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Validation study of synthetic models for esophageal atresia with tracheoesophageal fistula (EA/TEF): A simulation-based training in pediatric surgery

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ABSTRACT

Background: Pediatric surgery is a highly specialised field, with minimally invasive surgery (MIS) posing greater technical challenges than conventional open surgery. Proficiency requires both in and out-of-operating-room training, with simulation playing a crucial role. The purpose of this study was to explore MIS perceptions, training experiences, and preferences regarding laparoscopic simulation training. Furthermore, we aimed to validate two synthetic EA/TEF models.

Method: A questionnaire focused on the degree of adoption of MIS among paediatric surgeons was proposed online to participants at the 68th Czech and Slovak Pediatric Surgery Congress in Slovakia in 2024. All participants also had scheduled sessions to practice advanced laparoscopic skills on two synthetic EA/TEF models. The purpose of this study was to analyse experiences with paediatric MIS, the implementation of simulation training, and personal stances on integrating simulation training into training curricula. EA/TEF models were validated with a 5-point Likert scale.

Results: Thirty-three paediatric surgeons from 14 centres in two countries completed the questionnaire. Six (18 %) were novices, 12 (36 %) intermediate trainees, and 15 (45 %) specialists with over 11 years of practice. Eight participants (18 %) declared weekly access to simulation training, while 49 % had none. Additionally, 15 individuals (45.5 %) strongly agree and 48.5 % agree that regular training on simulators enhances surgical skills in MIS procedures in the operating room. Twenty-six respondents (76 %) believe that simulator training should be part of the requirements for pediatric surgical trainees, with no significant difference according to the surgeons' experience ($p = 0.290$). Thirty surgeons validated the EA/TEF models. Highest ratings were for overall impression and tool usefulness in experienced surgeons' training (mean scores: 4.5 and 4.6). The working space received the lowest score (mean: 3.6 ± 0.8), with experienced surgeons rating it significantly lower (3.4) than the inexperienced group (4.1, $p = 0.030$). No significant differences were observed between models in Likert scale parameters.

Conclusion: Simulation training is essential for teaching MIS in paediatric surgery, improving skills, and should be part of specialisation preparation. Synthetic EA/TEF models received high ratings as effective training tools for thoracoscopic EA/TEF training. Further studies are needed to prove construct validity.

Introduction

In recent years, laparoscopic surgery has gained significant popularity, supplanting traditional open methods in various medical fields, including general surgery, gastrointestinal surgery, gynecology, and urology. It has become the established norm in numerous procedures such as cholecystectomy, appendectomy, colectomy, hysterectomy, pyeloplasty, nephrectomy, and others. Laparoscopic procedures are associ-

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ated with reduced postoperative discomfort, shorter hospital stays, faster recovery times, and better cosmetic results. Despite surgeons' interest in embracing laparoscopic techniques, many lack formal training in this area. Challenges such as unfamiliar technology, limited training opportunities, concerns about complications, and the difficulty of mastering new skills hinder the shift to MIS procedures [1]. Therefore, the need of well-trained and certified laparoscopic surgeons will increase [2,3]. MIS is technically more difficult than ordinary open surgery and several complications can happen at the beginning of experience [4]. EA occurs in every 3000–4500 live births and is the result of incomplete separation of the trachea and oesophagus leading to an interruption in esophageal continuity with or without TEF [5]. Thoracoscopic repair for esophageal atresia (EA) with or without tracheoesophageal fistula (TEF) was introduced over two decades ago. However, this technique is preferred by only a select group of surgeons, and most neonates still undergo thoracotomy. Several studies have reported that thoracoscopic EA/TEF repair offers superior visualization of the anatomy, reduced pain, fewer skeletal deformities, and minimal scarring. This minimally invasive technique is as effective as open surgery regarding operating time, blood loss, postoperative ventilation time, and the incidence of postoperative leaks and strictures [5,6,7]. However, the procedure is technically demanding due to the restricted working space of the neonatal thorax combined with inherent difficulties of using thoracoscopic instruments to perform an esophageal anastomosis under tension, and therefore has not replaced thoracotomy [8,9]. MIS in infants presents a challenging learning curve, particularly for suturing techniques and tissue manipulation. This learning curve often results in extended operative times until surgeons achieve full proficiency in these skills [10,11]. On the other hand, simulation has proven to be a fundamental tool in surgical education [12]. In recent years, the learning curve has shown signs of shortening with the introduction of a diverse array of surgical models. By allowing repeated simulations, both surgeons and residents gain significant opportunities to learn surgical techniques or specific procedures. This enables them to explore various approaches, practice, and refine skills within standardized and supervised environments. Ideally, simulation should facilitate intentional, repetitive, and collaborative practice of neonatal MIS procedures, utilizing a validated model capable of identifying and correcting performance errors [13]. Similarly, it should reliably determine when the required skills have been acquired. The integration of three-dimensional (3D) printing technology and imaging data from CT and MRI scans has opened new possibilities for creating high-fidelity MIS simulators. These simulators accurately replicate, to scale, the environment encountered in neonatal surgery [14,15]. Despite high perceived need and desire among trainees and educators alike, there are few opportunities for relevant simulation experiences in pediatric surgery [16].

