นิพนธ์ต้นฉบับ • Original Article

อุบัติการณ์ของการเปลี่ยนท่อช่วยหายใจเมื่อใช้สูตรโมโตโมยาในการคำนวณขนาดท่อช่วยหายใจแบบมีกระเปาะลมสำหรับผู้ป่วยเด็ก

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Incidence of Tube Changing when Using Motomoya Formula for Calculation of Cuffed Endotracheal Tube Size in Pediatric Patients

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หลักการและวัตถุประสงค์: ปัจจุบันท่อช่วยหายใจแบบมีกระเปาะถูกพิสูจน์แล้วว่าปลอดภัยสำหรับผู้ป่วยเด็ก โดยมีสูตรคำนวณคือสูตรของ Motomoya [(อายุ/4) +3.5] และสูตรของ Khine [(อายุ/4) +3.0] ทว่าในปัจจุบันยังไม่มีความชัดเจนว่าสูตรใดมีความเหมาะสมในการคำนวณขนาดท่อช่วยหายใจ การศึกษาครั้งนี้จึงมีวัตถุประสงค์เพื่อศึกษาอัตราการต้องเปลี่ยนท่อช่วยหายใจไปเป็นขนาดเล็กลงเมื่อใช้สูตรของ Motomoya

วิธีการศึกษา: ผู้เข้าร่วมการศึกษาเป็นผู้ป่วยเด็กจำนวน 50 ราย ที่มีแผนเข้ารับการผ่าตัดแบบไม่เร่งด่วนด้วยการระงับความรู้สึกทั่วตัว เงื่อนไขในการเข้าร่วมคืออายุระหว่าง 2 ถึง 10 ปี และ ASA physical status 1 หรือ 2 เงื่อนไขในการตัดออกคือความเสี่ยงต่อการสำลักอาหารหรือภาวะใส่ท่อช่วยหายใจยาก ขนาดท่อช่วยหายใจคำนวณโดยใช้สูตรของ Motomoya และการใส่ท่อช่วยหายใจทำโดยบุคลากรทางวิสัญญีผู้มีประสบการณ์ด้วยการดูกล่องเสียงโดยตรง (ขนาดท่อที่ใช้คือ 4.0 สำหรับอายุ 2-3.5 ปี ขนาด 4.5 สำหรับอายุ 3.5-5.5 ปี ขนาด 5.0 สำหรับอายุ 5.5-7.5 ปี ขนาด 5.5 สำหรับอายุ 7.5-9.5 ปี และ 6.0 สำหรับ 9.5-10 ปี)

ผลการศึกษา: สามารถใส่ท่อช่วยหายใจให้ผู้ป่วยได้ทุกคน ไม่มีผู้เข้าร่วมที่ต้องเปลี่ยนเป็นท่อช่วยหายใจขนาดเล็กลง ค่าเฉลี่ยของคาร์บอนไดออกไซด์ ณ จุดที่หายใจออกสุดคือ 34.1 ± 2.43 มม.ปรอท ค่าเฉลี่ยความดันทางเดินหายใจสูงสุดคือ 16.86 ± 3.86 ซม.น้ำ ผู้เข้าร่วมทุกคนไม่มีภาวะแทรกซ้อนจากการใส่ท่อช่วยหายใจในช่วงสองวันหลังการผ่าตัด

Background and Objectives: Cuffed endotracheal tube has been proven as safe to use in pediatric population. Two formulae have been proposed for calculation of tube size of cuffed endotracheal tube: Motomoya's formula [(Age/4) +3.5] and Khine's formula [(Age/4) +3.0]. However, it is not clear which formula is appropriate for calculation of endotracheal tube size. The present study aimed to investigate the frequency of tube exchange to a smaller tube size when the starting tube size is calculated using Motomoya's formula.

Methods: Fifty pediatric patients who had been scheduled for elective surgery under general anesthesia were recruited. Inclusion criteria were age between 2 to 10 years old, and ASA physical status 1 or 2. Exclusion criteria were increased risk of pulmonary aspiration or difficult airway. Cuffed endotracheal tube size was calculated using Motomoya's formula and patients were intubated by experienced anesthetic personnel using direct laryngoscopy. (Tube size 4.0 for age 2-3.5 years old, size 4.5 for 3.5-5.5 years old, size 5.0 for 5.5-7.5 years old, size 5.5 for 7.5-9.5 years old and 6.0 for 9.5-10 years old.

