Anesthesia-Related Cardiac Arrest in Children: The Thai Anesthesia Incidents Study (THAI Study)

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Background and Objective: *The Thai Anesthesia Incidents study (THAI Study) is the first national study of anesthesia outcomes during anesthesia practice in Thailand. The authors extracted data of 25,098 pediatric cases from the THAI Study in order to examine the incidence, suspected causes, contributory factors, and suggested corrective strategies associated with anesthesia-related cardiac arrest.*
Material and Method: *A multi-centered prospective descriptive study was conducted among 20 hospitals across Thailand over a year between March 1, 2003 and February 28, 2004. Data of cardiac arrests in children aged 15 years and younger were collected during anesthesia, in the recovery room and 24 hours postoperative period, and reviewed independently by at least two reviewers.*
Results: *Incidence of anesthesia- related cardiac arrest was 5.1 per 10,000 anesthetics, with 46% mortality rate. Infants accounted for 61% of cases. Incidences of overall cardiac arrest and anesthesia-related arrest were significantly higher in infants than older children and in children with ASA physical status 3-5 than those with ASA physical status 1-2. Most of the anesthesia-related arrests occurred in the operating room (61%) during induction or maintenance of anesthesia (84%). Respiratory-related cardiac arrest was the most common suspected cause of anesthesia-related cardiac arrest. Improving supervision, additional training, practice guidelines, efficient blood bank, equipment maintenance, and quality assurance monitoring are suggested corrective strategies to improve the quality of care in pediatric anesthesia.*
Conclusion: *The incidence of anesthesia-related cardiac arrest was 5.1:10,000 anesthetics. Major risk factors were children younger than 1 year of age and ASA 3-5. The identifications of airway management and medication-related problems as the main causes of anesthesia-related cardiac arrest have important implications for preventive strategies.*

Keywords: *Adolescent, Anesthesia, Child, Child preschool, Heart arrest*

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Previous studies showed that children have a higher incidence of perioperative cardiac arrest compared with adults[1-2] and within the pediatric population, perioperative cardiac arrests occur more frequently in infants than in older children[3-5]. The initial findings from the Pediatric Perioperative Cardiac Arrest (POCA) registry (1994-1997)[5] revealed that medication-related causes, in particular halothane induced cardiovascular depression, were the most common cause of anesthesia-related cardiac arrest. Recent findings from POCA registry (1998-2004)[6]

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showed a reduction of medication-related causes compared to the initial findings. This may be related to the declining use of halothane. The identification of suspected causes and contributory factors of the anesthesia-related cardiac arrest has important implications for preventive strategies. In 2003, The Royal College of Anesthesiologists of Thailand initiated the Thai Anesthesia Incidents study (THAI Study), a multi-centered research to find out adverse events in anesthesia practices in 20 hospitals across Thailand. Some of the results of this project have been published recently[7,8]. The author extracted data of 25,098 pediatric cases from the THAI Study to determine the incidence, suspected causes, contributory factors, outcomes, and suggested preventive strategies of perioperative cardiac arrest. The emphasis of the present study was on anesthesia-related cardiac arrest.

Material and Method

The present study was a multi-centered research of twenty hospitals comprising of seven university, five tertiary care, four general and four district hospitals across Thailand. The study protocol was approved by the ethics committee of each hospital. The data was collected prospectively over a year between March 1, 2003 and February 28, 2004. Details of preanesthetic conditions, anesthetic management, intraoperative events, and perioperative complications of consecutive patients within 24 hours were recorded on a preplanned structured data entry form (Form I). This form was developed according to the THAI study.

A cardiac arrest case was defined as an event requiring resuscitation with chest compressions that occurred in children aged 15 years and younger during anesthesia and the 24-hour postoperative period. An anesthesia-related cardiac arrest was defined as a cardiac arrest that anesthesia personnel or the anesthesia process played at least some roles in its genesis.

The attending anesthesiologist or nurse anesthetist described clinical details of cardiac arrest in another record form (Form II). Then that record form was reviewed by three peer reviewers to determine incidence, suspected causes, contributory factors, outcome, and suggested preventive strategies. Data from form I and II were reviewed independently by at least two reviewers. Any disagreement was discussed and judged to achieve a consensus.

