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Review article

Characteristics of hysteroscopic training models: A review of the literature

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A R T I C L E I N F O

Keywords:
Hysteroscopy
Model
Simulation
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A B S T R A C T

Objectives: The purpose of this review is to summarize the characteristics and applications of current hysteroscopic training models.
Methods: We conducted a systematic search of PubMed, Embase, and Cochrane Library for eligible studies published before March 2024. Manual screening of references and citation tracking were also performed.
Results: Reported hysteroscopic training models included virtual reality simulators, non-biological material models, plant tissue models, animal tissue models, and human tissue models. No training model was distinctly superior in terms of realism, haptic feedback, availability of standardized scoring of operations, preparation difficulty, reusability of surgical procedure, and prices. Utilizing any type of models for hysteroscopy simulation training could assist trainees in enhancing relevant knowledge, skills, self-confidence, and comfort, but virtual reality models had an advantage in training capacity.
Conclusions: Each hysteroscopic training model has its advantages and disadvantages. An appropriate training curriculum is needed to efficiently leverage the merits of different models. The realism and training effectiveness of various training models need to be compared using rigorously designed studies and standard evaluation tools.

1. Introduction

Hysteroscopy is a crucial minimally invasive technique for diagnosing and treating pathologies inside the uterine cavity [1,2]. If residents have never had systematic training before performing hysteroscopy, the likelihood of intraoperative problems such as uterine adhesions, failure of hysteroscope placement, severe endometrial injury, uterine perforation, hemorrhage, and electrosurgical injury is greatly increased [3,4]. Hence, before performing hysteroscopic procedure, residents must receive thorough training and assessment to ensure they develop sufficient hysteroscopic competency.

One-on-one apprenticeship instruction in the operating room is the classic hysteroscopic training method, but it has a long learning curve [5]. Residents work under the supervision of surgeons after seeing performance and receiving guidance from them in the operating room. This training approach is ineffective and significantly increases the duration and financial burden of hysteroscopic

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education [6,7]. Besides, novices may find it challenging to systematically and effectively acquire hysteroscopic skills through this training mode since they lack opportunities for hands-on training. Simulation has emerged as a pivotal method in training novices for the execution of hysteroscopic procedures [8]. It is more advantageous than traditional training in terms of patient safety, training effectiveness, and economic benefits. Therefore, in recent years, the use of simulation technology has received increasing attention and application. Prior studies have primarily shown that hysteroscopy simulation training can enhance residents' knowledge, technical skills, self-confidence, and comfort [9,10]; however, a comprehensive analysis of the benefits and drawbacks of hysteroscopic training models has not been provided. This paper aims to summarize the characteristics and applications of the hysteroscopic training models and then look forward to future research directions for hysteroscopic simulation training.

