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REVIEW

Can Non-Virtual Reality Simulation Improve Surgical Training in Endoscopic Sinus Surgery? A Literature Review

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Abstract: Simulation in endoscopic sinus surgery allows residents to learn anatomy, to achieve the correct handling of various rhinological instruments, and to practice different surgical procedures. Physically or non-virtual reality models are the main items in endoscopic sinus surgery simulation. The objective of this review is to identify and make a descriptive analysis of non-virtual endoscopic sinus surgery simulators which have been proposed for training. As a new state of the art, surgical simulators are developed continuously, so they can be used to learn basic endoscopic surgery skills by repetitive maneuvers, permitting detection of surgical error and incidents without risk for the patient. Of all training physical models, the ovine model stands out because of the similarities of the sinonasal pathways, the wide availability, and the low costs. Considering the similar nature of the tissues involved, the techniques and surgical instruments can be used almost interchangeably with minimal differences. Every surgical technique studied until now has a degree of risk and the only aspects that consistently reduced the number of complications are training, repetition, and hands-on experience.

Keywords: simulator, training, physical, rhinology

Introduction

Simulation has been a key factor in the evolution of medical learning and practice since the 20th century, leading to higher precision and quality in medical training. A surgical procedure that is commonly used for reducing and improving symptoms of sinus infections and nasal obstruction is known as endoscopic sinus surgery. In order to provide superior patient care with minimal risk, the training of surgical residents and young specialists has become increasingly important. As a result, various methods have been researched to enhance their surgical techniques.[1–3]

Endoscopic sinus surgery provides multiple opportunities for instructing young doctors outside of the operating room. By utilizing simulation in rhinology surgery, residents can gain knowledge of anatomy, perfect the correct application of various rhinology instruments, and practice performing different surgical procedures.[4–6]

Residents must attain several fundamental surgical skills before they can conduct endoscopic sinus surgery. The camera and monitor system makes it challenging to comprehend the three-dimensional (3D) image of structures. Residents must create in their mind a 3D image of the sinus pathway anatomy from two-dimensional (2D) computed tomography (CT) scan images.[7] Endoscopic sinus surgery simulators can vary from cheap, low-fidelity physical models constructed from inexpensive products, to expensive high-fidelity virtual reality simulators.[8]

A simulator must be validated in different domains before it is found useful for training surgical skills. The European Association for Endoscopic Surgery (EAES) developed guidelines to define the principles of simulator validation.[9] Face validity describes the ability of a simulator to create a realistic environment that is comparable to the actual surgical method. This can be assessed using an instructor and a group of beginners through a structured questionnaire.[10] Content validity is the assessment of

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the simulator's ability to deliver what is required to be obtained. This is demonstrated by the achievement of pre-established teaching objectives. In surgical simulators, the content can be grouped globally, such as hand-eye coordination, manual dexterity, and specific content, which examines the importance of the model in learning a distinct task, such as foreign body removal from the airways or nasal packing. The basis for using any simulator for evaluation and feedback is construct validity. This type of validity is the simulator's ability to make a measurable difference between the different levels of expertise between beginners. Predictive validity is the ability of the simulator to estimate the actual performance of skills[11] and concurrent validity is the simulator's ability to resemble another simulator that has already been validated or is considered the gold standard.[7]

Despite the increasing popularity of virtual reality simulators at the beginning of the century, physically, or non-virtual reality models are the main items in surgical simulation because technology has not evolved the haptic capabilities of real-life simulation yet.

The primary aim of this review article is to comprehensively explore the various non-virtual endoscopic sinus surgery simulators that have been proposed and utilized for the purposes of training. The central focus of this analysis will be to provide a detailed and descriptive examination of these simulators, with the objective of identifying their unique features and characteristics. The ultimate goal of this investigation is to offer a more comprehensive understanding of the current state of non-virtual endoscopic sinus surgery simulators and to provide a basis for further research in this area.

Materials and Methods

We performed a general analysis of the studies published before 2023 about the models proposed and used for training in endoscopic sinus surgery. In this way, we have collected data from the MEDLINE, EMBASE, and OVID databases. Key terms used in the search for each database included "endoscopic sinus surgery", "rhinology", "simulation", "training". Also, the reference list of included studies was searched for other additional articles.

Were included articles that studied non-virtual physical simulators, task trainers, and cadaveric animal models proposed for training in endoscopic sinus surgery. Non-English language studies, conference abstracts and those not related to training using physical simulators were excluded. The literature review is presented in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A flow chart showing the literature review process is shown in Figure 1.

