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ORIGINAL ARTICLE

From rigid to flexible bronchoscopy: a tertiary center experience in removal of inhaled foreign bodies in children

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Abstract

Rigid bronchoscopy is the procedure of choice for removal of inhaled foreign bodies. In this retrospective study, we assessed the safety and efficacy of flexible bronchoscopy use in the removal of inhaled foreign bodies in children. One hundred eighty-two patients (median age of 24 months, 58% males) underwent an interventional bronchoscopy for the removal of inhaled foreign body between 2009 and 2019, 40 (22%) by flexible, and 142 (78%) by rigid bronchoscopy. 88.73% of rigid and 95% of flexible bronchoscopies were successful in foreign bodies removal (p value = 0.24). Complication rate was higher among rigid bronchoscopy (9.2% vs. 0%, $p = 0.047$). From 2017 onwards, following the implementation of flexible bronchoscopy for foreign bodies removal, 64 procedures were performed, 33 (51.6%) flexible, and 31 (48.4%) rigid. Procedure length was shorter via flexible bronchoscopy (42 vs 58 min, $p = 0.016$). Length of hospital stay was similar.

Conclusion: In our hands, flexible bronchoscopy is an efficient and safe method for removal of inhaled foreign bodies in children, with shorter procedure time and minimal complication rate. Flexible bronchoscopy could be considered as the procedure of choice for removal of inhaled foreign bodies in children, by an experienced multidisciplinary team.

What is Known:
- *Rigid bronchoscopy is currently the gold standard for removal of inhaled foreign bodies in children.*
- *Rigid bronchoscopy has a relatively high complication rate compared to flexible bronchoscopy.*

What is New:
- *Flexible bronchoscopy is a short, safe, and efficient procedure to remove inhaled foreign bodies in children, compared to rigid bronchoscopy.*
- *Flexible bronchoscopy could be proposed as the procedure of choice for removal of inhaled foreign bodies in children, if an experienced operator is available.*

Keywords Flexible bronchoscopy · Rigid bronchoscopy · Inhaled foreign body · Children

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Abbreviations

FB	Foreign body
IQR	Interquartile range
LOS	Length of stay in the hospital
OR	Operation room
PICU	Pediatric intensive care unit

Introduction

Foreign body (FB) inhalation in children has variable presentations ranging from complete airway obstruction to chronic indolent cough, requiring high index of suspicion and thorough history taking [1–3]. Appropriate diagnosis and removal of FB are important to prevent long-term complications in those children [4].The current procedure of choice for removal of inhaled FB is rigid bronchoscopy, with reported complications [5–7]. Complications may include laryngeal edema, severe mucosal damage, lung atelectasis, pneumothorax, and hemorrhage. Tracheal rupture, bronchial rupture, mechanical ventilation, cardiorespiratory arrest, and post-procedural respiratory failure and death have been also reported although rarely [8–12]. During the last decade, the indications for flexible bronchoscopy in adults and children were expanded and may include inhaled foreign body removal. Among adults, the overall success of flexible bronchoscopy for FB's removal is high [13]. In children, the need for smaller instruments delayed this process. Most of the instruments came from pediatric urology or gastroenterology invasive procedures, thus, made the removal of FB's more feasible in the pediatric population. Until now, small studies were published regarding the removal of FB in children by flexible bronchoscopy, with high rate of efficacy and high safety profile [1, 14–19]. Our aim was to compare flexible to rigid bronchoscopy in the removal of FB, specifically looking at efficacy and safety. We also examined the duration of the two procedures and the length of stay (LOS) in the hospital.

Methods

This is a retrospective study, following patients who underwent flexible or rigid bronchoscopy for the removal of inhaled FB between 2009 and 2019. This study included pediatric patients that were hospitalized in the Soroka University Medical Center (SUMC), the only tertiary center in the south of Israel. The data were analyzed according to two time periods: 2009–2016 and 2017–2019.

Patients

Children aged 0–18 years were highly suspected of FB inhalation, either by history or by a radiopaque shadow observed in the chest x-ray ($n = 45$, 25%), or a demonstrated FB by diagnostic flexible bronchoscopy ($n = 131$,72%). A definitive removal procedure in the operation room (OR) was performed, either by rigid or by flexible bronchoscopy.