Our aim was to survey the extent of MIS adoption within the pediatric surgical community and evaluate the current state of simulation training among pediatric surgeons. An online anonymous questionnaire was distributed to attendees of the MIS workshop at the 68th Congress of Czech and Slovak Pediatric Surgeons. Additionally, all participants were given dedicated sessions for hands-on practice using laparoscopic simulators, following approved research protocols.

In our previous study, we introduced a 3D-printed synthetic model for thoracoscopic repair of EA/TEF. Initial data analysis indicated a highly positive perception of the value of our simulator [15]. While this study provided preliminary evidence of validity regarding content and internal structure, it highlighted the need for further refinement of the simulator and a more comprehensive evaluation of validity evidence to support its integration into simulation-based education in pediatric surgery. In the subsequent phase, the newly developed synthetic EA/TEF model and the commercially available silicone EA/TEF model (LAPARO ® Medical Simulators, Poland, European Union) were validated by workshop participants using Analytic – Simulation with Analysis by LAPARO ® Medical Simulators . The objective was to validate EA/TEF synthetic models with a 5-point Likert scale.

Methods

Study setting

After review and exemption determination by the National Institute of Children's Diseases Institutional Review Board, data were collected during an MIS course offered at the 68th Czech and Slovak Pediatric Surgery Congress in Slovakia in 2024. The online anonymous questionnaire, provided in Additional File 1, was designed following the recommendations outlined in the published guidelines for developing and implementing web-based surveys (CHERRIES) [18]. The questionnaire was anonymous and distributed online using Google Forms (Alphabet Inc., Mountain View, CA, USA).The self-administered questionnaire comprised five sections:

1. Personal characteristics
2. Pediatric surgery department characteristics (number of MIS procedures annually)
3. Experiences with pediatric MIS
4. Possibility of simulation training
5. Personal stance on integrating simulation training into training curricula

Participants were categorized into three levels based on years of experience: novice (0-5 years), intermediate (6-10 years), and expert (11 or more years of experience).

All participants also had scheduled sessions to practice on laparoscopic simulators as part of approved research protocols. Each participant provided written consent to participate in the research. During the laparoscopic course, participants trained in basic and advanced laparoscopic skills (needle holding, sliding knot suturing) according to a video tutorial, tailored to individual experience levels. The Laparo Advance and Laparo Analytic simulation tools (LAPARO ® Medical Simulators., Poland, European Union) were were used for training. The surgical instrument setup included a 5-mm telescope at a 30-degree angle and 5-mm instruments (grasper, needle holder, and scissors).

All participants were anonymized and categorized as inexperienced or experienced based on their previous training and experience levels. Inexperienced participants were defined as surgical trainees in their 1st to 10th years of training. Expert participants had a minimum of 11 years of experience in pediatric surgery. Prior to attempting the trial, every participant viewed instructional videos. During each trial, participants also received straightforward instructional cues. The time allocated for the task was 30 minutes. Participants performed their tasks on one of the two available silicone models, which were randomly selected.

The tasks included:

a) Closure of TEF with a clipper
b) Division of TEF
c) Opening of the upper esophageal pouch
d) Esophageal anastomosis using sliding knots

Content and face validity were determined using a post-simulation questionnaire. Participants were asked to rate the following characteristics of the model on a five-point Likert scale: anatomical and surgical realism, positioning of TEF and esophageal pouches, haptic feedback on materials, working space, and difficulty of the required tasks. Content validity was evaluated based on these aspects: utility of the model to pediatric surgery trainees, usefulness as a thoracoscopic EA/TEF training tool, and usefulness as training and educational tools for surgeons and students.

Design and construction of the simulation models

Model n. 1. (new created silicon 3D printed model)

Parental informed consent was obtained to use a preexist-ing computerised tomography (CT) scan of a 1 month old neonate (weighing 3.2 kg) for the purposes of developing a simulation model. Subsequent data processing occurred within a graphical software environment, facilitating conversion into a format amenable to 3D printing protocols. Employing a Phrozen Mighty 8K resin-based 3D printer, tracheal structures were fabricated (Fig. 1 a). The chosen material substrate for tracheal fabrication was Flex Resin. Notably, resin constituents feature a chemical composition akin to a viscous fluid, exhibiting a discernible toxicological profile. Photopolymerization, triggered via exposure to blue or ultraviolet light, induced resin solidification, delineating solid regions upon illumination while preserving fluidity elsewhere—a phenomenon analogous to dental resin curing. A judicious selection of resin variety ensured post-cure flexibility, coupled with structural fidelity to authentic tracheal morphology. Iterative retrieval of solidified structures, followed by subsequent light exposure, enabled iterative production of tracheal 3D models (Fig. 1 b).