Results: All patients were successfully intubated. None required exchanging to a smaller tube size. Mean end tidal CO_2 was 34.1 ± 2.43 mm Hg. Mean of peak airway pressure was 16.86 ± 3.86 cm H_2O. None of the patients had complications related to intubation wihtin two days after the operation.

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สรุป: สูตรของ Motomoya เหมาะสมที่จะเป็นสูตรคำนวณสำหรับท่อช่วยหายใจแบบมีกระเปาะในผู้ป่วยเด็ก

Conclusion: Motomoya's formula is appropriate as a starting formula for cuffed endotracheal tube size in pediatric population.

Keywords: pediatric, cuffed endotracheal tube, size

ศรีนครินทร์เวชสาร 2561; 33(3): 206-10. • Srinagarind Med J 2018; 33(3): 206-10.

Introduction

In the past, physicians frequently chose uncuffed endotracheal tubes for pediatric patients due to better safety profile and fewer respiratory complications compared to cuffed endotracheal tube. This was mainly because old generations cuffed endotracheal tubes had high pressure cuffs and thus were not suitable for pediatric airway anatomy. Nevertheless, modern cuffed endotracheal tubes have low-pressure and high-volume cuffs, and have been shown to be safe in pediatric patients[1]. Currently, cuffed endotracheal tube is recommended for pediatric anesthesia, chronically ventilated children beyond the neonatal period, and in emergency situations[2].

There are many benefits to using appropriately sized cuffs to allow complete sealing of the airway. First, it decreases the rate off tube exchange[3], thereby reducing trauma to the airway and stress on the patients. Second, it reduces anesthetic gas leakage and operating room pollution and allows for a more accurate measurement of exhaled gas concentration[4].

Two formulae have been proposed for calculation of tube size of cuffed endotracheal tube in pediatric patients: Motomoya's formula [(Age/4) +3.5], which will yield bigger tube sizes[5]; and Khine's formula [(Age/4) +3.0], which will yield smaller ones[6].To the best of our knowledge, there has not been a study determining if one is more suitable than the other as the starting formula for tube size calculation.

Sample Size Calculation

As there was no information regarding incidence of tube changing using these two formulas, there was no basis for sample size calculation. Therefore, we conducted a pilot study to gauge the incidence of tube changing using Motomoya formula. The pilot study followed the same protocol as described later in the present paper. Out of 20 patients in the pilot study, none required tube changing. However, this did not mean that the true incidence was zero. Rather, according to the Rule of Three as described by Hanley and Lippman-Hand[7], not encountering any problem in 20 cases would mean that there was 95% confidence that the true incidence was 15% or lower.

With this expectation that Motomoya formula would require tube changing in 15% of the cases, we performed a sample size calculation for a randomized controlled trial between the two formulas, using the incidence of tube changing as the primary end point with an expectation that Khine formula would reduce the incidence of tube changing by at least 10%. Power was set at 0.8 and significance threshold was $p< 0.05$.

However, the above calculation yielded a large, infeasible sample size. Therefore, instead of comparing the two formulas using an experimental design, we decided to conduct the present study to determine the incidence of tube changing using Motomoya formula. A low incidence would indicate that Motomoya formula, which predicts bigger tube sizes and hence less airway resistance, is appropriate as the starting formula for size calculation of endotracheal tube for pediatric patients. A high incidence would indicate that Motomoya formula predicts tube sizes that are too big, and therefore Khine formula, which predicts smaller tube sizes, is more appropriate.

The sample size of 50 was chosen because, according to the Rule of Three, not having to change tube in 50 cases would mean that we could assume, with 95% confidence, that the true incidence of tube changing would be 5% or lower, a number that we considered low enough to not be of clinical significance.