To ensure the reliability of the data among participating hospitals, the anesthesia providers at each site were trained and supervised by well-trained site managers. As well, an internal audit was done by the project's quality assurance team. External auditing was performed by external evaluators from the Clinical Research Collaboration Network.

All data entry forms were reviewed and verified by site managers for accuracy before submitting to the center where process of verification would be done. The site managers or the responsible anesthesia personnel were contacted for verification, correction or completion of the incorrect, doubtful, or missing information. All data was scrutinized at the data management centers before entering into the computer. To ensure the reliability of data entry, the standard double-data entry technique was used.

Data analysis was done by using SPSS version 13. The descriptive statistics were used to summarize the data in terms of frequency and percentage. Chi-square test was used to compare categorical data.

Results

From the database of 25,098 anesthetics performed in children, 50 perioperative cardiac arrests were identified from the data Form I. However, there were only 46 records describing clinical details of cardiac arrests completed in Form II. Therefore, the authors were only able to determine etiology- related to cardiac arrest from 46 anesthetics. Surgical and/or patient-related factors were the most significant etiology of cardiac arrests and deaths. Thirteen cardiac arrests were related to anesthesia resulting mortality of 46% (Table 1). Cases unrelated to anesthesia were predominately in ASA physical status III-V (73%) and in emergency status (70%). Nearly half of these cases (48%) had underlying congenital heart diseases and thirty nine percent were associated with severe trauma problems.

The overall incidence of cardiac arrest from all causes was 19.9:10,000 anesthetics while an incidence of anesthesia-related cardiac arrest was 5.1:10,000 anesthetics. Incidences of overall cardiac

Table 1. Etiology factors of cardiac arrests and their mortality rate

Etiology factor	Number n (%)	Mortality rate n (%)
Anesthesia-related	13 (26)	6 (46)
Surgical and/or patient-related	33 (66)	32 (97)
Inconclusive	4 (8)	2 (50)

arrest and anesthesia-related arrest were significantly higher in infants than older children and in children with ASA physical status III-V than those with ASA physical status I-II (Table 2). Children with ASA III-V were also at risk of death. Incidence of anesthesia-related cardiac arrests in an emergency procedure was 5.4:10,000 whereas in an elective procedure was 4.3:10,000 anesthetics.

In cases of anesthesia-related cardiac arrest, infants younger than 1 year of age accounted for the highest proportion (62%). Congenital heart disease (38%) and prematurity (23%) were the two most common preanesthetic problems. Twenty three percent of arrests occurred during the emergency procedure. Most of the anesthesia-related arrests occurred in the operating room (61%) during induction (23%) or maintenance of anesthesia (38.5%). The most common initial rhythm at the time of arrest or resuscitation was bradycardia (69%). Characteristics of cases and details of events at time of arrest are shown in Table 3-4.

Respiratory-related cardiac arrests accounted for 38% of all cases (Table 5). Out of the five cases, four were associated with airway problems and poor airway management, and three were infants. One patient had underlying severe pulmonary hypertension. He developed hypoxic spell after the occurrence of airway obstruction and light anesthesia during teeth extraction. The other patient had postanesthesia care after cardiac catheterization in the hospital ward and had a delayed detection of airway obstruction due to lack of monitoring there.

Medication-related cardiac arrests accounted for 31% of all cases. Most cases were related to cardiovascular depression effects from the inhalation of anesthesia. A case related to halothane had underlying heart disease. The cases related to sevoflurane or isoflurane were premature and ex-premature babies. The remaining two, were involved in the use of inappropriate drugs. One case with hypovolemic state, cardiac arrest was contributed to the effects of midazolam and atracurium. The other case was an infant with underlying heart disease, cardiac arrest was associated with the vasodilator effect of nitroprusside and nicardipine.

All of cardiovascular-related cardiac arrests were associated with inadequate blood and fluid therapy. The blood bank was the contributory factor of all cases in the cause of delayed blood transfusion during the operation. The details of anesthesia-related cardiac arrest cases and analyses regarding causes, contributory factors and suggested corrective strategies are shown in Table 6-7.

