</td>
<td>2.4 ± 2.2 (1.7, 3.0)</td>
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<tr>
<td>2.5</td>
<td>35.4 ± 3.8 (34.3, 36.4)</td>
<td>1.8 ± 2.9 (0.9, 2.6)</td>
</tr>
<tr>
<td>3</td>
<td>35.4 ± 3.7 (34.3, 36.4)</td>
<td>1.3 ± 1.5 (0.9, 1.7)</td>
</tr>
</tbody>
</table>

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

### Table 2. Patients who had clinically acceptable EtCO₂ and ImCO₂ at different fresh gas flow

<table>
<thead>
<tr>
<th>Fresh Gas Flow (LPM)</th>
<th>Patients who had clinically acceptable EtCO₂ and ImCO₂ (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>35 (70%) (56.2, 80.9)</td>
</tr>
<tr>
<td>2</td>
<td>46 (92%) (81.2, 96.8)</td>
</tr>
<tr>
<td>2.5</td>
<td>49 (98%) (89.5, 99.6)</td>
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<tr>
<td>3</td>
<td>50 (100%) (92.9, 100)</td>
</tr>
</tbody>
</table>

Values are number of patients (percentage). 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 EtCO₂ and ImCO₂ but not to a harmful level (Table 1, 2). By categorizing patients into groups by body weight (Table 3), EtCO₂ and ImCO₂ tended to be lower when using the same fresh gas flow in lighter than heavier children, corresponding with alveolar ventilation which

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**Table 3.** EtCO₂ and ImCO₂ at different fresh gas flow grouped by their weights

<table>
<thead>
<tr>
<th></th>
<th>FGF 1.5 LPM</th>
<th>FGF 2 LPM</th>
<th>FGF 2.5 LPM</th>
<th>FGF 3 LPM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EtCO₂ (mmHg)</td>
<td>ImCO₂ (mmHg)</td>
<td>EtCO₂ (mmHg)</td>
<td>ImCO₂ (mmHg)</td>
</tr>
<tr>
<td></td>
<td>(95% CI)</td>
<td>(95% CI)</td>
<td>(95% CI)</td>
<td>(95% CI)</td>
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<tr>
<td>5-10 kg, n = 23</td>
<td>38.4 ± 4.4 (36.5, 40.3)</td>
<td>3.3 ± 2.7 (2.2, 4.5)</td>
<td>35.9 ± 3.3 (34.5, 37.4)</td>
<td>2.2 ± 2.0 (1.3, 3.0)</td>
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<tr>
<td>11-15 kg, n = 22</td>
<td>39.9 ± 4.7 (37.8, 42.0)</td>
<td>4.1 ± 3.5 (2.5, 5.6)</td>
<td>36.8 ± 4.3 (34.8, 38.7)</td>
<td>2.4 ± 2.6 (1.2, 3.6)</td>
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<tr>
<td>16-20 kg, n = 5</td>
<td>43.6 ± 2.0 (41.0, 46.1)</td>
<td>6.4 ± 4.9 (0.3, 1.2)</td>
<td>39.8 ± 3.1 (35.9, 43.6)</td>
<td>3.0 ± 2.1 (0.3, 5.6)</td>
</tr>
</tbody>
</table>

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

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**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**

การหาปริมาณก๊าซที่เหมาะสมต่อการใช้งานทางคลินิกสำหรับวงจรวางยาสลบเด็กชนิด Baby EAR

สรรชัย อธิพงค์ภักดี, ธีรพงศ์ พิทยาภิรมย์, ติชยา จิติภักดี, นะรัตน์ บุญแสงเจริญ, มณีรัตน์ ธนาจารย์, ดวงธิดา นนท์เหล่าพล, ประกาศรัตน์ ลิมป์กุลวัฒนพร

วัตถุประสงค์: Baby EAR เป็นวงจรวางยาสลบแบบใหม่ที่ประดิษฐ์เพื่อใช้ในผู้ป่วยเด็กทารกที่ไม่สามารถหายใจเองได้ ประกอบด้วยแกนวงจรวางยาสลบแบบคอมพิวเตอร์ที่มีความสามารถจัดการควบคุมการหายใจได้ ผู้นิพนธ์จึงต้องการศึกษาการใช้วงจร Baby EAR ในการวางยาสลบผู้ป่วยเด็ก เพื่อ枯燥ผลิตภัณฑ์ทางคลินิกและศึกษาการเปลี่ยน fresh gas flow ที่เหมาะสม

วัสดุและวิธีการ: เป็นการศึกษาแบบพรรณนา โดยใช้วงจร Baby EAR วางยาสลบแบบควบคุมการหายใจในผู้ป่วยเด็กน้ำหนักตัว 5-20 กก. บันทึกค่า end-tidal carbon dioxide (EtCO₂) และ mean inspiratory carbon dioxide (ImCO₂) ขณะใช้ fresh gas flow ขนาด 3, 2.5, 2, 1.5 ลิตรต่อนาที ค่า EtCO₂ และ ImCO₂ ที่ยอมรับได้ทางคลินิกคือ 35-45 มม.ระดับ และ < 6 มม.ระดับ ตามลำดับ คำนวณค่าทางสถิติและนำเสนอในรูปค่าเฉลี่ย ร้อยละ และ 95% CI (95% confidence interval)

ผลการศึกษา: ผู้ป่วยเข้าร่วมการศึกษาจำนวน 50 ราย พบว่าค่าเฉลี่ย (95% CI) ของ EtCO₂ เมื่อใช้ fresh gas flow 1.5, 2, 2.5 และ 3 ลิตรต่อนาทีเท่ากับ 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.ระดับ และค่าเฉลี่ย (95% CI) ของ ImCO₂ เมื่อใช้ fresh gas flow 1.5, 2, 2.5 และ 3 ลิตรต่อนาทีเท่ากับ 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.ระดับ โดยทั่วไป 95% CI ของค่าที่ยอมรับได้ที่ใช้ fresh gas flow 1.5, 2, 2.5 และ 3 ลิตรต่อนาทีเท่ากับ 70% (56.2, 80.9), 92% (81.2, 96.8), 98% (89.5, 99.6) และ 100% (92.9, 100) ในปลายตัว และไม่มีผู้ป่วยเกิดภาวะแทรกซ้อนจากการใช้งานวงจรเด็ก

สรุป: วงจร Baby EAR เป็นวงจรวางยาสลบแบบคอมพิวเตอร์ที่เหมาะสมต่อการใช้งานทางคลินิก ผู้ป่วยที่มีค่ากล่าวที่เหมาะสมต่อการใช้งานทางคลินิกคือ 3 ลิตรต่อนาที