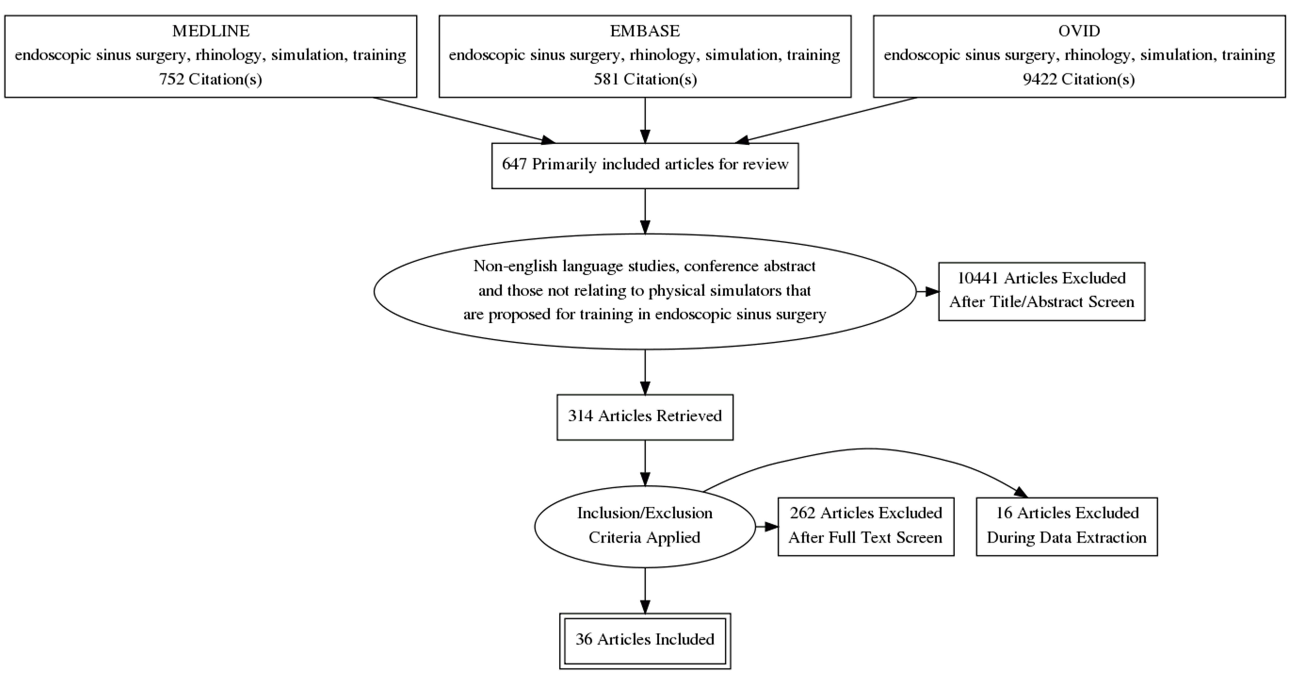

Figure 1 Flow chart of the literature review process.

Results

A total of 647 studies were identified and screened, of which, 314 articles were assessed as relevant. Of those, 262 were excluded after the full-text screen and 16 articles were excluded during data extraction. In final, a total of 36 studies were identified describing 20 non-virtual physical simulators for training in endoscopic sinus surgery skills. All the 36 studies are part of primary literature.

These were classified according to their design, physical bench models, 3D printed models, ovine models and vegetal models. Also, their evaluation was based on fidelity, the evaluation methods used, and the validation studies. Of these, 15 simulators have at least one validation study. Face validity was evaluated by 12 studies, 10 studies assessed content, 9 studies attempted to show construct, and only 2 concurrent validities.

The literature search for non-virtual reality surgical simulators for training in endoscopic sinus surgery procedures was resumed in Table 1.

Table 1 Summary of the Identified Studies

No.	Date	Study	Type of Simulator	Validation
1	1996	Gardiner et al[12]	Sheep head	–
2	2007	Briner et al[13]	Physical bench model	Face
3	2008	Leung et al[14]	Physical bench model	Unable to show construct validity
4	2008	Nogueira et al[15]	Physical bench model	–
5	2009	Stamm et al[16]	Physical bench model	Face
6	2010	Acar et al[17]	Sheep head	–
7	2011	Rowan Valentine et al[18]	Live sheep+physical bench model	–
8	2011	Mladina et al[19]	Lamb head	–
9	2012	Steehler et al[20]	Physical bench model	Face, content, and construct
10	2012	Burge et al[21]	Physical bench model	–
11	2012	Wais et al[22]	Physical bench model	–
12	2013	Steehler et al[23]	Physical bench model	–
13	2013	Touska et al[24]	Sheep head	–
14	2013	Mladina et al[25]	Lamb head	–
15	2014	Awad et al[26]	Sheep head	Face and content
16	2015	Fortes et al[27]	Physical bench model	Face
17	2015	Awad et al[28]	Sheep head	Construct
18	2015	Skitarelić et al[29]	Lamb head	–
19	2016	Mallman et al[30]	Lamb head	–
20	2016	Delgado-Vargas et al[31]	Sheep head	–
21	2016	Chang et al[32]	3D printed model	Face and content
22	2017	Harbison et al[33]	Physical bench model	Face, content, and construct
23	2017	Alrasheed et al[34]	3D printed model	Content and construct

(*Continued*)

Table 1 (Continued).