Bronchoscopies

FB's were removed by using rigid Hopkins bronchoscope (Storz, 2.9 mm, 37 cm) or rigid ventilating bronchoscope or flexible bronchoscope (Olympus, external diameter of 3.6 mm, working channel of 1.2 mm) with the insertion of retrieval basket or grasping forceps, according to the nature and location of the foreign body. In children older than 6–7 years, we usually used the 4.9-mm bronchoscope. All the bronchoscopies were performed in the OR, with a multidisciplinary team that included an anesthesiology specialist, otorhinolaryngologist, and pediatric pulmonologist. During the flexible bronchoscopies, patients were lightly sedated, spontaneously breathing, and on oxygen supplementation by reservoir mask (we usually cut a small hole in the left side of the mask for introducing the scope) or by laryngeal mask airway (LMA). We used a bite protector and introduced the bronchoscope through the mouth. We overcome the hazard of impaction in the glottis area or trauma to the vocal cord by using one of the methods, depending on the size and shape of FB: (1) vocal cord retractors, (2) over-tubing (through endotracheal tube or rigid bronchoscope), or by (3) using a net in a case of sharp objects. When the FB was suspected to be relatively large, we used a basket. For rigid bronchoscopy, we used direct laryngoscopy equipment to enable the optic grasping forceps, or basket, under generalized anesthesia with spontaneous ventilation. Oxygen was administered via the laryngoscope or through nasopharyngeal airway.

The indication for choosing rigid or flexible bronchoscopy was operator dependent, regardless of the type or size of the inhaled foreign body and regardless of its location and the severity condition of the patients. One specialist performed all the flexible bronchoscopies, and if the child arrived while he was available, the procedure of choice was flexible bronchoscopy. If not, rigid bronchoscopy was performed. In this manner, although it is a retrospective study, the decision, which primary procedure to perform, was clearly random. The indication to switch from one procedure to another was up to three unsuccessful attempts or if a complication occurred (e.g., bleeding, need for intubation). Dr. Tsaregorodtsev has 22 years of experience in invasive endoscopies and 8 years of experience in foreign body removal using flexible bronchoscopy. Dr. Stiler-Timor has 16 years of experience in FB's removal using rigid bronchoscopies. The data on the procedures was taken from the OR reports. We excluded the reports, where flexible and rigid bronchoscopy were both performed and it was not clear what procedure indeed removed the FB, those where the FB was identified in the