Discussion

The present study provides an insight into origins and outcomes of cardiac arrest with emphasis to anesthesia-related causes in children under relevant practices in Thailand. The incidence of anesthesia-related cardiac arrest in the present study (5.1:10,000) was higher than studies by Tiret et al[3] (3:10,000), Keenan and Boyan[2] (4.7:10,000), Murray et al[5] (1.4:10,000), and Murat et al[9] (0.8:10,000). This differential of incidence rate among the studies is probably from differences in methodologies, and definitions of cardiac arrest related to anesthesia and operations included in the studies.

Table 2. Incidence of perioperative cardiac arrest and death according to age group and ASA physical status

	Total anesthetics No.	Overall				Anesthesia -related			
		Cardiac arrests		Death		Cardiac arrests		Death	
		n	per 10,000 anesthetics	n	per 10,000 anesthetics	n	per 10,000 anesthetics	n	per 10,000 anesthetics
Age (y)									
0-1	5406	26	48.1	19	35.1	8	14.8	2	3.7
> 1-8	10657	12	11.3	10	9.4	2	1.8	1	0.9
> 8-15	9035	12	13.3	11	12.2	3	3.3	3	3.3
0-15	25098	50	19.9	40	15.9	13	5.1	6	2.4
ASA									
I-II	22508	3	1.7	2	0.9	2	0.9	1	0.4
III-V	2522	47	182.4	38	150.7	11	43.6	5	19.8

Table 3. Characteristics of cases

Characteristic	All cardiac arrests (n = 50)	Anesthesia-related cardiac arrests (n = 13)
Age		
0-1 mo	12 (24%)	4 (30.8%)
>1 mo-1 y	14 (28%)	4 (30.8%)
>1-8 y	12 (24%)	2 (15.4%)
>8-15 y	12 (24%)	3 (23%)
Sex		
Male	29 (58%)	8 (61.5%)
Female	21 (42%)	5 (38.5%)
ASA physical status		
1, 2	3 (8%)	2 (15.4%)
3	23 (46%)	11 (84.6%)
4	15 (30%)	0
5	9 (18%)	0
Preanesthetic problems		
Respiratory abnormality	12 (24%)	1 (7.7%)
Infectious disease or sepsis	2 (4%)	0
Congenital heart disease	21 (42%)	5 (38%)
Liver disease	2 (4%)	1 (7.7%)
Renal impairment	2 (4%)	0
Neurological problem	9 (18%)	1 (7.7%)
Anemia	13 (26%)	1 (7.7%)
Prematurity	4 (8%)	3 (23%)
Elective/emergency status		
Elective	24 (48%)	10 (77%)
Emergency	26 (52%)	3 (23%)
Site of operation or procedure		
Cardiac	12 (24%)	1 (7.7%)
Intrathoracic	10 (20%)	3 (23%)
Intracranial	4 (8%)	2 (15.4%)
Intraoral	2 (4%)	1 (7.7%)
Abdomen	13 (24%)	3 (23%)
Extremity	5 (10%)	1 (7.7%)
Spine	1 (2%)	0
Eye	1 (2%)	1 (7.7%)
Cardiac catheterization	2 (4%)	1 (7.7%)

Table 4. Details of events at time of arrest

	All cardiac arrests (n = 50)	Anesthesia-related cardiac arrests (n = 13)
Location		
Operating room	23 (36%)	8 (61.5%)
Intensive care unit	22 (44%)	4 (30.7%)
Ward	4 (8%)	0
Dental room	1 (2%)	1 (7.7%)
Phase of anesthesia		
Induction	3 (6%)	3 (23%)
Intubation	2 (4%)	2 (15.6%)
Maintenance	16 (34%)	4 (38.5%)
Emergence or transport to recovery room	1 (2%)	0
Postoperative	26 (52%)	4 (30.7%)
Not stated	2 (4%)	0
Initial rhythm at time of resuscitation		
Ventricular tachycardia	4 (8%)	1 (7.7%)
Asystole	6 (12%)	2 (15.4%)
Bradycardia	29 (58%)	10 (69%)
Pulseless electrical activity	2 (4%)	0
Not stated	9 (18%)	0

Table 5. Suspected causes of anesthesia-related cardiac arrest and mortality

Suspected cause	n (%) (n = 13)	Mortality n (%)
Medication-related	4 (30.8)	0 (0)
Cardiovascular-related	3 (23.1)	3 (100)
Respiratory-related	5 (38.4)	2 (40)
Multiple etiology	1 (7.6)	1 (100)

