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Review

The impact of laryngeal mask versus other airways on perioperative respiratory adverse events in children: A systematic review and meta-analysis of randomized controlled trials

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ABSTRACT

Background: Increasing studies have shown that the use of laryngeal mask airways (LMAs) improved the perioperative respiratory adverse events (PRAEs) in children. However, the results of some of these studies still remained controversial as their sample sizes were small. A systematic review and meta-analysis was designed to evaluate the impact of LMAs in decreasing PRAEs in children.
Methods: We searched the Cochrane Library, PubMed, EMBASE and Web of Science up to May 29, 2018 to identify relevant randomized controlled trials (RCTs) which analyzed and evaluated the impact of LMAs in decreasing PRAEs in children. Participants were randomly assigned to receive LMAs (the intervention group) or other airways (the control group). We studied PRAEs which included breath apnea, laryngospasm, desaturation, cough, fever, pulmonary rales and pulmonary infection. Risk ratio (RR) with 95% confidence intervals (CIs) were estimated to compare the outcomes of the groups. We also performed subgroup analysis and sensitivity analysis to evaluate the impact of LMAs on further decreasing PRAEs. Two reviewers assessed the trial quality and extracted the data independently. All statistical analyses were performed using the standard statistical procedures provided in the Review Manager 5.2.
Results: Twelve RCTs (N = 1577 participants) were identified. Comparing with other airways, significant reduction were found in the overall PRAEs (RR 0.52, 95% CI 0.39–0.70; $P < 0.0001$), major PRAEs (RR 0.47, 95% CI 0.29–0.79; $P = 0.004$) as well as minor PRAEs (RR 0.57, 95% CI 0.45–0.74; $P < 0.0001$) in patients managed with LMAs. When compared with endotracheal tubes (ETTs), LMAs also significantly reduced PRAEs. Further analysis also found that LMAs reduced the incidences of postoperative cough (RR 0.44, 95% CI 0.31–0.63; $P < 0.00001$), pulmonary rales (RR 0.62, 95% CI 0.44–0.87; $P = 0.006$) and infections (RR 0.28, 95% CI 0.13–0.61; $P = 0.001$) in children.
Conclusions: LMAs reduced the incidences of many PRAEs in children and should be used as one of anaesthesia methods for children.

1. Introduction

Perioperative respiratory adverse events (PRAEs) as one of the most common critical complications encountered in anaesthesia in children, may have a strong impact on recovery of children from surgery [1–4]. The incidence of PRAEs was reported to be 15% and it was higher in infants [5,6]. PRAEs are clinically significant events that account for about three-quarters of critical incidents and a third of cardiac arrests in anaesthetised children. Infants and young children have high oxygen demands and low oxygen reserves, making them more susceptible to hypoxaemia. The incidence of PRAEs decreases by up to 11% per year with increasing age. Many PRAEs contribute to anaesthesia-related cardiac arrests in children [5].

A significant positive correlation exists between airway management and increased incidences of PRAEs, such as cough, laryngospasm, bronchospasm, arterial oxygen desaturation, apnea or breath holding, hospital readmission, and even death [3,6,7]. Endotracheal tubes (ETTs) have been the traditional choice of airway device in children.

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ETTs, particularly cuffed ones, reliably secure the airway and protect it from aspiration. The use of laryngeal mask airways (LMAs) is increasing but remains less common than the use of ETTs in children. LMA is easier to insert and minimizes direct mechanical stimulation of the airway due to its position being above the larynx, it is often assumed to be less secure in infants than in older children [8]. LMAs in younger children are more frequently associated with partial obstruction of the glottis, insertion success and quality of ventilation [8,9]. A study in which the airway management was done by one anaesthetist, there were higher rates of suboptimal LMA positioning by use of ultrasound [10].

Observational data from our group suggested that the use of an endotracheal tube was associated with an increased risk of PRAEs in infants compared with LMA [6]. To date, several randomized controlled trials (RCTs) have compared the use of LMAs and ETTs in the paediatric populations and have shown LMAs to be either advantageous or equivalent to ETTs [11–25]. A systematic review conducted by Yu et al. reported clinically significant lower incidences of laryngospasm in emergency, post-operative voice hoarseness and coughing with the use of LMA in adults than with ETT [26]. A meta-analysis by Patki et al. which included 1242 children aged younger than 12 years found a decreased risk of sore throat, coughing, and bronchospasm using LMA than ETT [27].

The role of LMAs in the management of young children still remains controversial in the paediatric anaesthesia community, with many institutions mandating the use of ETTs. To date, and to our knowledge, no robust evidence shows LMAs could reduce the incidence of perioperative PRAEs in children undergoing general anaesthesia. We thus designed the present meta-analysis of RCTs to comprehensively compare and analyze the incidence of PRAEs in children using LMA or other airways.

2. Methods and materials

2.1. Criteria for inclusion of the studies

We included studies which were: a. designed as RCTs that compared PRAEs using LMAs versus ETTs or other airways; b. included participants who underwent surgery excluding chest or lung surgery. Studies were excluded if they met the following criteria: a. experimental trials on animals or non-human studies; b. designed as non-RCTs; c. abstracts, letters, editorials, expert opinions, reviews, case reports; d. did not receive LMA; e. participants who had other severe respiratory diseases which may influence the outcomes and incidence of PRAEs; f. studies without sufficient data or did not meet our including criteria.

2.2. Types of outcome measures

Definition of outcomes:

(1) Major PRAEs: including breath holding or apnea, laryngospasm and bronchospasm;
(2) Minor PRAEs: including arterial oxygen desaturation, cough, fever, pulmonary rales and pulmonary infections;
(3) Overall PRAEs: including major or minor PRAEs or both of them.