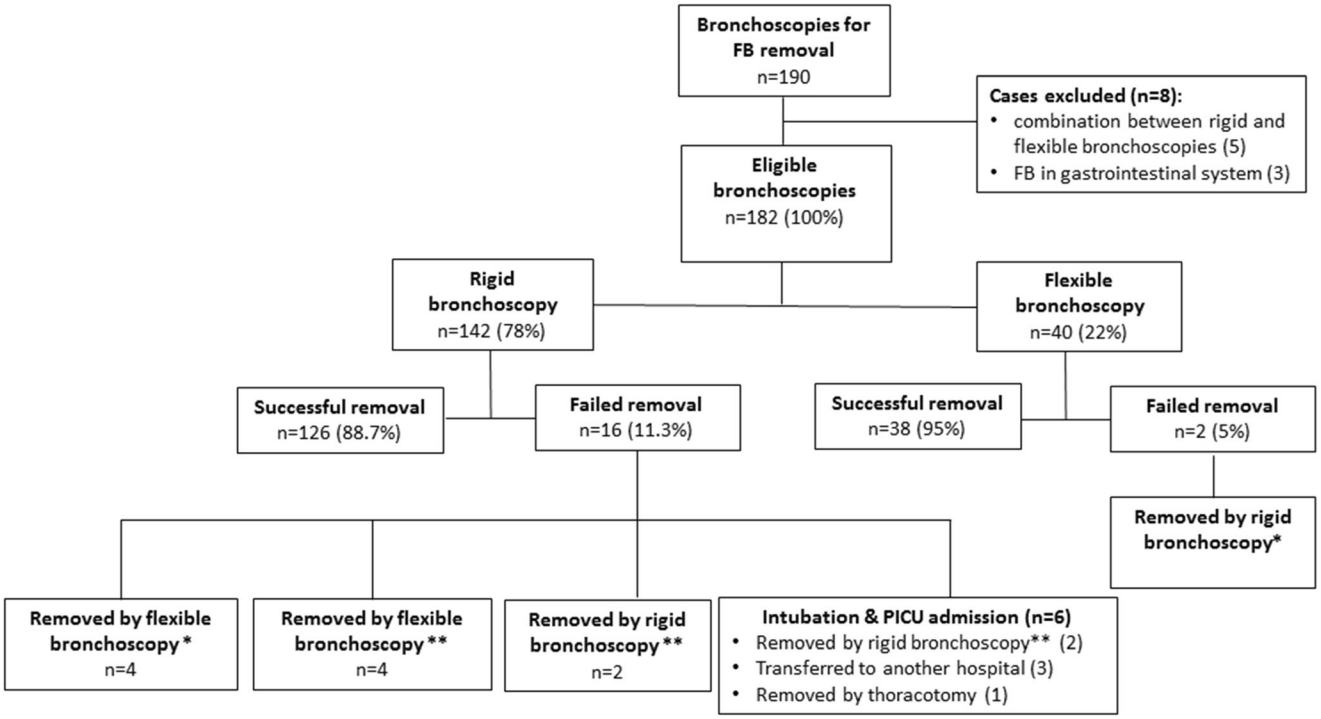

Fig. 1 Flow chart of study population. * during the same procedure; ** during a different procedure. FB = foreign body; PICU = pediatric intensive care unit

gastrointestinal system, and those where FB was not found during the procedure.

Statistical studies

We compared demographic, clinical, and procedure-related characteristics as well as outcomes between children who underwent rigid and flexible bronchoscopy, using appropriate univariate analyses. Specifically, nominal variables were compared using Pearson's chi-square test, continuous variables that matched parametric criteria were compared by using Student's *t* test, and ordinal variables and continuous variables that did not match parametric criteria were compared by using Wilcoxon or Mann-Whitney *U* tests. Continuous variables are depicted as mean ± standard deviation (SD) or as median and interquartile range (IQR), according to their distribution. Categorical data are expressed as percentages. Next, we assessed the difference in those parameters between groups for both trial time periods independently: 2009–2016 and 2017–2020. Statistical significance was defined as p value ≤ 0.05. Analyses were performed via IBM SPSS software version 24.

Results

One hundre ninety patients underwent interventional bronchoscopy for removal of inhaled FB. Eight were eliminated, five for combined use of flexible and rigid bronchoscopies during the same procedure, and three for ingestion rather than inhalation of FB (Fig. 1). One hundred eighty-two patients were eligible (median age of 24 months (Inter quartile range (IQR) 16 months–8 years), 58% males), 40 (22%) by flexible bronchoscopy, and 142 (78%) by rigid bronchoscopy. The demographic details and time interval from admission to procedure were similar between the groups (Table 1). Most of the FB were of organic origin (59%) and included sunflower seed shells (38), peanuts (24), pistachios (9), almonds (7), popcorn (6), cashews (2), citrus seeds (2), and rice, bean, tooth, fishbone, pieces of apple, coconut, and few unrecognized organic FBs. The non-organic FB's included metal pins (41), whistles (7), beads (6) plastic pen covers (3), thumbtacks (4), and small pieces of plastic toys. Most of the FB were located in the right main bronchus or its distal branches (53%) and were removed by grasping forceps (19%), when using rigid bronchoscopy or by retrieval basket (45%), when using flexible bronchoscopy (Tables 2 and 3). 88.73% of rigid bronchoscopies and 95% of flexible bronchoscopies were successful in the removal of FB (p value = 0.24). Thirty-eight out of 40 (95%) flexible bronchoscopies were successful in removing the FB, while two failed. In both cases, the FB was a metal pin, which was located in the left main bronchus. Both were successfully removed by rigid bronchoscopy during the same procedure. One hundred twenty-six out of 142 (90%) rigid bronchoscopies were successful in removing the FB, while 16 failed. Out of those that failed, four were successfully removed by flexible bronchoscopy during the same procedure, four were successfully removed by flexible bronchoscopy in a

Table 1 Population characteristics, procedural characteristics, and clinical outcomes