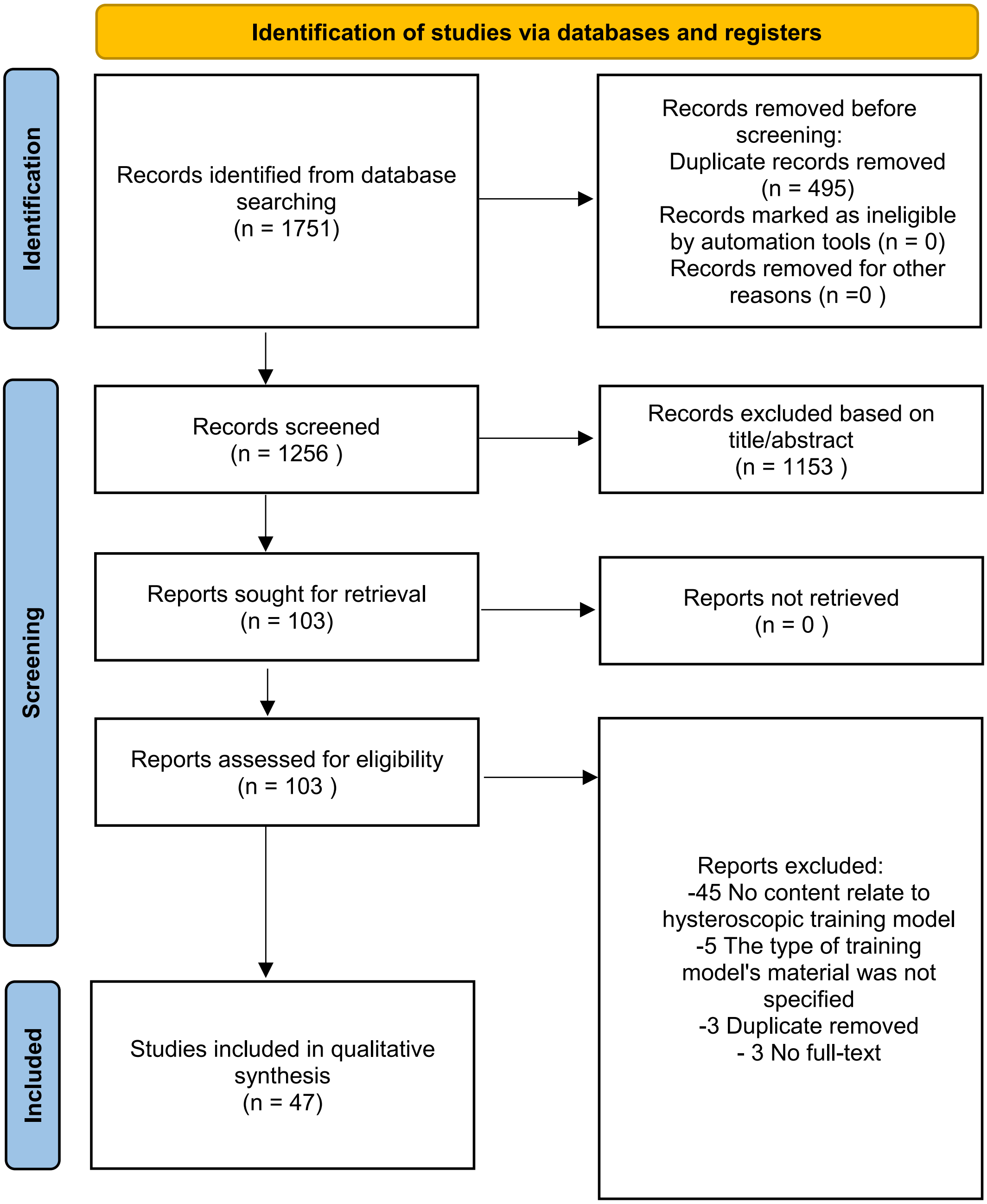

Fig. 1. PRISMA Flowchart

2. Materials and methods

2.1. Search strategy and study selection

We conducted searches in PubMed, Embase, and Cochrane to identify eligible studies published before March 2024. Our search terms comprised (hysteroscopy OR hysteroscope OR hysteroscopic OR gynecologist OR hysteroscopist) AND (simulation OR simulator OR model OR training OR trainer), and detailed search strategies were given in Supplementary Table 1. Moreover, we conducted cross-referencing of the references in the included studies to guarantee thorough coverage in the online search.

Studies were included if they provided a description of the characteristics of the hysteroscopic training models or explored the application of the hysteroscopic training models. Studies were excluded if no full text could be found or the training model's material was not specified.

2.2. Data extraction

Two authors (B·W·Y and J.J) independently extracted the main study characteristics using standardized forms. Discrepancies were resolved by a third author (L.Z.Y). The main study characteristics included country, study content, model, number of the population in each group, training curriculum and hysteroscopic skill, comparison, parameter, and conclusion.

2.3. Data synthesis

Data reported in the publications were synthesized narratively. Due to the variation in models, participants, and study designs among the eligible studies, there was significant heterogeneity between them. Consequently, it was not feasible to statistically aggregate the results of the different studies.

3. Results

3.1. Search results

A total of 1751 articles were identified, out of which 103 underwent full-text review and 47 studies published between 2001 and 2023 were included (Fig. 1). Among them, 26 articles introduced hysteroscopic training models [11–36], while 44 articles investigated the training effect of utilizing these models [11–20,37–43]. Detailed information of these investigations was summarized in Supplementary Tables 2–7.

3.2. Advantages and disadvantages of different traning models

3.2.1. Virtual reality simulator

A virtual reality simulator employs computer technology to depict the positioning and interrelations of anatomical structures within a three-dimensional space [44]. It establishes an authentic interaction between the user and the system while digitally recreating the surgical environment for simulation purposes. According to published articles [11–19,37–42], virtual reality simulators can simulate several hysteroscopic procedures, including diagnostic hysteroscopy, Essure sterilization, polypectomy, myomectomy, septum resection, and rollerball endometrial ablation.