The primary outcomes:

(1) The impact of LMAs on the incidences of overall and major PRAEs when compared with other airways;
(2) The impact of LMAs on the incidences of overall and major PRAEs when compared with ETTs.

Secondary outcomes:

(1) The impact of LMAs on the incidences of minor PRAEs when compared with other airways;
(2) The impact of LMAs on the incidences of minor PRAEs when compared with ETTs.

The incidences of event were monitored from initiation of anaesthesia until discharge from the post anaesthesia care unit. Events were considered to be postoperative if they occurred after transfer to the post anaesthesia care unit.

2.3. Search strategy

We searched the Cochrane Library, PubMed, EMBASE and Web of Science up to May 22, 2018. Our searching terms were: (1) “infant*” OR “children” OR “paediatric*”; (2) “laryngeal mask*” OR “facemask*” OR “tracheal tube*” OR “anaesthesia”; (3) “adverse event*” OR “complication*” OR “cough” OR “laryngospasm” OR “bronchospasm” OR “desaturation” OR “apnea” OR “breath holding” OR “fever” OR “infection*”. The search strategy was: (1) AND (2) AND (3). Other related references we read were also searched online for the full texts. Any of these references which met our including criteria were included in this meta-analysis. Two assessors independently screened the titles and abstracts of the studies. For the relevant studies, the full texts were obtained for further evaluation.

2.4. Quality assessment and data extraction

Two reviewers assessed the quality of each study using the previously validated 5-point Jadad scale [28]. Studies with scores of 3 or more were considered as high quality. In addition, the risk of bias for each RCT and the risk of bias across all RCTs were evaluated and shown with figures generated by the RevMan 5.2 software [29].

Data for the analysis of PRAEs of LMAs versus ETTs or other airways for children were extracted independently by two reviewers. Any disagreement was resolved through discussion. The extracted contents, including study demographics, publication years, interventions, mean age, main inclusion criteria and outcomes of each study, were displayed using a standardized form. Data collected were input into the RevMan 5.2 software for analysis [29].

2.5. Statistical analysis

The data of comparable outcomes between the LMAs groups and the other airways groups were combined-analyzed using the standard statistical procedures provided in RevMan 5.2 [29]. The incidences of PRAEs in both the treatment groups were measured with the risk ratio (RR) with its 95% confidence intervals (CIs). The heterogeneity between the studies was evaluated by the chi-square-based Q statistical test [30], with the P_h value and I^2 statistic, ranging from 0% to 100%, to quantify the effect of heterogeneity. A $P_h \leq 0.10$ was deemed to represent significant heterogeneity [31], and pooled RRs was estimated using a random-effect model (the DerSimonian and Laird method [32]). On the contrary, if statistical heterogeneity in study was not observed ($P_h > 0.10$), a fixed effects model (the Mantel–Haenszel method [33]) was used. The effects of outcome measures were considered to be statistically significant if the pooled RRs with 95% CI did not overlap with 1. We performed subgroup analysis for the pooled results of LMAs versus ETTs for PRAEs. In addition, we also analyzed the impact of LMAs versus other airways according to the ASA class (I–II vs. I–III) and sample size ($\leq$100 pts vs. $>$ 100 pts).

This work has been reported in line with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and AMSTAR (Assessing the methodological quality of systematic reviews) Guidelines.

Table 1
The characteristics of included studies for meta-analysis.

Study/Year	Country	ASA class	Sample size	Mean age (year)	Interventions	Follow-up time	Anaesthesia	Inclusion Criteria	Outcomes
Drake-Brockman TF et al. 2017	Australia	NR	181	0–1	LMA vs. ETT	24 h postoperative	S/I+F	Age 0–12 mo; undergoing general anaesthesia with anticipated fentanyl dose 1 μg/kg or lower.	The primary outcome was incidence of PRAE, assessed in the intention-to-treat population.
Gharaei B et al. 2011	Iran	II	145	2.8	LMA vs. FM	7 day postdischarge	S	Age 1–12 year; uncomplicated URTI; ASA II.	Cough, apnea, bronchospasm, laryngospasm, desaturation, vomiting, sore throat, hypotension, dysrhythmia, hospital readmission, cardiac arrest, and death.
Huang HJ et al. 2013	China	I, II	76	1–12	LMA vs. ETT	24 h postoperative	M + propofol + sufentanil + S	Age 1–12 year; URTI; ASA I–II.	Desaturation, fidgety, sore throat, and laryngospasm.
Lee JH et al. 2014	Korea	I, II	63	4–72 months	i-gel™ vs. LMA	PACU	NR	Age 4–72 months; ASA I–II.	The rates of successful insertion; Complications (Cough, Blood-tinged equipment)
Tait AR et al. 1998	USA	I, II	82	3.7	LMA vs. ETT	1 day postoperative	H ± I	Age 3 mo–16 y; uncomplicated URTI; ASA I–II.	Cough, laryngospasm, bronchospasm, breath holding, dysrhythmia, desaturation, sore throat, vomiting, nausea, URTI worsening, and hospital readmission.
Tartari S et al. 2000	Italy	I, II	84	3.5	LMA vs. ETT	6 h postoperative	H or propofol + F + I.	Age 6 mo to 12 y, ASA I–II, chronic URTI symptoms.	Laryngospasm, stridor, dysphonia, cough.
Wakhloo R et al. 2006	USA	NR	40	3.8	LMA vs. ETT	PACU	H	Clear rhinorrhea and mild cough.	Cough, laryngospasm, bronchospasm, breath holding, secretions, airway obstruction, and desaturation.
Jiang YZ et al. 2011	China	I–III	126	0.5–1	LMA vs. ETT	NR	M + K	Age 0.5–1 year; ASA I–II.	The incidence of anesthetic complications.
Liu Q et al. 2017	China	I–II	106	3.28 ± 1.17	LMA vs. ETT	3 day postoperative	M + I	Age 3.28 ± 1.17 year; ASA I–II.	Cough, fever, pulmonary infection.
Luo CS et al. 2014	China	I–III	200	2.02 ± 0.33	LMA vs. ETT	24 h postoperative	F + I	Mean age of 2.02 ± 0.33 y, ASA I–III, received selective surgery.	The incidence of anesthetic complications.
Ma YJ et al. 2013	China	I–III	134	5 mo − 1.5 y	LMA vs. ETT	PACU	M + K	Age 5mo–1 year; ASA I–III.	The incidence of PRAEs.
Xu K et al. 2014	China	I–III	120	5–16 mo	LMA vs. ETT	PACU	M + I	Age 5–16 mo year; ASA I–III.	The incidence of anesthetic complications.
Jamil SN et al. 2009	India	I–II	100	2–10	LMA vs. ETT	24 h	S/I+F	ASA I and II children weighing between 10 and 20 kg in the range of 2–10 years of age, scheduled for elective surgery	Pressure ventilation, its haemodynamic changes and postoperative complications.
Lalwani J et al. 2010	India	I–II	60	2–8	LMA vs. ETT	24 h	S	ASA I–II, weight 10–20 kg, age 2–8 years of undergoing elective surgeries of 30–60 min duration	The number of attempts, Haemodynamic responses, incidence of post-operative respiratory complications cough and bronchospasm, soft tissue trauma, aspiration and hoarseness/sore throat.
Sinha A et al. 2007	India	I–II	60	6 mo − 8 y	LMA vs. ETT	24 h	8%S/O_2/N_2O,NBA	ASA I–II children, 6 months to 8 years, scheduled for elective laparoscopic surgeries (duration of carboperitoneum < 60 min)	The incidence of anesthetic complications.