Similar to previous studies[1-6], the authors found that incidences of overall cardiac arrest and anesthesia-related arrest were significantly higher in infants than in older children and in children with severe underlying diseases. Prematurity and congenital heart diseases are the underlying indicators of patient-related risk factors as they were the two most common preanesthetic problems in the present study. A large-scale study is needed for further analysis. Keenan and Boyan[2] studied cardiac arrest due to anesthesia in overall population. They found that risk of emergency patients was six times that of elective patients. Gobbo Braz et al[10] also found that the incidence of perioperative cardiac arrest in children undergoing emergency surgery was eightfold higher than in elective surgery. The incidence of anesthesia-related cardiac arrests in emergency procedures of the present study was slightly higher when compared with the incidence in elective procedures (5.4:10,000 vs. 4.3:10,000)

Data from the first 4 years (1994-1997) of the POCA registry[5] showed that medication-related causes, in particular halothane induced cardiovascular depression, was the most common cause of arrest. Recently, reported data for the time period 1998-2004[6] which showed that the proportion of medication-related arrests in this period was lower (20%) than the

Table 6. Details of anesthesia-related cardiac arrest cases

No.	Age	ASA	Preanesthetic problems	Type of surgery	Surgical procedure	Anesthetic technique	Location	Periodat arrest	Initial rhythm at time of resuscitation	Outcome
1	3 m	2	Ex-Premature and vitreous hemorrhage	Elective	PPV	GA	OR	Maintenance	Bradycardia	Recovered
2	11 y	3	Lung mass Anemia	Elective	Thoracotomy to remove tumor	GA	ICU	Postoperative	Asystole	Death
3	5 d	3	Premature and duodenal atresia	Elective	Duodenostomy	GA	OR	Intubation	Bradycardia	Recovered, convulsion 5 hr after arrest
4	4 y	3	TOF	Elective	Cardiac catheterization	IV sedation	ICU	Postoperative	Bradycardia	Recovered, brain death
5	6 m	3	Intracerebral hemorrhage	Emergency	Craniotomy	GA	OR	Maintenance	Bradycardia	Death
6	3 d	3	Premature, ASD, VSD and meningocele	Elective	Dissected Meningocele	GA	OR	Maintenance	Bradycardia	Recovered
7	9 y	3	PDA with severe PHT	Elective	Teeth extraction and filling	GA	Dental room	Maintenance	Bradycardia	Death
8	5 y	3	Severe MR	Elective	Mitral valve repair	GA	OR	Induction	Bradycardia	Recovered
9	4 y	3	Blunt abdominal trauma (ruptured liver)	Emergency	Remove abdominal packing	GA	OR	Induction	Bradycardia	Death at ICU
10	11 d	3	Duodenal atresia jaundice	Emergency	Duodenostomy	GA	OR	Induction	Bradycardia	Recovered
11	1 d	3	TE fistula	Elective	Thoracotomy to repair fistula	GA	ICU	Postoperative	Bradycardia	Death
12	13 y	2	Closed fracture left tibia and femur Anemia	Elective	ORIF with plate and screw	Spinal block	ICU	Postoperative	Asystole	Death
13	4 m	3	PDA and coarctation	Elective	PDA ligation and coarctectomy	GA	OR	Maintenance	Ventricular tachycardia	Recovered