The following advantages are associated with the utilization of virtual reality simulators in hysteroscopy simulation training: 1. High-fidelity [11,14,16,36,37]: Virtual reality simulators can accurately simulate human anatomical structures and intraoperative problems such as uterine perforation, active bleeding, and difficult uterine distention, aiding trainees in simulating real surgical conditions as closely as possible and in enhancing their adaptability during surgery. 2. Facilitates repetitive practice [11–19]: The virtual reality simulators allow residents to perform repetitive exercises with multiple cases of differing degrees of complexity. This aids residents in developing particular hysteroscopic skills and progressively increasing surgical proficiency. 3. Real-time feedback [12–19]: After each operation, the virtual reality simulator provides real-time feedback to residents on surgical excision, operational safety, visual field management, and fluid management according to objective simulator metrics. This enables residents to immediately identify shortcomings and make targeted improvements [17]. Furthermore, by analyzing the scores of multiple operations, residents can know their learning curve [4].

Virtual reality simulators have the following limitations: 1. Lack of haptic feedback: Virtual reality simulators are difficult to simulate the resistance and elasticity of human tissues, nor can they distinguish between appropriate and excessive tool contact with the uterine wall [11,12,16]. 2. Lack of standardized evaluation parameters: Currently, the assessment of the learning curve depends on the completion quality of simulator metrics [12–19]. However, the clinical significance of these indicators has not been verified, and there is still controversy regarding which indicators should be used as evaluation criteria. 3. Expensive cost: The price of virtual reality simulators is expensive due to the difficulty of their manufacture and the need for specialized supporting equipment.

3.2.2. Non-biological material model

Non-biological material models refer to a type of training model that simulates the structure of human tissues using non-biological materials such as silicone and plastic. Published articles reported that diagnostic hysteroscopy, myomectomy, polypectomy, biopsy, and foreign body removal are the main procedures taught using non-biological material models in hysteroscopy simulation training [20–25,38,43,45–51].

The following are the key benefits of employing non-biological material models in hysteroscopy simulation training: 1. Moderate-fidelity [22,36,47,49]: During the preparation process of non-biological material models, the shape, thickness, size, and other morphological structures can be easily adjusted. Consequently, the female reproductive system's anatomical structure can be approximately simulated. Some studies reported that specially shaped polymer material plates can be used to simulate the female reproductive system. The uterine cavity could be covered with chloroprene rubber film to simulate distension of the uterine cavity, while the cervix and cervical canal were made of flexible polymer materials [52]. However, the realism of some non-biological material models still needs to be enhanced. For example, the Hysteroscopic Skills Training and Testing model features designated areas for both the "cornua" and "tubal ostium," situated in close proximity without additional indicators to distinguish between these anatomical terms. Consequently, these locations were often confused, even by numerous experts [22]. Thus, improving the morphological structure of the model and employing silicone material that offers realistic color effects may contribute to increasing realism. 2. Easy to simulate various uterine cavity pathologies: Existing studies reported that non-biological material models could simulate different intrauterine diseases, such as submucosal fibroids, intrauterine polyps, uterine anomalies, and intrauterine adhesions, by replacing different silicone gel component modules [52].

Non-biological material models mainly have the following drawbacks: 1. Lack of haptic feedback [23,49]: Non-biological materials cannot realistically simulate the elasticity and resistance, thus being unable to provide authentic haptic feedback. 2. Unable to simulate intraoperative emergencies: Inevitably, unexpected situations such as uterine perforation and bleeding may occur during hysteroscopic surgery. Residents need to know how to manage certain situations in particular. However, current non-biological material models cannot simulate such unforeseen circumstances. 3. Moderate cost: There were only two studies that introduced the price of the moderate-fidelity non-biological material hysteroscopic training model. The reports didn't specifically describe the preparation process of the models, but the price of the reusable hysteroscope training device is $407, while the price of the replaceable uterus model part used for surgical training is $61 [20,21], which is primarily caused by the production challenges. In addition, some models are made from plastic bottles or are 3D-printed. Although they possess lower cost, they are low-fidelity and only suitable for teaching some basic skills [50,51].

3.2.3. Plant tissue models

Plant tissue models are a type of model that simulates the anatomical structure of the human tissue by processing plant materials. According to published articles [31,32,34,35,53–56], plant tissue models that can be used for hysteroscopy simulation training include potatoes, butternut pumpkins, pepper, and brinjal. These models can simulate hysteroscopic procedures such as diagnostic hysteroscopy, endometrial ablation, polypectomy, septum resection, and biopsy.