PRAEs = perioperative respiratory adverse events. ASA = American Society of Anesthesiologists. LMA = laryngeal mask airway. ETT = endotracheal tube. FM = facemask. NBA = neuromuscular blocking agents. PACU = postanesthesia care unit. URTI = upper respiratory tract infection. S = sevoflurane. I = ssoflurane. F = fentanyl. M = midazolam. H = halothane. K = ketamine. NR = not reported.

Table 2
The pooled results of each PRAEs regarding to LMAs versus other airways.

PRAEs	Pooled results			Heterogeneity		
	RR	95% CI	*P* value	I^2	P_h value	Analytical effect model
Breath apnea	0.89	0.49, 1.64	0.71	0%	0.58	Fixed-effect model
Laryngospasm/Bronchospasm	0.46	0.23, 0.92	0.03*	57%	0.02	Random-effect model
Desaturation	0.73	0.51, 1.03	0.07	38%	0.17	Fixed-effect model
Cough	0.41	0.29, 0.58	< 0.00001*	0%	0.73	Fixed-effect model
Fever	0.44	0.19, 1.03	0.06	0%	0.54	Fixed-effect model
Pulmonary rales	0.62	0.44, 0.87	0.006*	0%	0.70	Fixed-effect model
Pulmonary infection	0.28	0.13, 0.61	0.001*	0%	0.94	Fixed-effect model

PRAEs, Perioperative respiratory adverse events; RR, relative ratio; CI, confidence intervals.

3. Results

3.1. Retrieval results and study characteristics

At the beginning of the search, 1355 records of citations were obtained; 1048 records were obtained after duplicates were removed. After screening the titles and abstracts of the 1048 citations, 986 studies were excluded preliminarily and 62 studies were chosen to obtain the full texts for further evaluation. After reading the full texts of the 62 studies, 47 studies were further excluded (4 studies for review articles [26,27,34,35], 2 for wrong comparisons [36,37], and 41 for the lack of available data or wrong aims). Eventually, 15 studies [11–25] (N = 1577 participants) were included in this meta-analysis. The sample sizes ranged from 40 to 200 patients (Tables 1 and 2).

The detailed search process and summary of studies are shown in the study flow diagram (Fig. 1). The other characteristics of each study are shown in Table 1.

Additionally, the risk-of-bias graphs were generated to further identify the risk of bias of the included studies. The risk of bias for each RCT was presented as a percentage across all the included studies, and the risk-of-bias item for each included study was displayed (Figs. 2 and 3). The risk-of-bias graphs indicated generally good methodological quality. Selection issues were having a low risk of bias in these studies. A high risk of bias was mainly on attrition bias. An unclear risk of bias was mainly observed in performance and other biases. A low risk of bias was also observed in reporting bias.

3.2. Impact of LMAs on overall PRAEs

A total of 16 studies were included for analysis of the impact of LMAs on overall PRAEs. As shown in Fig. 4, a significant result was obtained with the pooled RR of 0.49 (95% CI 0.36–0.65; $P < 0.00001$) on comparing the impact of LMAs and other airways in reduction of overall PRAEs in children. In addition, when comparing LMAs with