Production of Silicone Tracheal Prostheses: Design synthesis of silicone casting molds was facilitated within a graphical software framework, subsequently transposed into a 3D-printable format. These molds catered to both silicone pads and the tracheal structures themselves. Fabrication was executed utilizing a dual-component silicone formulation—Ecoflex 00-30—incorporated with pigments emulating human skin tones. Noteworthy in the tracheal casting process was the integration of a fine mesh reinforcement, enhancing resultant prosthetic integrity and elasticity. Post-curing, tracheal prostheses were demolded and trimmed to requisite dimensions. Subsequent assembly involved the adhesive bonding of tracheal components with silicone adhesives, ensuring structural cohesion and integrity (Fig. 2).

Model n. 2. (commercially available silicon model of EA ± TEF LAPARO Medical Simulators, LAPARO ® Medical Simulators)

The TEF/EA model is designed to provide a realistic simulation environment for training purposes. It comprises a silicone model that faithfully replicates the pediatric trachea, upper and lower esophagus, and includes a simulated azygos vein. The silicone material used in the model mimics the connective tissue encountered during surgical dissection, accurately representing the anatomical structures that need to be navigated to access the esophagus and trachea. This high-fidelity simulation allows medical professionals to practice and refine their skills in the management of esophageal atresia with tracheoesophageal fistula, enhancing their proficiency and confidence in performing these delicate procedure (Fig. 3 a, b).

Statistical analysis

Statistical analysis utilized SPSS version 24 (IBM, USA). Significance was determined at a p value of < 0.05. Data are expressed as mean (± standard deviation) unless specified otherwise. The questionnaire was created using the Google Forms tool (Alphabet Inc., Mountain View, CA, USA). Parametric variables were assessed via the t-test, while non-

Fig. 1. (a) Fabrication of tracheal structures by employing resin-based 3D printer. The tracheas were created through the process of photopolymerization. (b) Solidified tracheal 3D structures created through the process of photopolymerization followed by light exposure for four minutes. Created tracheas were then cured in 98 % alcohol.

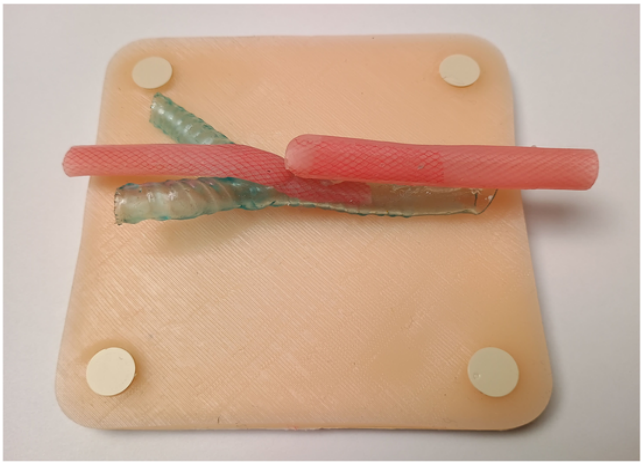

Fig. 2. Production of model of esophageal atresia with tracheoesophageal fistula. The components – silicone pad, 3D-printed trachea, and silicone tracheal prostheses – were assemblet together by using silicone glue allowing for the firm adhesive bonding.