Table 7. Analyses of anesthesia-related cardiac arrest cases

No.	Suspected cause of cardiac arrest	Contributory factors	Suggested corrective strategy
1	Medication-related: Sevoflurane	Human factor: inadequate knowledge or experience	Improving supervision Additional training
2	Inadequate blood/fluid therapy	Human factor: inadequate preoperative preparation Organization factor: blood bank problems	Improving supervision Additional training Quality assurance activity
3	Inadequate oxygenation from tube problem	Human factor: inadequate knowledge or experience	Improving supervision Additional training
4	Airway obstruction	Human factor: improper postanesthesia management Organization factor: no postanesthesia practice guideline for remote anesthesia	Improving supervision Guideline practice for postanesthesia care
5	Inadequate blood/fluid therapy	Human factor: inadequate knowledge and experience Organization factor: blood bank problems	Improving supervision Additional training Quality assurance activity
6	Medication-related: Isoflurane	Human factor: inexperience	Improving supervision Additional training
7	Hypoxic spell Airway obstruction	Human factor: inexperience Organization factor: wrong selection of patient for remote anesthesia	Improving supervision Additional training Guideline practice for remote anesthesia
8	Medication-related: Halothane	Human factor: error of judgment (inappropriate agent)	Improving supervision Additional training
9	Medication-related: midazolam and atracurium Inadequate blood/fluid therapy	Human factor: - inadequate preoperative assessment and preparation - error of judgment (inappropriate agent)	Improving supervision Additional training Improving communication
10	Esophageal intubation and failure mask ventilation	Human factor: inadequate skill and experience Equipment failure: leakage of anesthetic circuit	Additional training Equipment maintenance
11	Inadequate oxygenation from pneumothorax	Human factor: inexperience (delayed detection of pneumothorax)	Improving supervision Additional training
12	Inadequate blood/fluid therapy	Human failure: inexperience Organization factor: blood bank problems	Improving supervision Additional training Improving communication Quality assurance activity
13	Medication-related: vasodilator (nitroprusside and nicardipine)	Human factor: error of judgment (inappropriate agent) Communication failure: need consultation	Improving supervision Additional training Improving communication

1994-1997 period. They explained this change is possibly due to the declining use of halothane in favor of sevoflurane in pediatric anesthetic practice. In Thailand, halothane is used as frequently as sevoflurane in pediatric anesthesia (36% vs. 34%)[8] because of cost constraints. However, the authors found only one case with an underlying heart disease that cardiac arrest was associated with the use of halothane. Although sevoflurane and isoflurane, when compared with halothane cause less myocardial depression[11,12], cardiac arrests associated with sevoflurane and isoflurane still occurred in the present study. The case of cardiac arrests associated with sevoflurane use in the present study occurred during induction with 5% of sevoflurane for an ex-premature baby. The other case occurred during anesthesia maintenance with isoflurane in a premature baby with an underlying heart disease. Other studies[6,10] also reported cardiac arrests associated with sevoflurane in children with ASA physical status 3 or higher.

Therefore, special consideration should be focused on children with prematurity and heart diseases when using any inhalation anesthesia.

In the present study, respiratory-related cardiac arrest was the most common cause of anesthesia-related cardiac arrest. This finding is similar to the study by Gobbo Braz et al[10], which reported respiratory events were the main cause of anesthesia attributable cardiac arrest (71.5%). Most cases from the present study were associated with airway problems and poor airway management. Additional training in airway management, especially in young children is suggested for the anesthesiologists in charge. Moreover, there was an esophageal intubation case associated with a cardiac arrest in a newborn with a full stomach problem. Neonates should be taken care of by specially trained pediatric anesthesiologists.

Most cardiovascular-related cardiac arrests were associated with inadequate preoperative assessment and preparation, which were preventable. Vigilant and cautious anesthesiologists may help reduce this problem. Blood bank was also a contributory factor in delayed blood transfusion. This may be from inadequate blood stock or the prolonged processes of requesting blood. Quality assurance monitoring is suggested.

Two cases of anesthesia outside the operating room were associated with cardiac arrests. One was a patient with a severe underlying disease. This patient should not have been a candidate for anesthesia in the dental room. The other was improper postoperative care in a ward, which had a lack of monitoring facilities. Nurses in the ward were also inexperienced in taking care of patients after sedation. Practice guidelines for remote anesthesia including criteria for patient selection and postoperative care are essential.

In conclusion, the risk of anesthesia-related cardiac arrest was 5.1:10,000 anesthetics with 46% mortality rate. Major risk factors were children younger than 1 year of age and ASA 3-5. Respiratory related-cardiac arrest was the most common cause of anesthesia-related cardiac arrest. Improving supervision, additional training, practice guidelines, efficient blood bank, equipment maintenance, and quality assurance monitoring are recommended corrective strategies to improve the quality of care in pediatric anesthesia.