Aims of the Present Study

With the above considerations, the primary aim of the present study was to investigate the rate of tube exchange down to a smaller size when Motomoya's formula was used for initial calculation. Secondary measurements included number of intubation attempts, size of endotracheal tube used, mean peak airway pressure, mean end-tidal carbon dioxide, and airway complications within 48 hours.

Methods

The present study is a prospective, descriptive study. Khon Kaen University Ethics Committee in Human Research gave approval for the study (Reference code HE571233). Data collection took place at Srinagarind Hospital, Faculty of Medicine, Khon Kaen university.

The present study included pediatric patients with ASA physical status I or II who were 2 to 10 years old, and were scheduled to undergo elective surgery under general anesthesia requiring tracheal intubation. Informed consent was obtained from the parents of each subject. Subjects were excluded from the study if they had histories of airway abnormality, anticipated difficult airway, severe pulmonary diseases, or related difficult airway conditions, such as tracheal stenosis, that could alter the size of the trachea. Patients with Down syndrome or Pierre Robin syndrome were also excluded.

Study protocol started once the patient was in the operating theater with monitoring equipment on. First, all patients received 100% oxygen for preoxygenation for 3 minutes on the operating bed while a parent was still present in the theater. Then induction of anesthesia was done with either sevoflurane 8% with oxygen flow 6 liters per minute or intravenous propofol 2 mg/kg. Following induction of anesthesia, cisatracurium 0.2 mg/kg was given. At 5 minutes after injection of cisatracurium, an experienced anesthesia provider (a board-certified anesthesiologist; a third-year anesthesia resident; or an anesthesia nurse with at least 3 years of experience) intubated the subject using the selected size of endotracheal tube, as calculated by using Motomoya's formula in Table 1. Depth of tube was assessed by the intubating personnel by passing the cuff just beyond the true vocal cords. If the endotracheal tube could not be passed into the trachea, another endotracheal tube that was 0.5 cm shorter in diameter (the size that Khine's formula would have predicted) would be used instead.

After intubation, a leak test was performed by occluding the pressure relief valve to 30 cm H_2O and performing positive pressure ventilation by manually compressing the anesthetic bag. This was done before the cuff was inflated. A stethoscope was placed over the trachea to detect the sounds of a leak. A leak pressure of 30 cm H_2O or more indicated that the tube was too big. A tube deemed too big would be replaced by another tube that was 0.5 cm shorter in diameter (the size that Khine's formula would have predicted). The leak pressure would be checked again, and the new tube would be removed if it was still too big. These steps were iterated until a proper tube size had been reached. If there was a leak at a pressure lower than 30 cm H_2O, then the cuff would be inflated as necessary to produce a leak pressure between 25 and 30 cm H_2O.

The ventilator was set to target a tidal volume of 6-8 ml/kg of body weight and a peak airway pressure less than 25 cm H_2O. Respiratory rate was then adjusted to reach target end-tidal carbon dioxide of 35 mm Hg. The number of intubation attempts, size of tube, peak airway pressure, and end-tidal carbon dioxide level were recorded.

Statistical analysis was done using SPSS 22, using mean, standard deviation (SD) and 95% confidence interval (CI).

Table 1 Size of cuffed endotracheal tube calculated by Motomoya's formula

Aged	Cuffed endotracheal tube size
2 years - 3 years 6 months	4
> 3 years 6 months - 5 years 6 months	4.5
> 5 years 6 months - 7 years 6 months	5
> 7 years 6 months - 9 years 6 months	5.5
> 9 years 6 months - 10years	6

Results

The study included 50 subjects ranging in age from 2 to 10 years old. There were 27 boys and 23 girls. Full demographic data can be found in Table 2. The number of times each tube size was used and the number of cases requiring tube exchange are described in Table 3. Four subjects were in group “size 4”, 11 subjects were in group “size 4.5”, 14 subjects were in group “size 5”, 14 subjects were in group “size 5.5”and 7 subjects were in group “size 6” as present in table 2. All subjects could be intubated in the first attempt and had a leak pressure of less than 30 cm H_2O, indicating that the tubes were appropriately sized. No patient required tube exchanging. Peak airway pressure did not exceed 20 cm H_2O in all subjects and $ETCO_2$ ranged between 30 to 35 mm Hg.