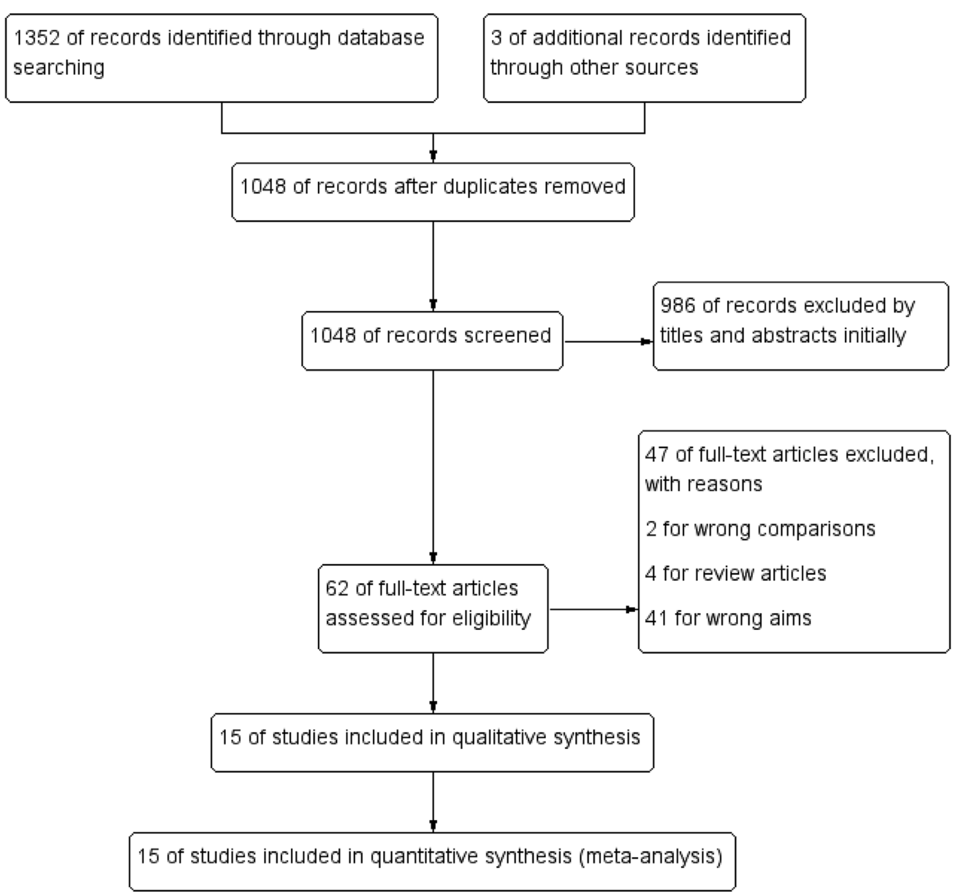

Fig. 1. Flow diagram showing the search strategy for studies included in this systematic review and Meta-analysis.

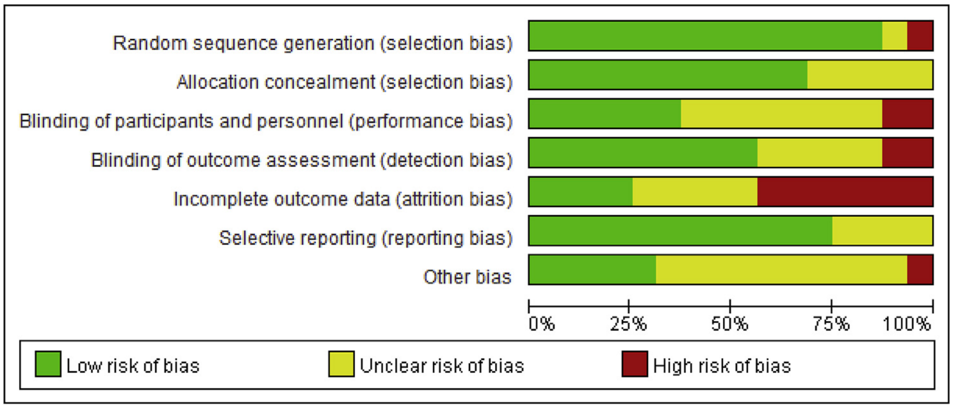

Fig. 2. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

ETTs, a significant reduction of overall PRAEs was also found in the LMAs groups, with a pooled RR of 0.41 (95% CI 0.28–0.58; $P < 0.00001$) (Table 3). The pooled analyses were estimated using the random-effect models because significant heterogeneity ($P_h < 0.00001$, $I^2 = 85\%$ and $P_h < 0.00001$, $I^2 = 83\%$) among the studies was found.

3.3. Impact of LMAs on major PRAEs

A total of 12 studies were included for analysis of the impact of LMAs on major PRAEs. As shown in Fig. 5, compared with other airways, children who received LMAs experienced a significant reduction of major PRAEs with the pooled RR of 0.45 (95% CI 0.28–0.72; $P = 0.001$). The pooled analysis was estimated using a random-effect model because a significant heterogeneity ($P_h = 0.002$ and $I^2 = 63\%$) among the studies was found. Similarly, when comparing LMAs with ETTs on major PRAEs, a significant reduction of major PRAEs was also found in the LMAs group, with a pooled RR of 0.40 (95% CI 0.30–0.55; $P < 0.00001$). The pooled analysis was estimated using a fixed-effect model because a significant heterogeneity ($P_h = 0.23$ and $I^2 = 23\%$) among the studies was found (Table 3).

3.4. Impact of LMAs on minor PRAEs

As shown in Fig. 6, compared with other airways, children receiving LMAs experienced a significant reduction of minor PRAEs with the pooled RR of 0.55 (95% CI 0.43–0.71; $P < 0.00001$). In addition, when comparing LMAs with ETTs, a significant reduction of minor PRAEs was also found in the LMAs groups, with a pooled RR of 0.48 (95% CI 0.35–0.66; $P < 0.0001$) (Table 3). The pooled analyses were estimated using the random-effect models because of significant heterogeneity ($P_h = 0.009$, $I^2 = 56\%$ and $P_h = 0.004$, $I^2 = 63\%$) among the studies.