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การศึกษาการเกิดภาวะหัวใจหยุดเต้นที่เกี่ยวข้องกับการให้ยาระงับความรู้สึกในเด็ก จากฐานข้อมูล Thai Anesthesia Study

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ภูมิหลังและวัตถุประสงค์: *วิเคราะห์ข้อมูลผู้ป่วยเด็กจำนวน 25,098 รายที่มารับบริการทางวิสัญญี จากฐานข้อมูลการศึกษาอุบัติการณ์การเกิดภาวะแทรกซ้อนทางวิสัญญีในประเทศไทย (THAI Study) เพื่อหาอุบัติการณ์ สาเหตุ ปัจจัยส่งเสริม ของภาวะหัวใจหยุดเต้นที่เกี่ยวข้องกับการให้ยาระงับความรู้สึกในเด็ก ตลอดจนเสนอแนะแนวทางการแก้ไข*

วัสดุและวิธีการ: *เป็นการศึกษาสหสถาบันแบบพรรณนาไปข้างหน้า ในผู้ป่วยที่ได้ยาระงับความรู้สึกในโรงพยาบาล 20 แห่งในประเทศไทย ระหว่างวันที่ 1 มีนาคม พ.ศ. 2546 ถึงวันที่ 28 กุมภาพันธ์ พ.ศ. 2547 รวบรวมข้อมูลผู้ป่วยเด็กที่อายุน้อยกว่าและเท่ากับ 15 ปีที่เกิดภาวะหัวใจหยุดเต้นระหว่างการให้ยาระงับความรู้สึก ในห้องพักฟื้น จนถึง 24 ชั่วโมงหลัง การผ่าตัด และทบทวนวิเคราะห์โดยผู้วิเคราะห์อย่างน้อย 2 คน*

ผลการศึกษา: *อุบัติการณ์การเกิดภาวะหัวใจหยุดเต้นเกี่ยวข้องกับการให้ยาระงับความรู้สึกในเด็กเป็น 5.1 ต่อ 10,000 ราย และเป็นสาเหตุให้ผู้ป่วยเสียชีวิตร้อยละ 46 เกิดในเด็กที่มีอายุน้อยกว่าและเท่ากับ 1 ปี คิดเป็น ร้อยละ 61 ของจำนวนทั้งหมด พบอุบัติการณ์การเกิดภาวะหัวใจหยุดเต้นรวมทั้งหมดและที่เกี่ยวข้องกับการให้ยาระงับความรู้สึกในเด็กที่มีอายุน้อยกว่าและเท่ากับ 1 ปีมากกว่าเด็กโต และในเด็กที่จัดอยู่ใน ASA class 3-5 มากกว่าเด็กที่จัดอยู่ใน ASA class 1-2 พบว่าส่วนใหญ่เกิดในห้องผ่าตัด (ร้อยละ 60) ช่วงการนำสลบ หรือ ระหว่างการให้ยาระงับ ความรู้สึก (ร้อยละ80) โดยสาเหตุส่วนใหญ่ของภาวะหัวใจหยุดเต้นเกี่ยวข้องกับการให้ยาระงับความรู้สึกเกี่ยวข้องกับปัญหาทางระบบหายใจ แนวทางแก้ไขเพื่อพัฒนาการให้บริการวิสัญญีแก่ผู้ป่วยเด็กได้แก่ การมีผู้เชี่ยวชาญ ให้คำแนะนำดูแล การฝึกอบรมเพิ่มเติมแก่บุคลากรเฉพาะในการดูแลผู้ป่วยเด็ก การมีแนวทางการปฏิบัติที่ การพัฒนาคลังเลือดให้มีประสิทธิภาพ การดูแลอุปกรณ์และเครื่องมือให้สามารถใช้งานได้อย่างมีประสิทธิภาพ การจัดให้มีระบบประกันคุณภาพ*

สรุป: *อุบัติการณ์การเกิดภาวะหัวใจหยุดเต้นเกี่ยวข้องกับการให้ยาระงับความรู้สึกในเด็กเป็น 5.1 ต่อ 10,000 ราย เด็กอายุน้อยกว่าและเท่ากับ 1 ปี และเด็กที่จัดอยู่ใน ASA class 3-5 เป็นกลุ่มเสี่ยง โดยมีสาเหตุส่วนใหญ่เกี่ยวข้องกับปัญหาในการดูแลทางเดินหายใจและยาที่ใช้ในระหว่างการระงับความรู้สึก*