Using plant tissue models for hysteroscopy simulation training has the following advantages: 1. Easy to obtain: Potatoes, butternut pumpkins, pepper, and brinjal are widely available, inexpensive, and easy to prepare. The butternut pumpkin and pepper model has pre-formed cavities that are similar to the uterus, and the texture of the flesh is similar to the endometrium, making it easy to prepare as a hysteroscopic training model [32,33]. The preparation process for the potato model is more complex compared to the butternut pumpkin and pepper. It requires freezing and thawing to improve its cuttability, puncturability, and compressibility. Staining is also needed to enhance the realism of the model's appearance. Anatomical cavity and opening is established to simulate the internal structures of the uterine cavity and cervix [31]. 2. Practicality: Peppers contain grains and strips that can simulate polyps and uterine septa [35]. The seeds inside the butternut pumpkin provide a good target for practicing grasping and removal. It also allows for the passage of electricity, making it more suitable for simulating electrosurgical procedures [32]. When using the butternut pumpkin model for diagnostic examinations, residents can insert the hysteroscope component into the non-stem end of the butternut pumpkin for exploration. This operation can help residents understand the impact of the optical device angle on the view and the relationship between gas and fluid. Besides, filling the cavity with a non-conductive solution aids in comprehending the effects of refraction and fluid on the flesh and seeds. During simulated surgery, residents can practice biopsy techniques by removing butternut pumpkin seeds and flesh, and practice hysteroscopic adhesiolysis by dividing the fibrous flesh. The butternut pumpkin without seeds and flesh can be used for practicing endometrial and fibroid resection.

Plant tissue models have the following limitations: 1. Low-fidelity [33,34,36]: Plant tissue models can be processed to be more morphologically similar to human anatomical structures, but they are unable to simulate the genuine anatomical morphology of human tissue. Thus, they seem more suitable for practicing basic hysteroscopic skills, such as camera navigation and perforation biopsy. Teaching more complex hysteroscopic skills, such as fluid distension and cervical dilation, requires models with higher fidelity for training. 2. Low haptic feedback [33]. 3. Unable to simulate intraoperative emergencies [31,32].

3.2.4. Animal tissue model

Animal tissue models refer to a type of training model that uses organs and tissues from animals to simulate human organs and tissues. When selecting animal tissue models, the similarity between their anatomical structure and that of the human tissue needs to be considered. Previous studies have reported that pig bladders [26,27,57,58], pig uterus [26], cow uteruses [28,30], cow rumen [29], cow bladders [30,59], and cow tongue [60] are the more suitable animal tissue models for hysteroscopy simulation training. Using these models, various routine hysteroscopic procedures such as diagnostic hysteroscopy, endometrial resection, septum resection, IUD retrieval, endometrial ablation, and ablation of simulated lesions and synechiae can be simulated.

Using animal tissue models for hysteroscopy simulation training has the following advantages: 1. Moderate-fidelity: Pig bladders, pig uterus, cow uteruses, cow rumen, and cow bladders are all hollow muscular organs that can preferably simulate the anatomical structure of the human uterus. 2. Good haptic feedback: Since animal tissue models can simulate the flexibility, resistance, and tactile sensations of human tissues, residents can learn to modify their actions based on the haptic feedback [29,30,49]. 3. Simulating surgical emergencies: Using animal tissue models can simulate potential issues encountered during actual operations, such as blurred vision caused by tissue floating, generation of bubbles during electrocautery, and uterine perforation during surgery [27]. This aids trainees in mastering surgical techniques and increasing adaptability. 4. Easy to obtain: Animal tissue models are widely available and relatively easy to prepare [26,29]. However, it should be noted that cow cervixes are longer than human cervixes, so the cow cervix needs to be shortened to a maximum of 2 cm to better simulate the human cervix [59]. To prevent the flushing fluid from flowing out, porcine bladders and bovine bladders need to have their ureteral openings plugged before use, and bovine uteruses need to have their oviductal openings plugged before use. 5. Strong operability: In order to increase practicality, animal models can be modified. For example, pig bladders can be fixed in a box to simulate a retroverted or anteverted uterus or be tied to simulate a bicornuate uterus. A meatball can be sutured inside the cavity to simulate an endometrial polyp or leiomyoma of the uterus [27,29]. A long suture can be sewn on the anterior and posterior walls of the bladder to simulate the pressure of uterine septum [26]. The open end can be turned over and tightened with numerous rubber bands to simulate the cervical canal and the isthmus [29]. The packed rumen is placed on a closed metal support, which allows it to expand [29].