3.5. Impact of LMAs on each PRAEs item

This study also analyzed the incidence of each PRAEs item we collected including Breath apnea, Laryngospasm or Bronchospasm, Desaturation, Cough, Fever, Pulmonary rales, Pulmonary infection. When compared with other airways, children who received LMAs experienced a significant reduction in Laryngospasm or Bronchospasm (RR 0.46; 95% CI 0.23–0.92; $P = 0.03$), Cough (RR 0.41; 95% CI 0.29–0.58; $P < 0.00001$), Pulmonary rales (RR 0.62; 95% CI 0.44–0.87; $P = 0.006$), and Pulmonary infection (RR 0.28; 95% CI 0.13–0.61; $P = 0.001$). However, in Breath apnea, Desaturation as well as Fever, no significant results were found.

Compared with ETTs, LMAs was more effective in reducing the incidences of Laryngospasm/Bronchospasm (RR 0.33; 95% CI 0.19–0.56; $P < 0.0001$), Desaturation (RR 0.55; 95% CI 0.36–0.85; $P = 0.007$), Cough (RR 0.39; 95% CI 0.26–0.59; $P < 0.00001$), Pulmonary rales (RR 0.62; 95% CI 0.44–0.87; $P = 0.006$), and Pulmonary infection (RR 0.28; 95% CI 0.13–0.61; $P = 0.001$). However, in Breath apnea, Desaturation as well as Fever, no significant results were found. No significant reduction of the incidences of breath apnea and fever were found in LMAs when compared with ETTs.

3.6. Subgroup analysis of impact of LMAs on PRAEs

Subgroup analysis of LMAs versus other airways according to the ASA class (I–II vs. I–III) and sample size (≤100 pts vs. > 100 pts) were conducted. Table 4 shows significant reduction of overall PRAEs (RR 0.43; 95% CI 0.23–0.79; $P = 0.007$), major PRAEs (RR 0.46; 95% CI 0.33–0.65; $P < 0.00001$) and minor PRAEs (RR 0.51; 95% CI 0.29–0.90; $P = 0.02$) using LMAs when compared with other airways in ASA I–II children. In ASA I–III children, significant reduction of overall PRAEs (RR 0.60; 95% CI 0.51–0.72; $P < 0.00001$), major PRAEs (RR 0.25; 95% CI 0.12–0.53; $P = 0.0003$) and minor PRAEs (RR 0.65; 95% CI 0.55–0.77; $P < 0.00001$) were also found.

We compared the incidences of PRAEs of LMAs versus other airways in different sample sizes of the studies. The pooled results showed that LMAs had a significant reduction in overall PRAEs (RR 0.45; 95% CI 0.26–0.81; $P = 0.008$), major PRAEs (RR 0.46; 95% CI 0.33–0.65; $P < 0.00001$) and minor PRAEs (RR 0.57; 95% CI 0.35–0.93; $P = 0.02$) in the sample size ≤100 pts subgroup when compared with other airways. In the sample size > 100 pts subgroup, significant reduction of overall PRAEs (RR 0.50; 95% CI 0.32–0.76; $P = 0.001$) and minor PRAEs (RR 0.51; 95% CI 0.53–0.73; $P = 0.0002$) were also found. However, no significant reduction of major PRAEs (RR 0.42; 95% CI 0.14–1.28; $P = 0.13$) was found in the sample size > 100 pts subgroup.

4. Discussion and conclusions

The present analysis showed that the use of LMAs was associated with a lower incidence of PRAEs than with ETTs in children. To our knowledge, current airway device selection in children is still a topic of controversy in clinical practice. PRAEs, and particularly major PRAE, are clinically significant events and are major contributors to anesthetic morbidity. Our analysis clearly showed clinically significant reductions in the rates of overall PRAEs, including major or minor PRAEs, in children whose airway was managed with LMA rather than ETT or other airways. These results are likely to substantially affect the choice of airway device in children.

A decreased risk in PRAEs using LMAs was most prominent in laryngospasm/bronchospasm, cough, pulmonary rales and pulmonary infections when compared with other airways. Our subgroup analysis further indicated that when compared with ETTs, children receiving