	Rigid bronchoscopy $N = 142$ (78%)	Flexible bronchoscopy $N = 40$ (22%)	p value	Total $N = 182$ (100%)
Demographic characteristics				
Age; median [IQR]	2 years [1.3–8]	2 years [1.6–8.6]	0.656	2 years [1.4–8]
Sex (female)	58 (40.8%)	18 (45%)	0.638	76 (41.8%)
Origin (Bedouin)	113 (79.6%)	32 (80%)	0.953	145(79.7%)
Procedural characteristics				
Admission to procedure time	14 h [4–23]	17 h [9.5–21]	0.05	15 h [5–23]
Procedure length	50 min ± 27 46 min [27.5–62.5]	45 min ± 22 45 min [29–55]	0.292 0.526	48 min ± 25 46 min [28–58]
Nonorganic FB	57 (41.6%)	17 (44.7%)	0.730	74 (42.3%)
Location of FB				
- Larynx	3 (2.1%)	0		3 (1.6%)
- Trachea	21 (14.8%)	3 (7.5%)		24 (13.2%)
- Right main bronchus	67 (47.2%)	19 (47.5%)	0.385	86 (47.3%)
- Left main bronchus	42 (29.6%)	12 (30%)		54 (29.7%)
- Right distal branches	7 (4.9%)	4 (10%)		11 (6%)
- Left distal branches	2 (1.4%)	2 (5%)		4 (2.2%)
Failure to remove FB	16 (11.3%)	2 (5%)	0.241	18 (10%)
Clinical outcomes				
Post-bronchoscopy complication	13 (9.2%)	0	0.047	13 (7.1%)
LOS	39 h [20.5–52.5]	33 h [24–45.5]	0.649	39 h [21–50]

delayed procedure, and four were successfully removed by rigid bronchoscopy in a delayed procedure, usually 2–4 days later, after initiation of systemic steroid and antibiotic treatment. Two of them required intubation and admission to pediatric intensive care unit (PICU). Four additional patients were intubated and admitted to the PICU for respiratory and hemodynamic stabilization. Then, three were transferred to a different hospital, where the FB was removed by successful flexible bronchoscopy and one went through thoracotomy in our institution with successful removal of the FB. The

Table 2 Procedure characteristics and complications, 2009–2016

	Rigid bronchoscopy $N = 111$ (94.1%)	Flexible bronchoscopy $N = 7$ (5.9%)	p value	Total 118 (100%)
Assist tool				
- Forceps	21 (18.9%)	0		21 (17.8%)
- Basket	2 (0.9%)	0		1 (0.8%)
- Tweezers	0	0		0
- Crocodile	4 (3.6%)	1 (14.3%)		5 (4.2%)
- Other	0	1 (14.3%)		1 (0.8%)
- Unknown	85 (76.6%)	5 (71.4%)	0.001	90 (76.3%)
Failure to remove FB	11 (9.9%)	0	0.382	11 (9.3%)
Alternative bronchoscope technique succeeded	1 (0.9%)	0	0.801	1 (0.8%)
Any complication	13 (11.7%)	0	0.337	13 (11%)
Disintegrating FB	7 (6.3%)	0	0.493	7 (5.9%)
Pneumothorax	0	0	–	0
Tracheal rupture	0	0	–	0
Laryngeal edema	0	0	–	0
Intubation and PICU admission	7 (6.3%)	0	0.493	7 (5.9%)
Bleeding	2 (1.8%)	0		2 (1.8%)

Table 3 Procedure characteristics and complications, 2017–2019

	Rigid bronchoscopy $N = 31$ (48.4%)	Flexible bronchoscopy $N = 33$ (51.6%)	p value	Total 64 (100%)
Assist tool				
- Forceps	6 (19.4%)	5 (15.2%)		11 (17.2%)
- Basket	0	18 (54.5%)		18 (28.1%)
- Tweezers	0	0	< 0.001	0
- Crocodile	1 (3.2%)	1 (3%)		2 (3.1%)
- Other	0	0		0
- Unknown	24 (77.4%)	9 (27.3%)		33 (51.6%)
Failure to remove FB	5 (16.1%)	2 (6.1%)	0.197	7 (10.9%)
Alternative bronchoscope technique succeeded	2 (6.5%)	2 (6.1%)	0.949	4 (6.3%)
Any complication	0	0	–	0
Disintegrating FB	0	0	–	0
Pneumothorax	0	0	–	0
Tracheal rupture	0	0	–	0
Laryngeal edema	0	0	–	0
Intubation and PICU admission	0	0	–	0
Bleeding	0	0	–	0

complication rate during or post-procedure was higher among rigid compared to flexible bronchoscopy, 9.2% vs. 0, respectively (p value = 0.047). Most of the complications were disintegrating of the FB ($n = 7$, 6.3%), intubation requiring PICU admission ($n = 7$, 6.3%), and bleeding ($n = 2$). Some patients had more than one complication. Out of the patients that needed intubation, two inhaled organic FBs (nut, peanut) that disintegrated, two inhaled metal pins (Hijab) [20], and two had plastic pen covers that turned out to be one of the most difficult FB to remove, due to its round shape and slippery characteristic. One unstable patient was intubated before the bronchoscopy and not as a consequence of the procedure. Throughout the first period of the study (2009–2017), 118 procedures were performed: 111 (94%) rigid bronchoscopies and 7 (6%) flexible bronchoscopies. We found no statistical significant difference in procedure length between flexible and rigid bronchoscopies (61 min vs. 48 min, respectively, p value 0.408) (Table 4). From 2017 onwards, after implementation of the flexible bronchoscopies for removal of inhaled FB, 64 procedures were performed: 33 (51.6%) flexible bronchoscopies and 31 (48.4%) rigid bronchoscopies. Procedure length was found to be significantly shorter by 16 min, flexible compared to rigid bronchoscopy (42 min vs. 58 min, respectively, p value 0.016) (Table 5). No statistically significant difference was found in LOS after flexible compared to rigid bronchoscopy (33 vs 39 h, p value 0.649).