Animal tissue models have several limitations in practical applications. 1. Animal tissue models still differ from human tissue: The uterine cavity in humans and many animal tissue models vary in size and shape. Consequently, animal tissue models are still unable to accurately replicate human tissue, despite the fact that they can be used to imitate a variety of hysteroscopic procedures. For example, the bovine cervix is wider than the human cervix, so it cannot simulate the potential difficulties in inserting the lens and dilating the cervix during hysteroscopic surgery. In addition, the bovine uterus has thicker endometrium compared to the human uterus, which poses certain limitations in simulating endometrial resection [59]. 2. Unable to simulate intraoperative bleeding [30]: Bleeding is inevitable during surgery. However, animal tissue models are only partial in vitro tissues and cannot simulate the realistic bleeding that occurs during surgery. 3. Moderate cost: In addition to the expense of the animals, large and well-equipped operating rooms are required to guarantee that the animals are cared for and sacrificed in humane ways [23,30,36,61].

3.2.5. Human tissue models

Chatzipapas et al.'s manuscript reported using a human uterus model for diagnostic hysteroscopy simulation training for the first time [36]. The uterine model consisted of a human uterus obtained from women who underwent surgery for benign pathologies and was extracted following a hysterectomy.

Using human tissue models for hysteroscopy simulation training has the following advantages: 1. Excellent realism and haptic feedback: Human tissue models can realistically simulate the actual conditions of hysteroscopic procedures. Trainees may be tasked with the challenge of navigating the uterine cavity's pathway and identifying all anatomical landmarks. Furthermore, uteri procured through hysterectomies might contain pathological entities, including polyps, fibromas, and septa, thereby providing residents with the opportunity to diagnose these pathologies. 2. Widespread availability: All uteri resected due to benign diseases can serve as models. 3. Low cost: The specimens themselves do not require expenditure; only the process of specimen transportation incurs labor costs.

Human tissue models have several limitations in practical applications.1. Potential ethical issues: Despite the authors outlining protective measures for the ex vivo uterus (each uterus was transferred in special containers labeled with patients' information, different hysteroscopies were used for different uterine specimens, strict timekeeping of training before put uterine specimens in formalin solution and returned them to the pathology department for further evaluation, etc), there remains a potential for misidentification, affection of pathological examination or contamination of the uterus. 2. Unable to simulate intraoperative bleeding.

3.3. Traning effect of different training models

3.3.1. Virtual reality simulator

15 studies investigated the applications of virtual-reality simulators. The curriculum of hysteroscopy simulation training included single hands-on simulator practice [11,14,16,19,38,39]; theory teaching and hands-on training with pre-test and post-test [17,41] or only with post-test [18]; and repetitive hands-on training with or without a time interval [12,13,15]. Overall, 5 studies assessed sterilization procedures [14–16,40,41]; 7 studies assessed surgical hysteroscopic skills [11,13,18,19,37,38,42]; 3 studies assessed diagnostic hysteroscopic skills [11,12,40]; and 1 study assessed theoretical knowledge [41].

8 studies were conducted to assess the hysteroscopic performance of people with varying hysteroscopic experiences on virtual reality simulators [12–14,16–19,42]. The findings indicated that the expert group performed better in the majority of the procedures. 9 studies that contrasted trainees' performance before and after training showed that increasing hysteroscopic practices enhanced trainees' theoretical understanding and technical competence [12,13,15,17,38–41], and even improved the performance of trainees in real surgery [42].

2 studies reported a learning plateau phase as the number of repetitions increased. In Bajka et al.'s study, medical students reached a plateau in trials 9 and 10 in the visualization trial [12]. In Janse et al.'s study, for medical students, a plateau phase was recognized at the fifth or seventh repetition in some metrics (patient comfort, trauma, and correctly placed micro-inserts) and all tested metrics approached expert levels after 9 to 14 repetitions (performance time, path length, patient comfort, trauma, mean Global Ratings Scale (GRS) score, and correctly placed micro-inserts) [15]. These findings suggest that a certain number of repetitions can significantly enhance novices' hysteroscopic skills.

3 studies also tested skills retention. Bajka et al. found that students' performance in visualization exercises dropped slightly after 2 weeks while there was no drop in diagnosis exercises [12]. Janse et al. found that medical students did retain hysteroscopic skills after

a 2-week time interval [15]. Remarkably, in Patel et al.'s study, 3-month repeat assessment by Objective Structured Assessment of Technical Skills (OSATS) showed retention of skills in all residents [39].

The aforementioned studies' results collectively indicated virtual reality simulators can effectively assist trainees in significantly enhancing their operative skills and knowledge. Performance of skills reached a plateau after a small number of practices and had good retention of hysteroscopic skills. These evidences underscored the necessity of using a virtual reality simulator for hysteroscopy simulation training.