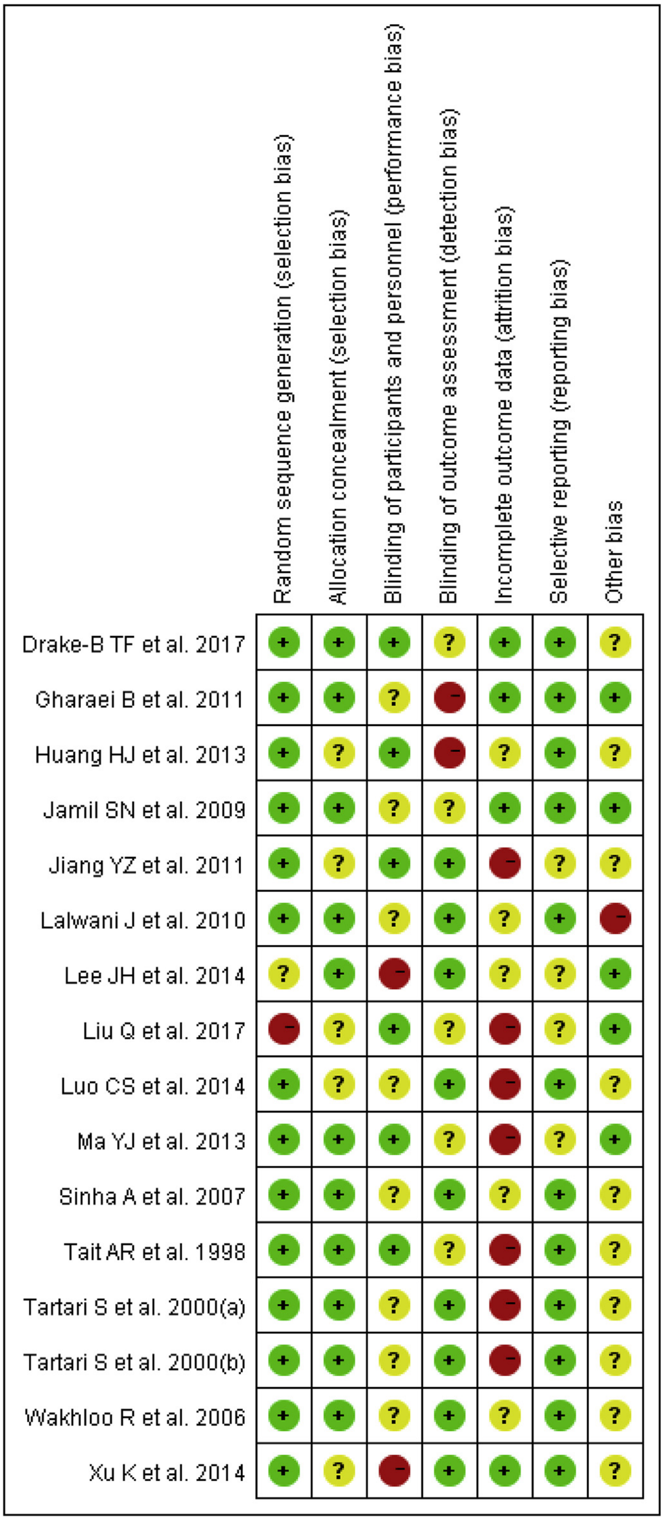

Fig. 3. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.

LMAs experienced a reduction in PRAEs which included laryngospasm/bronchospasm, desaturation, cough, pulmonary rales and pulmonary infections. For other PRAEs such as breath apnea and fever, no significant differences were found in the incidences between the two groups. These results indicated that the incidences of breath apnea and fever in children who were managed with LMAs and ETTs or other airways were similar, and LMAs did not affect the incidences of these PRAEs.

This systematic review summarized 15 RCTs which involved 1577 participants. This meta-analysis demonstrated the impact of LMAs in decreasing the incidence of PRAEs of children. The analysis supported the conclusion that the incidence of PRAEs in children managed with LMA was significantly decreased when compared with children receiving other airways. The significant reductions included overall PRAEs (RR 0.52, 95% CI 0.39–0.70; $P < 0.0001$), major PRAEs (RR 0.47, 95% CI 0.29–0.79; $P = 0.004$) as well as minor PRAEs (RR 0.57, 95% CI 0.45–0.74; $P < 0.0001$). In addition, significant reduction of PRAEs was also observed in children managed with LMAs when compared with ETTs. Our results were in line with the observed trend of increased PRAEs for younger children (11% increased risk per year of younger age) identified in a previously reported large cohort study [6]. However, no significant reduction was found in breath apnea (RR 0.89, 95% CI 0.49–1.64; $P = 0.71$) and desaturation (RR 0.73, 95% CI 0.51–1.03; $P = 0.07$). These results were consistent with the results in one study on LMAs versus other airway devices for anaesthesia in children with upper respiratory tract infections (breath apnea: RR 0.82, 95% CI 0.41–1.65; $P = 0.58$) and (desaturation: RR 0.44, 95% CI 0.16–1.17; $P = 0.10$) [34]. There is no evidence to show LMA increased severe anaesthesia adverse events in normal children without respiratory infections. Meanwhile, LMA also did not increase the incidence of any severe anaesthesia adverse events in children with preoperative respiratory infections. Additionally, our results and one meta-analysis both found significant reduction in cough in children managed with LMAs (RR 0.41, 95% CI 0.29–0.58 and RR 0.75, 95% CI 0.58–0.96). In the present analysis, we studied three PRAEs including fever, pulmonary rales and pulmonary infections. Our results showed significant reduction of pulmonary rales and pulmonary infections in children managed with LMAs when compared with other airways, but not in fever.

We compared the incidence of PRAEs in children managed with LMAs versus ETTs, similar results were found in the reduction of incidence of PRAEs in children managed with LMAs versus other airways (Table 3). Randomized studies comparing airway devices in older children have found in ETTs, children managed with LMAs had a lower incidence of PRAEs [15,38], which was also found in our study. However, it is worth noting that although ETTs are associated with greater incidences of PRAE than with LMA, invasive devices offer other benefits which should be considered in deciding on which device to use [6,39]. Endotracheal tubes remain a useful device in the management of infant airway and they are required in infants in whom LMAs are contraindicated. They provide the most secure airway with respect to aspiration. In choosing the airway device, the treating anaesthetist has to consider several factors including PRAEs, which are of particular importance in infants [40].

This meta-analysis had several limitations. First limitation was the inconsistency in the anaesthesia scheme or anesthetic of the studies which we included. The anaesthesia scheme or anesthetic may affect the outcomes or PRAEs. This is reflected in one study by de Carvalho et al. which indicated different results of Halothane and Sevoflurane [34]. Second, the timing of airway removal was not standardized. Many studies did not even report on this. However, in the study by Drake-Brockman et al., they reported the timing of ETT extubation did not have a large impact on frequency of PRAEs, with PRAEs occurring in 15 (50%) of 30 deep anaesthesia extubations and 29 (52%) of 56 awake extubations [34]. Third, many of our included studies were designed as a single centre RCT with small sample size, which restricts the generalisability of the results. Multicentre trials would help to establish to what extent the results can be generalized across different paediatric settings worldwide. Finally, we failed to analyze the PRAEs by perioperative, intraoperative and postoperative groups. However, one study [12] analyzed this and found that many PRAEs occurred more in the intraoperative than the postoperative period. Further studies are needed to clarify this.