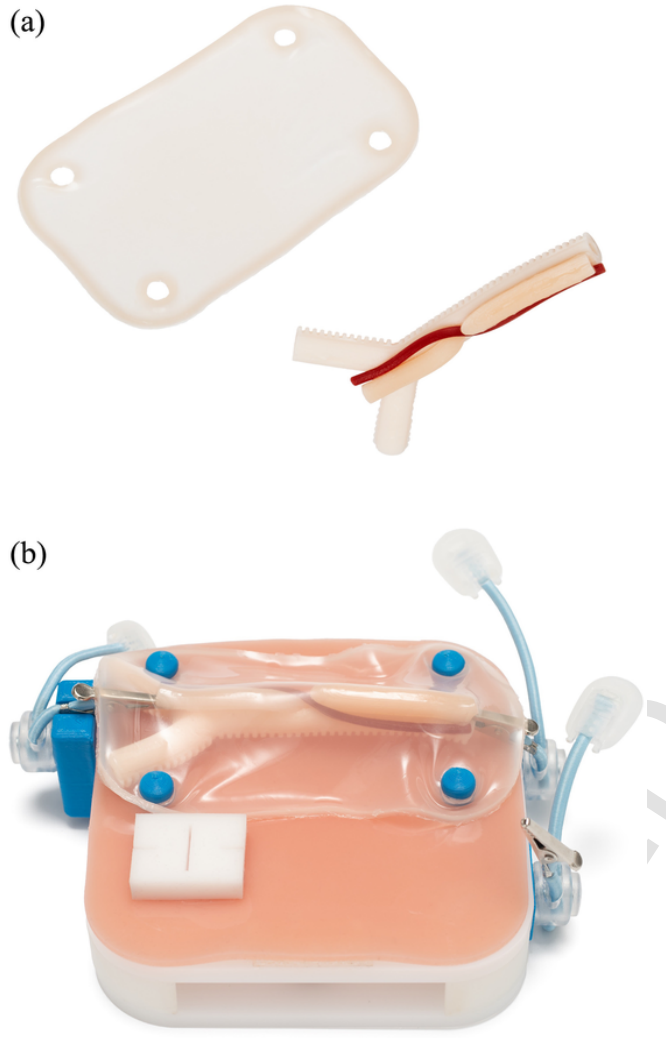

Fig. 3. a, b Commercially available silicon model of EA + TEF LAPARO Medical Simulation, LAPARO Sp. z o.o.).

parametric variables underwent analysis via the chi-square test. Fisher's exact test was employed for the comparison of categorical variable.

Results

Simulation Training Needs Assessment

Thirty-three pediatric surgeons completed the online questionnaire, representing 14 pediatric surgery centers across 2 countries. Five (16 %) respondents were categorized as novices, 13 (40 %) as intermediate trainees, and 15 (44 %) as specialists in pediatric surgery with over 11 years of practice. Twenty (60 %) were male, and 15 (45.5 %) respondents were in the age category of 26-35 years, 33.3 % in the category of 36-45 years, 6 (18.2 %) were aged 46-55 years, and only one respondent was older than 56 years. The majority of responders 36.5 %, worked in centers with over 151 pediatric minimally invasive procedures, while 6 % declared less than 50 pediatric MIS procedures per year. Table 1 presents complete participant details.

Fig. 4

Operative experience among experienced and inexperienced groups was the same, with a mean number of procedures observed assisting (66.7 % <50 vs. 66.7 % <50 procedures during the last year, $p = 0.989$). On the other hand, 86.7 % of inexperienced surgeons performed fewer than 50 MIS procedures during the last year as lead operators. Satisfaction with surgical skills in MIS was significantly higher in the experienced surgeon group compared to the inexperienced group ($p = 0.022$). A total of 52 % declared the possibility of using simulators for MIS training, while 48 % did not have the possibility of training on simulators. The group of experienced surgeons evaluated their possibility of using simulators for MIS training significantly lower than the group of inexperienced ones (11 (73 %) vs. 6 (33.3 %), $p = 0.022$). Across all centers, 18 % of participants had access to surgical simulation training facilities at least weekly, but on the other side, 49 % declared no possibilities for simulation training, with no significant differences between inexperienced and experienced groups ($p = 0.137$). Twenty (60.6 %) respondents had access to training box simulators, 3 (9 %) to analytic simulators, and only 2 (6 %) to simulators with virtual reality. Table 2 shows the self-declared rate of MIS experience.

The questionnaire also included personal attitudes towards integrating simulation training into pediatric surgery training curriculum. Twenty-nine (88 %) of respondents believe that regular training on simulators improves MIS skills; moreover, 15 individuals (45.5 %) strongly agree and 48.5 % agree that regular training on simulators enhances surgical skills in MIS procedures in the operating room. Twenty-six (76 %) respondents believe that simulator training should be part of specialization preparation, with no significant difference according to surgeons' experience ($p = 0.290$). Twenty-six (76 %) survey participants believe that completing simulator training should be mandatory before

Table 1
Characteristics of survey respondents

	Median (IQR)	n	%
Age (years)	35 (13)		
25-35		15	45.5
36-46		11	33.3
46-55		6	18.2
>55		1	3
Gender			
Male		20	60.6
Female		13	39.4
Professional experience (years)	9 (8)		
<5		5	16
5-10		13	40
11-15		2	6
>15		13	40
Number of MIS procedures per year in the institution			
I don't know		7	21.2
<50		2	6
50-100		8	24.2
101-150		4	12.1
>151		12	36.5

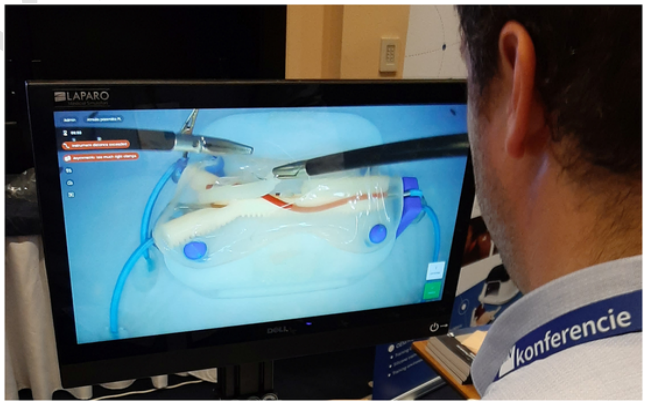

Fig. 4. Suturing the anastomosis of esophageal atresia using a sliding knot.