3.3.2. Non-biological material model

15 studies investigated the applications of non-biological material models [20–25,38,43,45–51]. The curriculum of hysteroscopy simulation training included single hands-on simulator practice [38]; theory teaching and hands-on training with pre-test and post-test [21,43,45] or only with post-test post-test [20,24,46,49,51]; repetitive hands-on training with or without a time interval/educational instructions [20,22,23,25,48]. 3 studies assessed technical skills [20,21,24,25,38,45,48–50]; 6 studies examined sterilization procedures [43]; 3 studies assessed diagnostic hysteroscopic skills [22,23,25,46,49]; and 2 studies assessed theoretical knowledge [21,43]. Overall, these studies demonstrated that both technical skills and theoretical knowledge were enhanced with simulation training. Besides, hysteroscopic experience is positively correlated with performance on training models.

5 studies explored the effects of repetitive hands-on practices on trainees. In Janse et al.'s study [22], novices progressed towards expert level in performance time and reached a plateau at the seventh repetition, while experts performed stably after their first exercise. However, the two plateau phases did not coincide. The learning curve analysis for the GRS indicated that experts experienced an improvement in their scores up to the seventh repetition, whereas no plateau phase was observed in the learning curve of novices. In Huang et al.'s study, gynecologists with different hysteroscopic experiences reached a plateau in suture time after 18 to 27 repetitions [48]. In Panazzolo et al.'s study [25], with the increase in the number of repetitions, residents' scores of procedure-specific checklists were significantly improved, and the performance time was significantly shortened, but the improvement of experts was not obvious. Neither experts nor residents reached the plateau after five repetitions. VanBlaricom et al.'s study [20] and Hernansanz et al.'s study [23] both reported a significant improvement in trainees' abilities with an increase in the number of hands-on practices.

Three studies tested skills retention. In Janse et al.'s study, students' performance time increased and GRS showed no significant decrease after the 2-week interval, and a significant improvement of performance time and GRS was observed by repetitive hands-on practices, indicating a prolonged learning curve [22]. Burchard et al. found that residents' hysteroscopic skills and knowledge increased after a 1-month interval, but decreased after a 6-month interval (Still better than before training) [21].

These findings suggest that non-biological material models have a sufficient capacity for training. It is important to note that repeated hands-on practices are effective, but the efficacy of simulation training may diminish over time, necessitating the repetition of such training at short intervals for sustained benefit.

3.3.3. Plant tissue model

7 studies investigated the applications of animal tissue models [31,32,34,35,53–56]. The curriculum of hysteroscopy simulation training included single hands-on simulator practice [54]; theory teaching and hands-on training with pre-test and post-test [53]; and repetitive hands-on training [35]. Overall, 7 studies assessed surgical hysteroscopic skills [31,32,35,53–56]; 3 studies assessed diagnostic hysteroscopic skills [32,34,54]; and 1 study assessed theoretical knowledge [34]. These investigations revealed that hysteroscopy simulation training improved trainees' theoretical knowledge and technical skills. No studies reported on the content related to learning curves.

3.3.4. Animal tissue model

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The curriculum of hysteroscopy simulation training included single hands-on simulator training [28]; and theory teaching and hands-on training with pre-test and post-test [29] or only with post-test [27]. Overall, 6 studies assessed surgical hysteroscopic skills [26–29,37,60,62]; 3 studies assessed diagnostic hysteroscopic skills [27,29,62]; and 1 study assessed theoretical knowledge [29]. In summary, these studies demonstrated that trainees' technical skills and theoretical knowledge were enhanced through hysteroscopic practice. However, none of the studies addressed content about learning curves.

3.3.5. Comparison of training effect among different models

4 studies compared the training capacity and realism of different training models. The study conducted by Goff et al. [38], found that the virtual reality simulator (HystSim) had better interrater reliability and reliability when compared to the Synthetic uterus. Besides, the study conducted by Glazerman et al. [37]. found that the virtual reality simulator (HystSim) was better in training capacity but had similar realism when compared to the pig bladder model. Chan et al. [49] compared the 3D-print model with the pig bladder model and found the time taken to complete the tasks and performance scores were not significantly different between the models; the participants preferred the 3D-printed simulator for ascertaining direction of uterus and locating cervical os, whereas the pig bladder model was ranked superior for resection procedures; however, the pig bladder model won more preference for providing a realistic training experience. Kingston et al.'s study [32] compared the Hysteroscopic Resection Trainer with the butternut pumpkin and indicated residents exhibit a preference for the butternut pumpkin.