The search strategy for this review was comprehensive, broad, and

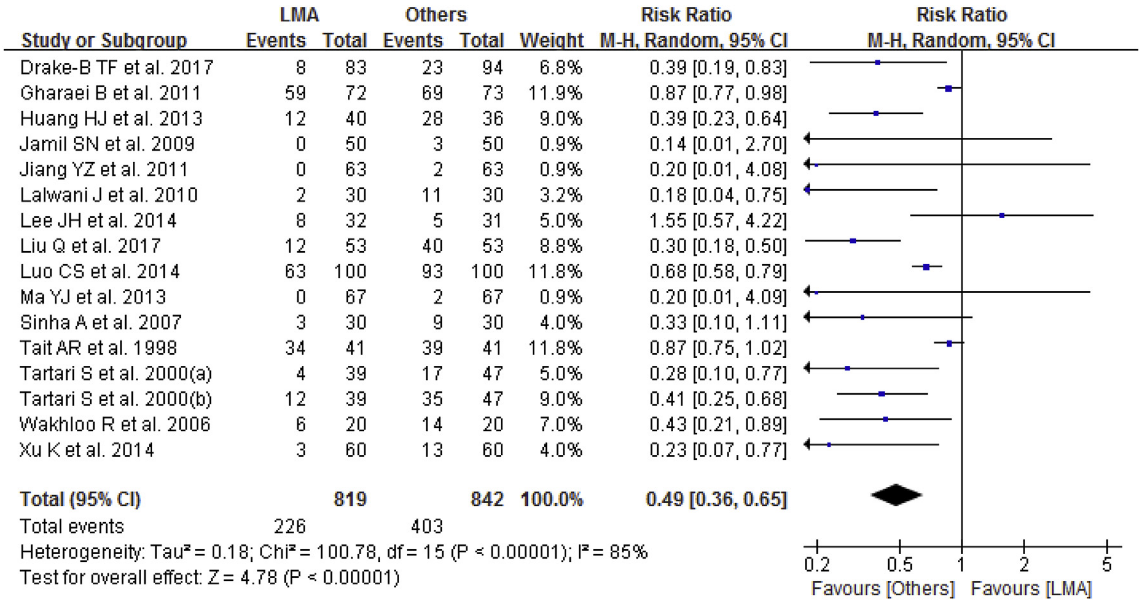

Fig. 4. Forest plot showing the comparison between LMA and other airways for children regarding the overall PRAEs.

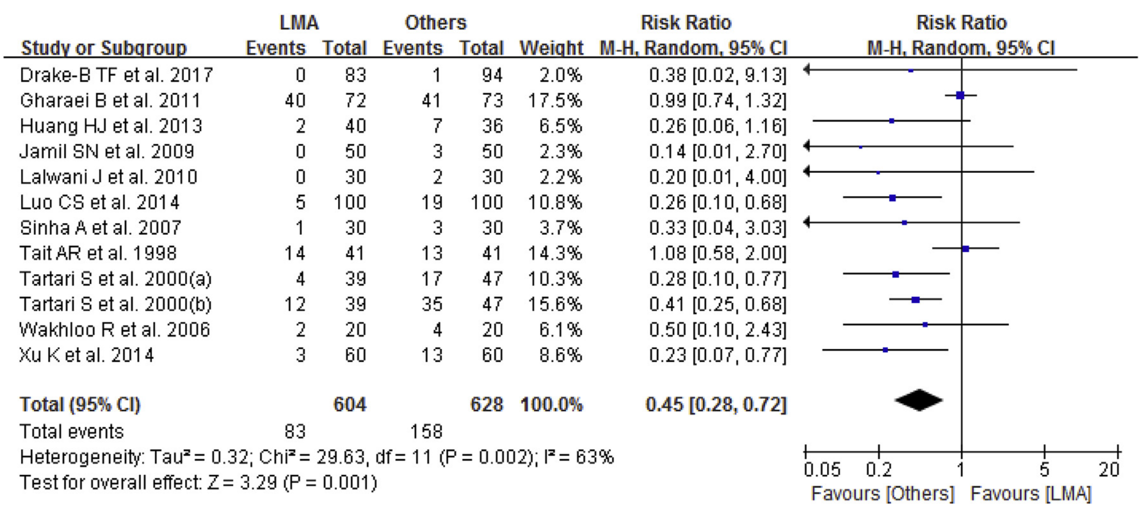

Fig. 5. Forest plot showing the comparison between LMA and other airways for children regarding the major PRAEs.