Table 2
Self-declared rate of MIS experience.

Procedure Count	Overall n = 33	Overall %	Inexperienced n = 15 (45%)	Experienced n = 18 (55%)	p value
Number of MIS procedures performed as assistant during last year					0.989*
I don't know	1	3	0	1 (5.6)	
<50	23	69.7	10 (66.7)	12 (66.7)	
51-100	9	27.3	5 (33.3)	4 (22)	
101-150	1	3	0	1 (5.6)	
>151	0	0	0	0	
Number of MIS procedures performed as leading surgeon during last year					0.675*
I don't know	1	3	0	1	
<50	25	75.8	13 (86.7)	12 (66.7)	
51-100	6	18.2	2 (13.3)	4 (22)	
101-150	1	3	0	1 (5.6)	
>151	0	0	0	0	
Self-declared expertise					0.022*
I don't know	3	9.1	3 (20)	0	
Insufficient	10	30.3	7 (46.7)	3 (16.7)	
Satisfactory	8	24.2	3 (20)	5 (27.8)	
Good	11	33.3	2 (13.3)	9 (50)	
Very good	1	3	0	2 (11.1)	

* isher's exact test

a doctor begins performing MIS on patients, with no significant difference between experienced and inexperienced surgeons ($p = 0.736$). Table 3 shows the personal stance on integrating simulation training into training curricula.

Validation of the Simulation Model

Participants

Thirty participants were enrolled in the study. The median age was 45 years (interquartile range: 29.1–48.0). Eight participants (26.6 %) were female. Eighteen participants (60 %) were categorized as experienced, while 12 (40 %) were categorized as inexperienced. During the allotted 30 minutes, participants undertook tasks including the closure of the tracheoesophageal fistula (TEF) using clipper application, TEF division, pouch opening, and esophageal anastomosis using sliding knots. Silicone models were randomly assigned for the tasks. Content and face validity were evaluated using a post-simulation questionnaire.

Content Validity

Using a 5-point Likert scale, the majority of participants indicated that they found the 3D synthetic models of EA/TEF to be effective training tools for thoracoscopic EA/TEF training, with an average score of 4.6 ± 0.4. There was no significant difference between the inexperienced and experienced groups ($p = 0.851$). Nearly all participants agreed that synthetic EA/TEF models are valuable as training and educational tools, with an average score of 4.4 ± 0.7 ($p = 0.542$). However, participants expressed slightly less confidence in the model's utility for assessing a trainee's skill level (mean: 3.0 ± 0.8, $p = 0.116$). Importantly, there were no significant differences in mean scores for content validity between the experienced and inexperienced groups.

Face Validity

In the assessment of face validity, the experienced group evaluated various aspects of the simulator's realism using a 5-point scale. The mean score for the face validity of both models was 4.6 ± 0.7. However, the group of experienced surgeons rated face validity lower than

Table 3
Personal stance on integrating simulation training into training curricula.

	Overall n = 33	Overall %	Inexperienced n = 15 (45 %)	Experienced n = 18 (55 %)	p value
Do you have the opportunity to use laparoscopic simulators for training MIS skills at your workplace?					0.022**
Yes	17	52	11 (73)	6 (33.3)	
No	16	48	4 (27)	12 (66.7)	
How often can you use simulators at your workplace?					0.137**
I don't know	3	9	2 (13.4)	1 (5.5)	
More than once a week	6	18	5 (33.3)	1 (5.5)	
Less than once a month	8	24	3 (20)	5 (27.8	
I don't have the opportunity to train on simulators	16	49	5 (33.3)	11 (61.2)	
During your training on laparoscopic simulators, what can you utilize?					0.426**
Laparoscopic box simulators	20	60.1	11 (73.3)	9 (50)	
Analytical simulators	3	9.1	1 (6.7)	2 (11)	
VR simulators	2	6.1	0	2 (11)	
I don't have the opportunity	8	24.3	3 (20)	5 (28)	
Do you think regular simulation training improves MIS skills?					0.741**
I don't know	3	9.1	2 (13.4)	1 (5.5)	
Yes	29	88	13 (86.6)	17 (94.5)	
No	1	3	0	0	
Do you think the experience gained from regular simulator training is transferable to the operating room?					0.733**
I don't know	3	3	2 (20)	1 (5.5)	
Strongly agree	15	45.5	7 (46.7)	8 (45.5)	
Agree	14	48.5	5 (33.3)	9 (50)	
Disagree	1	3	1 (66.7)	0	
Strongly disagree	0	0	0	0	
How often should a doctor train on simulators to improve their MIS skills? (average training time of 60 minutes)					0.251**
I don't know	10	30.3	4 (26.7)	6 (33.3)	
More than once a week	12	36.3	8 (53.3)	4 (22.2)	
Less than once a week	10	30.3	3 (20)	7 (38.9)	
Less than once a month	1	3	0	1 (5.5)	
Should simulator training be part of the preparation for specialization in pediatric surgery?					0.290**
I don't know	5	15.2	1 (6.7)	4 (22.2)	
Strongly agree	10	30	6 (40)	4 (22.2)	
Agree	16	48.5	6 (40)	10 (55,4)	
Disagree	2	6.3	2 (13.3)	0	