Discussion

Our tertiary center's 10-year experience reveals the high success rate, low complication rate, and shorter length of procedure in children, when inhaled FB was removed by a flexible bronchoscopy, in comparison to children that underwent the classical recommended procedure, i.e., rigid bronchoscopy. Flexible bronchoscopy has become a common practice for removal of inhaled FB in adults, due to safety profile and high successful rate. In a systematic review of 1185 adults (18 studies), the overall success in removal of FB was 89.6% [13]. However, the limitations of equipment's size in pediatric population made this procedure less practical in children. Lately, additional studies have been published, regarding the use of flexible bronchoscopy in children for removal of FB. Although it was already described as an efficient and safe

Table 4 Procedural and clinical outcomes, 2009–2016

	Rigid bronchoscopy $N = 111$ (94.1%)	Flexible bronchoscopy $N = 7$ (5.9%)	p value	Total 118 (100%)
Procedure length	43 min ± 23 min 40 min [24–58]	61 min ± 43 min 57 min [22.5–101.5]	0.408 0.415	45 min ± 26 min 40 min [24–58]
LOS	2 days [1–3] 40 h [22.5–63.5]	1 day [0–2] 27 h [10–52]	0.170 0.448	2 days [1–3] 39 h [22–62.5]

Table 5 Procedural and clinical outcomes, 2017–2019

	Rigid bronchoscopy $N = 31$ (48.4%)	Flexible bronchoscopy $N = 33$ (51.6%)	p value	Total 64 (100%)
Procedure length	58 min ± 31 min	42 min ± 17 min	0.016	50 min ± 25 min
	51 min [34–83]	45 [28.5–55]	0.087	46.5 min [29–58]
LOS	1 day [1, 2]	1 day [1, 2]	0.701	1 day [1, 2]
	33 h [19–44]	34 h [24–45]	0.577	33.5 h [19–44]

method in children [18, 19], it was described either in small series [1, 12, 21] compared to rigid bronchoscopy or as a descriptive study with larger series [22, 23]. Nevertheless, rigid bronchoscopy is still the recommended method by the American [24] and European task forces [25]. As far as we know, this is the first study aimed to compare those two procedures, performed during the same period, under the same conditions. In this manuscript, we focused on the evolution from rigid to flexible bronchoscopy during the last 10 years, with increasing experience, higher success rate, and low complication rate, compared with rigid bronchoscopy. Our results demonstrate the trend towards using flexible bronchoscopy as an option in the pediatric population, as presented by the elevated rate of flexible bronchoscopies since 2017 (Fig. 2). Our results also support the notion that removal of FB by a flexible bronchoscopy is an evolving technique and, like every new technique, has a learning curve. Higher success rate, lower complication rate, and shorter length of procedure emphasize the experience the performer achieved over time. We further demonstrated a significantly shorter procedure length (42 vs 58 min). Kapoor et al. [23] reported a mean procedure time of 31 min. The difference in length is probably related to how the beginning and the end of the procedure were defined. Regarding LOS, although the procedure was significantly shorter by flexible bronchoscopy, there was no difference in LOS, probably reflecting the fact that length of hospitalization is determined by different medical and non-medical parameters.

It is interesting, but in many institutions, the otorhinolaryngologists have to face this common dilemma, while in other countries, pediatric pulmonologists are the address, with the option to perform either flexible or rigid bronchoscopy. This dilemma was described lately in Germany [26] with 20% of the medical centers reporting a preference for flexible bronchoscopy as the procedure of choice. Swanson et al. [27] reported that all FBs' removal since 1993 were performed by flexible bronchoscopy in Mayo Clinic Rochester.

The advantages to the patients are clear; diagnostic and therapeutic procedure performed at the same time, lighter and shorter anesthesia and shorter procedure time, with high safety and efficiency profile.