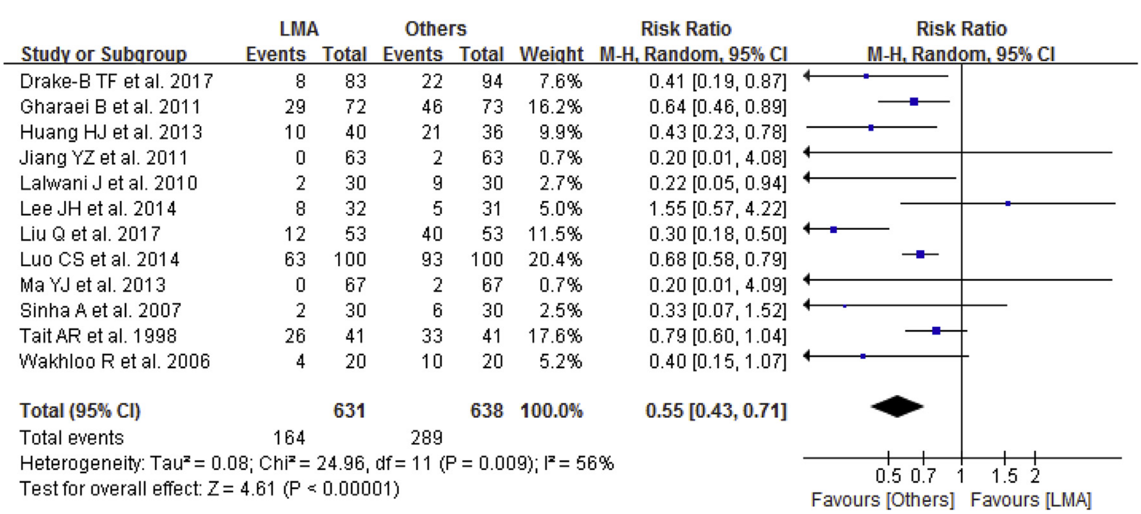

Fig. 6. Forest plot showing the comparison between LMA and other airways for children regarding the minor PRAEs.

Table 3
The pooled results of PRAEs regarding to LMAs versus ETTs.

PRAEs	Pooled results			Heterogeneity		
	RR	95% CI	*P* value	I^2	P_h value	Analytical effect model
Overall PRAEs	0.41	0.28, 0.58	< 0.00001*	83%	< 0.00001	Random-effect model
Major PRAEs	0.40	0.30, 0.55	< 0.00001*	23%	0.23	Fixed-effect model
Minor PRAEs	0.48	0.35, 0.66	< 0.0001*	63%	0.004	Random-effect model
Breath apnea	0.79	0.39, 1.57	0.50	0%	0.39	Fixed-effect model
Laryngospasm/Bronchospasm	0.33	0.19, 0.56	< 0.0001*	0%	0.50	Fixed-effect model
Desaturation	0.55	0.36, 0.85	0.007*	49%	0.14	Fixed-effect model
Cough	0.39	0.26, 0.59	< 0.00001*	0%	0.89	Fixed-effect model
Fever	0.44	0.19, 1.03	0.06	0%	0.54	Fixed-effect model
Pulmonary rales	0.62	0.44, 0.87	0.006*	0%	0.40	Fixed-effect model
Pulmonary infection	0.28	0.13, 0.61	0.001*	0%	0.94	Fixed-effect model

PRAEs, Perioperative respiratory adverse events; RR, relative ratio; CI, confidence intervals.

Table 4
The subgroup analysis of PRAEs according to ASA class and sample size regarding to LMAs versus other airways.

Subgroups	Pooled results			Heterogeneity		
	RR	95% CI	*P* value	I^2	P_h value	Analytical effect model
ASA class						
I–II						
Overall PRAEs	0.43	0.23, 0.79	0.007	89%	< 0.00001	Random-effect model
Major PRAEs	0.46	0.33, 0.65	< 0.00001	39%	0.13	Fixed-effect model
Minor PRAEs	0.51	0.29, 0.90	0.02	75%	0.001	Fixed-effect model
I–III					0	
Overall PRAEs	0.60	0.51, 0.72	< 0.00001	45%	0.14	Fixed-effect model
Major PRAEs	0.25	0.12, 0.53	0.0003	0%	0.87	Fixed-effect model
Minor PRAEs	0.65	0.55, 0.77	< 0.00001	0%	0.50	Fixed-effect model
Sample size						
≤100 pts						
Overall PRAEs	0.45	0.26, 0.81	0.008	84%	< 0.00001	Random-effect model
Major PRAEs	0.46	0.33, 0.65	< 0.00001	29%	0.20	Fixed-effect model
Minor PRAEs	0.57	0.35, 0.93	0.03	56%	0.05	Random-effect model
> 100 pts						
Overall PRAEs	0.50	0.32, 0.76	0.001	87%	< 0.00001	Random-effect model
Major PRAEs	0.42	0.14, 1.28	0.13	79%	0.003	Random-effect model
Minor PRAEs	0.51	0.35, 0.73	0.0002	63%	0.02	Random-effect model

PRAEs, Perioperative respiratory adverse events; RR, relative ratio; CI, confidence intervals.

systematic, with hand searching used for some references of the included studies [26,27,34,35,41,42]. Keeping in mind considerable heterogeneity in the study design of the included trials, especially in the anaesthesia interventions, more studies should be designed to focus on comparing the impact of different anaesthesia interventions. Also, further studies with sufficient sample sizes should be performed to demonstrate the impact of LMAs, and to provide more clinically convincing results.

Although the LMAs are not suitable for all children undergoing all types of surgery, this study showed a clear benefit of the use of LMA compared with ETT in a large number of children undergoing elective surgery. The overall occurrence of PRAEs, minor and major PRAEs were all significantly lower with the use of LMAs in children than with other airway devices or the endotracheal tubes.

Ethical Approval

Ethical Approval is not applicable.

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Author contribution

The authors on this paper all participated in study design. All authors have read and approved this version of the article, and due care has been taken to ensure the integrity of the work. The material of this article is original research and no part of this paper has been previously published. The material has also not been submitted for publication elsewhere while under consideration. No conflict of interest exits in the submission of this manuscript. All authors have the appropriate permissions and rights to the reported data.

Conflicts of interest

The authors declare no relevant conflict of interest.

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Data statement

The material of this article is original research. All data in this manuscript is available and transparent for readers.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijsu.2019.02.020.

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