No studies have directly compared the learning curves of different models. The same authors investigated the learning curve of hysteroscopic sterilization on a virtual reality simulator (HystSim) [15] and a non-biological material model (Hysteroscopic Skills Training and Testing box trainer) [22]. The learning curves of both training models showed similar shapes, indicating an adequate training capacity of repetitive training for both models. Concerning performance time, the novices learned somewhat faster and reached a plateau phase within nine repetitions on the non-biological material model in comparison to the virtual reality simulator. Regarding the Global Rating Scale score, the novice group showed a slightly greater improvement in clinical skills on the non-biological material model.

4. Discussion

4.1. Comparison of hysteroscopic training models

Currently mentioned hysteroscopic training models in the studies include virtual reality simulators, non-biological material models, plant tissue models, animal tissue models, and human tissue models. The characteristics of different types of hysteroscopic training models are listed in Table 1. Virtual reality simulators can simulate realistic surgical conditions concerning tissue morphology, structure, and operation process, which is convenient for residents to practice repeatedly and can provide real-time feedback to residents on their performance. However, it is expensive and difficult to simulate the haptic feedback of human tissues. Non-biological models can moderately simulate the structure of human tissues, but it still remains challenging to simulate haptic feedback and can't simulate emergencies such as uterine perforation and bleeding that may occur during the operation. In addition, the prize of moderate-fidelity non-biological models is not cheap. Plant tissue models are widely available, inexpensive, and easy to prepare, but they have major shortcomings regarding realism. Animal tissue models are more realistic at simulating the haptic feedback and structural characteristics of human tissues, as well as a variety of surgical emergencies beyond intraoperative hemorrhage. However, it remains prohibitively expensive for widespread use. Human tissue models are realistic, possess haptic feedback, are easy to obtain, and with no price, but have some potential ethical problems. In terms of training capacity, utilizing any training model for hysteroscopy simulation training can assist trainees in enhancing hysteroscopic knowledge, skills, self-confidence, and comfort. Current research findings indicated that virtual reality models have an advantage in training capacity. Learning with a virtual reality simulator (HystSim) [15] and a non-biological material model (Hysteroscopic Skills Training and Testing box trainer) [22] exhibited similar learning curves.

In summary, the hysteroscopic training models are extremely variable and have their distinct characteristics Any type of simulation model can be beneficial to the trainees, and practicing with simulation models before performing actual hysteroscopic operations is essential. Due to the ethical problems in the application of the human tissue model, whether it can be accepted and widely used in hysteroscopy simulation training remains to be discussed by more studies. Disregarding cost factors, animal tissue models currently serve as the optimal simulation models for familiarizing trainees with haptic feedback, and virtual reality simulators are the best for repeated practice to understand the realistic structure of human tissues and potential intraoperative problems. If economic constraints exist, utilizing inexpensive and widely available plant tissue models and non-biological material models can also effectively assist operators in learning basic hysteroscopic procedures. When economic conditions permit, a curriculum that progresses from low-fidelity to high-fidelity simulators may facilitate learning for trainees [29]. For example, they can start with preparatory exercises on low-fidelity plant tissue models or non-biological models to get familiarized with the instrument. Then, by using moderate-fidelity non-biological models and animal tissue models, the trainees consolidate the movements to be used in diagnosed hysteroscopy and are challenged to perform simple operations. Finally, the virtual reality model was used to practice the complex hysteroscopy operation repeatedly. This incremental and progressive training method enables the trainee to methodically and efficiently acquaint themselves with the proper hysteroscopic procedure.

4.2. Limitations of hysteroscopic training models and related studies

There are many limitations in current hysteroscopic training models and related studies: 1) No model is superior in every aspect. 2) Research on hysteroscopic training models commonly lacks detailed descriptions of the characteristics of these models, such as the methodology of their construction, cost, reusability, and the problems encountered in educational settings. 3) Despite numerous academic institutions having carried out hysteroscopy simulation training, a well-recognized standardized curriculum for trainees

Table 1
Characteristics of different types of hysteroscopic training models.

Type of model	Realism	Rating of haptic feedback	Availability of standardized scoring of operations	Preparation difficulty	Reusability of surgical procedure	prices
Virtual Reality Simulator	High-fidelity [11,14,16,36,37]	low [18,36]	yes [12–19,23]	difficult [11–19,36]	yes [11–19]	expensive [23,36]
Non-Biological Material Models	Moderate-fidelity [21,22,25,36,47,49,51] or low-fidelity [50,51]	low [23,49]	no	Medium [49] or low [50,51] to	part of the structure can [22,32,47]	Medium [20,36], low [25,50,51]
Plant Tissue Models	Low-fidelity [33,34,36]	low [33]	no	low [33–35,55]	no	cheap [33–35,55]
Animal Tissue Models	Moderate-fidelity [23,49]	high [29,30,49]	no	medium [29,36,49]	no	medium [23,30,36,61]
Human tissue models	High-fidelity [36]	high [36]	no	low [36]	no	no [36]