Our results strengthen the conclusion that flexible bronchoscopies are highly efficient and safe procedure in the removal of FB among children. In the cases which flexible bronchoscopy was not successful, the FBs (metal pins) were removed by rigid bronchoscopy during the same procedure. Therefore, in a case of inhaled metal pin or other slippery objects (piece of glass, plastic pen cover), we recommend a combination of the two procedures in the OR, with immediate backup of rigid bronchoscopy.

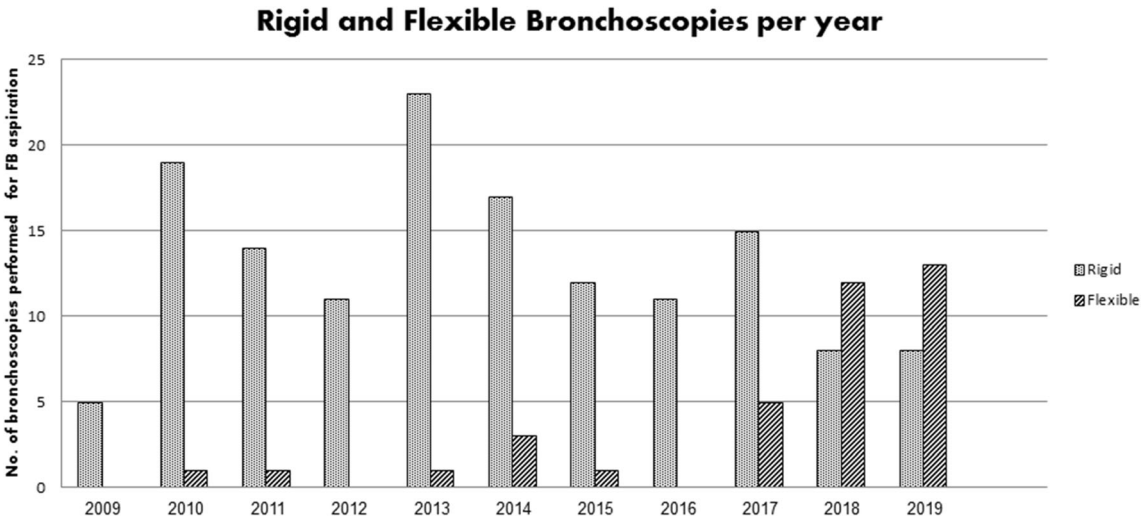

Fig. 2 Trends in flexible and rigid bronchoscopies during 10 years period

Our main limitation is the retrospective nature of our study, with missing reported data in the patients' files. For example, the assisted tool that was used for removal was not documented in the majority of the files (77% and 35% of the rigid and flexible bronchoscopy, respectively). Another limitation that results from the retrospective design is an operator bias; since all the flexible bronchoscopies were performed by a single operator, while rigid bronchoscopies were performed by a number of otorhinolaryngologists, it may contributed to the respectively higher complication rate during rigid bronchoscopies.

Another important point is the procedure length; in our institution, while performing bronchoscopy in the OR, the time is recorded from the minute the patient enters the OR until the end of anesthesia. Of course, this time frame is much longer than the actual procedure itself. Since we compared the two procedures in similar conditions, meaning both were measured longer than the actual time, this bias is negligible.

Conclusion

Flexible bronchoscopy is an efficient and safe method for removal of inhaled foreign bodies in children. It is associated with shorter procedure length but with similar LOS. Flexible bronchoscopy could be considered for removal of inhaled foreign bodies, in setting of the OR, with the backup of otorhinolaryngologist and rigid bronchoscopy.

Authors' contributions IGT: Contributed to conception and design, critically revised the manuscript for important and intellectual content, gave final approval, and agrees to be accountable for all aspects of work ensuring integrity and accuracy.

DWM: Contributed to conception and design, drafted the manuscript, and gave final approval.

ST: Contributed to conception and design, drafted the manuscript, and gave final approval.

LST: Contributed to conception and design, critically revised the manuscript for important and intellectual content, and gave final approval.

YD: Contributed to acquisition, analysis, and interpretation and critically revised the manuscript for important and intellectual content.

AG: Contributed to conception and design, critically revised the manuscript for important and intellectual content, and gave final approval.

MA: Contributed to cenception and design, critically revised the manuscript for important and intellectual content, and gave final approval.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

Ethical approval The study was approved by the institutional ethics committee (Soroka University Medical Center, No.148-19).

Consent to participate N/A

Consent for publication N/A

Code availability N/A

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