All subjects were followed up for 48 hours after operation. No airway complications were found.

Table 2 Demographic data based on tube size used

Group		Age(Months)	BW (Kg)	Gender		ASA	
ETT No.	N	Mean ± SD	Mean ± SD	Male N (%)	Female N (%)	1 N (%)	2 N (%)
4	4	30.2 ± 1.70	11.03 ± 0.56	2 (50.0)	2 (50.0)	3 (75)	1 (25)
4.5	11	53.36 ± 8.90	16.85 ± 3.21	5 (45.5)	6 (54.5)	7 (63.6)	4 (36.6)
5	14	76.21 ± 7.64	19.06 ± 4.18	9 (64.3)	5 (35.7)	10 (71.4)	4 (28.6)
5.5	14	101.29 ± 5.77	29.16 ± 9.02	8 (57.1)	6 (42.9)	10 (71.4)	4 (28.6)
6	7	116.43 ± 1.81	36.70 ± 17.58	3 (42.9)	4 (57.1)	4 (57.1)	3 (42.9)
Total	50			27 (54)	23 (46)	34 (68)	16 (32)

Table 3 Exchange rate, attempt, $ETCO_2$, PAW

Group (ETT no.)	Attempt	# of cases requiring tube exchange	$ETCO_2$ (mm Hg)	PAW (cm H_2O)
4	4	0	32.5 ± 1.7	19.2 ± 7.8
4.5	11	0	35.0 ± 1.9	15.1 ± 2.7
5	14	0	33.0 ± 1.9	17.1 ± 2.6
5.5	14	0	35.1 ± 2.1	15.9 ± 2.9
6	7	0	34.1 ± 1.2	19.4 ± 5.0
Total	**50**	**0**	**34.1 ± 2.4**	**16.8 ± 3.8**

Discussion

Altun et al described the benefits of using ultrasonography in determining proper endotracheal tube size in pediatric patients over using age-based or height-based formulae[8]. While this is approach seems promising, availability of ultrasonographic machines and technical difficulties remain a significant barrier. Determining the formula that will provide the highest chance of best-fit for tube size in pediatric patients remains important. In the present study, we provide data to back up Motomoya’s formula as the more preferred one of the two age-based formulae.

In the present study, all subjects could be intubated in the first attempt, thus no exchanging of endotracheal tube was required. It should be noted that this does not mean that Motomoya’s formula will never produce a tube size that is too big for prospective patients. Hanley and Lippman-Hand described methods for calculation of 95% confidence interval when the numerator is zero[7]. In summary, observing zero event does not mean that the event will never happen, just that the incidence is likely very low. Using the calculation methods described in their article, our results predict that Motomoya’s formula may still produce tube sizes that are too big in 6% of patients.

Every patient's ventilatory settings could be adjusted to reach the required parameters ($ETCO_2$ 30-40 mm Hg and peak airway pressure less than 30 Cm H_2O), indicating that Motomoya's formula produced tube sizes that were adequate for proper ventilation.

There was a question of whether to start with a tube that is big and change to small if necessary, or vice versa. In general, it is preferred that a bigger tube be used first, as it reduces airway pressure, and it also reduces work of breathing if the patient is breathing spontaneously. Considering this approach and the results of the present study, Motomoya's formula is preferred to Khine's formula and should be the starting point for tube size calculation in pediatric patients.

Some factors may mandate bigger or smaller tube sizes than those predicted by the age-based formulae, such as the presence of airway abnormalities or pulmonary diseases, or when patients have height or weight that are outside normal limits for their age. However, such conditions were excluded from the present study, and thus we can make no claims as to how the results present here apply in those situations.

Conclusion

Motomoya's formula is appropriate as a starting formula for cuffed endotracheal tube size in pediatric population without airway or pulmonary abnormalities.

Limitations and Future Directions

The sample size is relatively small and follow up lasted only 48 hours. Furthermore, to directly compare the two formulae, a randomized controlled trial may be needed. Future studies should try to include longer follow-ups and a larger sample size.

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