(*continued on next page*)

Table 3 (*continued*)

	Overall n = 33	Overall %	Inexperienced n = 15 (45 %)	Experienced n = 18 (55 %)	p value
Strongly disagree	0	0	0	0	
Should it be mandatory to complete simulator training before a physician starts performing MIS on patients?					0.736**
I don't know	2	6	1 (6.7)	1 (5.5)	
Strongly agree	11	33.3	5 (33.3)	5 (27.8)	
Agree	15	45.5	7 (46.7)	9 (50)	
Disagree	4	12	1 (6.7)	3 (16.7)	
Strongly disagree	1	3	1 (6.7)	0	

** Chi-square test

the group of inexperienced ones, with scores of 3.5 and 3.9, respectively. Nevertheless, this difference was not statistically significant ($p = 0.083$). The working space received the lowest score (mean: 3.6 ± 0.8), and the group of experienced individuals significantly rated working space lower compared to the inexperienced group, with scores of 3.4 and 4.1, respectively ($p = 0.030$). Regarding the overall impression, the highest ratings in the physical attributes domain were for the overall impression and the usefulness of the tool to be included in the training of experienced pediatric surgeons, with mean scores of 4.5 and 4.6, respectively. A detailed breakdown of responses from all participants can be found in Table 4.

During the study implementation, participants were unaware of which models they would be using for tasks. In the expert group, 6 (33.3 %) participants successfully completed TEF closure with a clipper, TEF division, upper esophageal pouch opening, and made an incomplete anastomosis using 4 sliding knots. However, only 1 (8.3 %) inexperienced participant managed to suture the anastomosis with 4 stitches. Additionally, 8 (75 %) inexperienced participants managed to finish the task involving TEF closure and esophageal anastomosis with one sliding knot. Notably, significantly more sufficient stitches within the 30-minute time limit were made by experienced compared to inexperienced participants ($p = 0.006$).

Subsequently, they evaluated the models using the same questions on a 5-point Likert scale. Both models received high ratings in terms of overall impression, achieving scores of 4.9 and 4.5, respectively, without a significant difference ($p = 0.682$). The lowest scores were assigned in the assessment of content validity as a useful tool to be included in the training of novice pediatric surgeons, with scores of 3.1 for model 1 and 3.0 for model 2, also without significance ($p = 0.775$). When comparing both models, no statistically significant differences were observed in the indicators of the Likert scale parameters. Table 5 contains a comprehensive breakdown of responses from all participants.

Discussion

Minimally invasive techniques are increasingly adopted worldwide for various indications in pediatric surgery and are becoming the gold standard for certain procedures. The successful application of laparoscopic surgery in children has also led to its increased use in neonates and infants [19]. Performing MIS is technically more challenging than conventional open surgery, with higher complication risks during initial proficiency stages, increasing the demand for well-trained and certified laparoscopic surgeons [4]. To support the safe implementation of laparoscopic approaches, early and intensive training is required. Our study highlighted that MIS experience between the experienced and inexperienced groups was almost the same, with a mean number of procedures assisting at 66.7 %. Satisfaction with surgical skills in MIS was

Table 4
Model validation: results from the Likert Scale Survey (n = 30).

	Inexperienced group (n = 12)	Experienced group (n = 18)	Overall (n = 30)	p value
Content validity (mean score [SD])	4.6 [0.7]	4.5 [0.6]	4.3 [0.8]	0.576*
Useful as thoracoscopic EA/TEF training tool (for surgeon) (mean score [SD])	4.7 [0.5]	4.8 [0.4]	4.6 [0.4]	0.851*
Useful as training and educational tools (for surgeon and students) (mean score [SD])	4.5 [1]	4.6 [0.6]	4.4 [0.7]	0.542*
Useful tool to be included in an MIS pediatric surgeon training curriculum (mean score [SD])	4.3 [0.4]	4.7 [0.4]	4.5 [0.6]	0.575*
Useful tool to be included in the training of novice pediatric surgeons (mean score [SD])	3.1 [1.0]	2.9 [0.6]	3 [0.8]	0.683*
Useful tool to be included in the training of intermediate pediatric surgeons (mean score [SD])	4.1 [0.5]	3.7 [0.7]	3.7 [0.6]	0.116*
Useful tool to be included in the training of experienced pediatric surgeons (mean score [SD])	4.6 [0.5]	4.9 [0.2]	4.6 [0.5]	0.455*
Face validity (mean score [SD])	3.9 [0.1]	3.5 [1.3]	4.6 [0.7]	0.083*
Realism of experience (mean score [SD])	4 [0.7]	3.8 [0.7]	4 [0.8]	0.223*
Positioning of TEF and esophageal pauches (mean score [SD])	3.9 [0.6]	4 [0.6]	4 [0.7]	0.411*
Haptic feedback on materials (mean score [SD])	4.1 [0.3]	3.7 [0.5]	4 [0.9]	0.542*
Working space (mean score [SD])	4.1 [0.7]	3.4 [0.9]	3.6 [0.8]	0.030*
Difficulty (mean score [SD])	3.9 [0.4]	3.9 [0.6]	3.8 [0.7]	0.210*
Overall impression (mean score [SD])	4.6 [0.4]	4.6 [0.5]	4.5 [0.3]	0.202*