remains absent. 4) There is a lack of standardized assessment tools to evaluate the realism and training capacity of simulation models, as well as the knowledge and abilities of trainees affected by hysteroscopy training. Some studies used simulator metrics and OSATS to assess participant performance in simulated environments. Nonetheless, many studies still relied on subjective outcomes such as participants' opinions via a Likert scale. 5) There is a scarcity of studies comparing the educational effectiveness of various training models. Additionally, existing studies often lack a proper control group, mainly depending on comparisons before and after training of the same trainees, potentially leading to biased outcomes. This issue arises as trainees might simultaneously receive conventional training, complicating the attribution of learning outcomes to distinct factors. Moreover, if identical tests are given before and after the training, the improvement in test scores could be artificially enhanced due to trainees' increased familiarity with the same test. 6) Only a limited number of studies have evaluated the training effectiveness in clinical settings and no studies have demonstrated training impact on patient morbidity, mortality, quality of life, or hospital stay duration. This highlights the necessity for additional studies to explore the clinical transfer of hysteroscopy simulation training.

4.3. Prospects for hysteroscopic training models and related studies

Appropriate hysteroscopy simulation training can help reduce the waste of time and money in traditional surgical education in the operating room and unnecessary harm to patients, while also facilitating the rapid development of trainees into competent surgeons. To explore a better training model and method, several key considerations merit attention in future studies: 1) The ideal training model, which has a high simulation degree, can provide real-time assessment of various abilities, can stand up to repetitive use, and is not prohibitively expensive, can be used to prepare new physicians to be able to offer the safest, most efficient, and cost-effective surgery available. High-fidelity models are crucial for the enhancement of trainees' surgical skills. Models that encompass not just the uterus and its associated adjacent organs, vasculature, ligaments, and potential anatomical spaces are adept at simulating the complexities inherent in surgical procedures. Haptic feedback allows trainees to discern the resistance and texture of various tissues, thus augmenting their proficiency in executing intricate surgical maneuvers in the absence of direct visual cues. Prompt and precise feedback plays a crucial role in the expedited skill acquisition of residents. Thus, a validated assessment tool to describe the progress, plateau, and learning curves of both technical skills and theoretical knowledge in hysteroscopy is needed. Repetitive practice is essential for the mastery of skills, promoting the improvement of surgical skills and confidence among trainees. While errors are undesirable in the operating room, simulation training provides an opportunity for trainees to hone their skills through continuous practice and to circumvent avoidable errors [63,64]. For the existing training models, the haptic feedback of virtual reality simulators, non-biological material models, and plant tissue models needs to be improved; the price of virtual reality simulators needs to be reduced; the realism of non-biological material models, plant tissue models, and animal tissue models needs to be improved; the ethical problems in the application of human tissue models need to be carefully considered. 2) Based on the current studies [29,65], the hysteroscopy curriculum combines theory and hands-on training, aiming to teach instruments, indications, the basic principles of the surgical technique, and how to recognize and manage the pathologies can be an effective training approach. Theoretical knowledge can be imparted through lectures and videos, while hysteroscopic operations can be learned through repetitive practice from low-fidelity to high-fidelity models. Additional studies are needed to explore effective training methods. 3) There is a need for more rigorously designed studies that provide a comprehensive description of the characteristics of training models and compare the training effects of different models, especially regarding their impact on clinical treatment. The experiment should use well-established and reliable instruments to measure the realism, training capacity, and training effectiveness of the simulation model.

5. Conclusion

Current hysteroscopic training models include virtual reality simulators, non-biological material models, plant tissue models, animal tissue models, and human tissue models. Trainees can benefit from any type of hysteroscopic training models. No training model is distinctly superior in terms of realism, haptic feedback, availability of standardized scoring of operations, preparation difficulty, reusability, and prices. Virtual reality models are superior in training capacity. Appropriate training curriculum can help most efficiently leverage the advantages of different models. To decide which hysteroscopic training model and curriculum is better, meticulously planned studies comparing the training effects of various models and giving a thorough explanation of models' features are required, along with trustworthy instruments to measure the simulation model's realism, training capacity, and training effectiveness.

Data availability statement

Data sharing is not applicable to this article as no new data were created in this study.

CRediT authorship contribution statement

Wanying Bao: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Jin Jia:** Writing – review & editing, Methodology, Conceptualization. **Zhengyu Li:** Writing – review & editing, Project administration, Methodology, Conceptualization.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31698.

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