* Fisher's exact test

significantly higher in the experienced surgeon group compared to the inexperienced group ($p = 0.022$), with the inexperienced group performing fewer than 50 MIS procedures as the lead surgeon in the last year. Widder et al. demonstrated in a prospective randomized controlled trial that participants showed a significant increase in performance throughout the laparoscopic course [20], other studies proved the likelihood of laparoscopic skill transfer from training to the clinical setting [21,22] in particular the Fundamentals of Laparoscopic Surgery (FLS) technique [23]. Torricelli et al. concluded that a short period of training can improve laparoscopic surgical skills, though it is often insufficient to confer full laparoscopic expertise. Nevertheless, this brief training period can enhance laparoscopic practice among surgeons in their communities. Comprehensive laparoscopic training in medical residency or fellowship programs is the most effective way to promote the widespread adoption of laparoscopic techniques [1]. However, working-hour restrictions and a high administrative workload severely limit the time young surgeons spend in the operating theatre. Adequate exposure time poses a major challenge to surgical education and the development of laparoscopic skills. Our survey focused on simulation training in institutions, finding that while 52 % of surgeons reported the availability of simulators for MIS training, experienced surgeons rated their access to simulators significantly lower than inexperienced ones (11 [73 %] vs. 6 [33.3 %], $p = 0.022$). Across all centers, 18.2 %

Table 5
Models validation: results from the Likert Scale Survey (n = 30).

	Model 1 (n = 16)	Model 2 (n = 14)	p value
Content validity (mean score [SD])	3.9 [1.1]	4 [1.0]	0.812*
Useful as thoracoscopic EA with TEF training tool (for surgeon) (mean score [SD])	4.8 [0.6]	4.5 [1.1]	0.657*
Useful as training and educational tools (for surgeon and students) (mean score [SD])	4.8 [0.9]	4.1 [1.1]	0.669*
Useful tool to be included in an MIS pediatric surgeon training curriculum (mean score [SD])	4.7 [0.9]	4.9 [0.7]	0.773*
Useful tool to be included in the training of novice pediatric surgeons (mean score [SD])	3.1 [1.2]	3 [1.2]	0.775*
Useful tool to be included in the training of intermediate pediatric surgeons (mean score [SD])	4 [0.8]	3.2 [1.3]	0.771*
Useful tool to be included in the training of experienced pediatric surgeons (mean score [SD])	4.9 [0.8]	4.5 [0.9]	0.603*
Face validity (mean score [SD])	3.6 [0.1]	4 [0.1]	0.894*
Realism of experience (mean score [SD])	4 [0.9]	4.1 [0.9]	0.159*
Positioning of TEF and esophageal pauches (mean score [SD])	3.9 [0.9]	4.4 [0.8]	0.062*
Haptic feedback on materials (mean score [SD])	4 [0.7]	4.2 [0.8]	0.387*
Working space (mean score [SD])	3.8 [0.4]	3.9 [0.9]	0.722*
Difficulty (mean score [SD])	4.1 [0.9]	4.1 [1.0]	0.571*
Overall impression (mean score [SD])	4.9 [0.8]	4.5 [0.5]	0.682*

* Fisher's exact test

of participants had access to surgical simulation training facilities at least weekly, whereas 48.5 % reported no access to simulation training.

In contrast, Schlottman et al., in an online survey focused on simulation capacities and activities, as well as chairs' perceptions of the value and purpose of simulation in the Department of Surgery in the United States, demonstrated that 98 % of respondents have a simulation center in their institution, and 95 % have a formal simulation curriculum. In this study, most chairs felt that simulation improves patient safety (72 of 84; 86 %) and is useful for practicing surgeons (68 of 84; 81 %). However, only 40 % reported that faculty use simulation to maintain technical skills, and only 17 % reported using simulation to address high complication rates [24]. These differences are mainly due to insufficient healthcare financing and low technical progress in our institutions; however, 88 % of respondents believe that regular training on simulators improves MIS skills, and 76 % believe that simulator training should be part of specialization preparation.

Traditionally, training has been based primarily on the apprenticeship model and mentoring. However, without strict supervision, this approach can increase the risk of treatment failure and expose patients to higher complication risks. In the current era, where maintaining competency, patient outcomes, and safety are increasingly scrutinized, it is important to critically consider alternative training methods beyond the traditional apprenticeship model [25]. An alternative is simulation based training, using inanimate or animate simulation models. We have previously reported our experiences with a synthetic 3D-printed inanimate model for thoracoscopic repair of EA/TEF, consisting of three components: a baseplate, a ribcage model, and an internal fixator model. The models used in this study are considered effective training tools for thoracoscopic EA/TEF practice, with an average score of 4.6 ± 0.4. Additionally, there were no significant differences in the opinions of participants who agreed that synthetic EA/TEF models are valuable as training and educational tools, with an average score of 4.4 ± 0.7 (p = 0.542). However, participants expressed slightly less confidence in the model's utility for assessing a trainee's skill level (mean: 3.0 ± 0.8, p = 0.116) [17]. Similarly, Barsness and colleagues described a low-cost synthetic tissue EA/TEF repair simulation model [26]. The highest rated items were the value of the simulator as a training tool (4.4), physical attributes - chest circumference, chest depth, and intercostal space (4.3), and realism of experience - realism of the location of the "fistula" (4.3) [26]. In our study, realism of experience was rated 4.0, with no difference between the two available models. Böckerink and colleagues described a low-cost procedural model for EA repair without TEF, consisting of two rubber balloons separated on a suture pad inside a laparoscopic box trainer. It was perceived as useful as a training tool, and scored 3.8/5 (± 0.8) for visual realism and 3.6/5 (± 0.8) for tissue haptics [27]. Our study shows that experienced surgeons rated the working space at 3.4 and face validity at 3.5, which were the lowest scores. Additionally, there was no significant difference in face validity between the models. Similar scores for anatomical and surgical realism were obtained in a study conducted by Neville et al. (4.2/5 and 3.9/5), as in Wells et al. (3.6/5 and 3.6/5), and Barsness et al. (4.1/5 and 4.2/5) [26,28,29].

There are several limitations to this study. First, the sample size was small, which may have decreased the precision of the measures and should be considered when interpreting and applying the findings. The relatively small number of participants was due to conducting the study within the congress and wanting to allow as many participants as possible to take part. Additionally, the time allotted to complete the task was demanding, making it impossible to sew a complete esophageal anastomosis. For respondents with no experience in intracorporeal suturing, the task was particularly challenging. The definition of inexperienced and experienced groups was based on years of experience rather than the number of EA/TEF operations performed. Questions regarding the number of individual MIS procedures were omitted to simplify the questionnaire. Furthermore, the visual realism of the models is limited due to the low-budget nature of the model. Consequently, the focus was mainly on the suturing tasks of the procedure rather than the dissection required. The simulators are not designed specifically for newborn MIS training, and we only had 5 mm instruments available for use in the analytic simulator.

In conclusion, this survey indicates that MIS techniques in pediatric surgery are still underutilized by many surgeons. A key factor in increasing the adoption of MIS is incorporating simulation education into the surgical curriculum. Simulation is becoming essential for teaching technical skills to trainees in a safe environment, especially with the advent of new devices and procedures. Practicing a procedure in a simulation center before performing it on a patient offers significant advantages.

Pediatric surgery is increasingly using high-fidelity simulators to enhance technical skills for bedside and operative cases. Studies evaluating these models have focused on face and content validity (how realistic a simulation subjectively feels) compared to construct validity (the objective accuracy of the simulation in representing a real task). We developed and validated a cost-effective simulation model for open OA-TOF repair, which was highly regarded by both experienced and inexperienced pediatric surgeons for its realism and usefulness in skill acquisition. Participants, both novice and expert, found the simulator realistic and relevant for pediatric surgical training.

Including validated performance measures on the simulator provides critical benchmarking data, which will be important for future studies on the use of the simulator in pediatric surgical training curricula. For further use, it is necessary to evaluate construct validity and objectively measure performance on the model, and these assessments are planned for the future.

CRediT authorship contribution statement

Zahradníková Petra: Writing – original draft, Visualization, Validation, Resources, Methodology, Funding acquisition. **Hnilicová Silvia:** Writing – review & editing, Validation, Supervision, Resources, Formal analysis. **Lindák Martin:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Pechanova Re-**

beka: Writing – review & editing, Resources, Methodology. **Števková Dominika:** Methodology, Formal analysis, Data curation, Conceptualization. **Vitovič Pavol:** Supervision, Resources, Methodology, Investigation. **Laurovičová Miroslava:** Visualization, Project administration, Methodology, Conceptualization. **Horn František:** Writing – review & editing, Validation, Supervision. **Tvrdoň Tomáš:** Visualization, Validation, Methodology. **Babala Jozef:** Writing – original draft, Supervision, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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