No.	Date	Study	Type of Simulator	Validation
24	2017	Mosaad el Sissi et al[35]	Sheep head	–
25	2017	Fernandes de Oliveira et al[36]	Lamb head	–
26	2018	Mladina et al[37]	Lamb head	–
27	2018	Luis Macias-Valle et al[38]	Live sheep	–
28	2018	Hsieh et al[39]	3D printed model	–
29	2019	Yoshiyasu et al[40]	3D printed model	Construct
30	2019	Ding et al[41]	3D printed model	–
31	2019	Zhuo et al[42]	3D printed model	Face and content
32	2020	Alwani et al[43]	3D printed model	Face, content, concurrent, and construct
33	2020	Dong et al[44]	3D printed model	Face, content, and construct
34	2021	Gallet et al[45]	3D printed model	Face, content, and construct
35	2021	Rosenbaum et al[46]	Physical bench model	Face, content, construct, and concurrent
36	2021	Tikka et al[47]	Vegetal model	–

Abbreviations: 3D, three-dimensional; 2D, two-dimensional; CT, computed tomography; EAES, European Association for Endoscopic Surgery; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; SIMONT, Sinus Model Otorhino Neuro Trainer.

Ovine Models

Several studies have presented the ovine model as a good alternative to surgical training in functional endoscopic sinus surgery. Gardiner et al, to our knowledge, described for the first time a series of endoscopic surgical maneuvers performed on the sheep's head, ranging from simple steps such as endoscope maneuvering to much more complex maneuvers. Although the anatomy of the sheep's head is different from that of the human head, the maxillary, ethmoidal and frontal sinuses have approximately the same orientation. On top of that, the model itself is cheap, accessible and with good tissue quality.[12]

Awad et al proposed the sheep's head for use as a step in the simulation scale, previous to in-vivo exercises, as it expresses a chance to concentrate on basic endoscopic sinus surgery procedures, to learn on virtual reality training models and cadaveric simulators. The training was evaluated by a task distinctive checklist and global evaluation instrument. The simulator proved an obvious connection between surgical skills and competence efficiency.[26,28]

Mladina et al[19,25,37] chose the lamb's head instead of the sheep's head, because it has nasal cavities that do not correspond to the dimensions of the standard endoscopic sinus surgery instruments, the lamb's head has smaller dimensions than the sheep's head, closer to the human head. Also, due to the absence of a lacrimal sac, dacryocystorhinostomy training could not be performed on the lamb's head, proved by endoscopic and macroscopic dissection.[19] In another study, Mladina et al demonstrated that training in cerebrospinal fluid leak repair could be done by elevation of a nasoseptal flap using lamb's head model, but only just as a previous step before starting practice on a human cadaver.[25]

Thus he developed a training plan defined by 10 surgical steps performed on each nasal fossa of the lamb's head, training that proved to be useful for the 10 participating beginners, by improving working times and rapidly gaining obvious progress, which allows moving on to the next step in training, training on the human cadaver head.[37]

Rowan Valentine et al[18] used eight sheep under general anesthesia and underwent internal carotid artery isolation followed by arterial pressure monitoring and placement of a rapid infuser.[18] The Sinus Model Otorhino Neuro Trainer (SIMONT) nasal model was modified to allow placement of the internal carotid artery in the sphenoid sinus, which could allow the simulation of a catastrophic internal carotid lesion. This is the first model that simulates the endoscopic endonasal injury of a large blood vessel like the internal carotid artery and was useful for the management of such critical situations.[15]

The ovine head model, presented previously in the literature[12,17,24,29–31,35,36,38] with good results, offers a rational choice for training in endoscopic sinus surgery. The benefits of using the sheep model for learning consists in validity, effectiveness, and pertinence of acquired skills in endoscopic procedures. The tissue feel and endoscopic view makes it a superior model for young trainees who are about to start executing endoscopic sinus procedures.

In-vivo animal models and cadaveric simulation offer the best handling fidelity for training in endoscopic sinus surgery. Having fresh tissue offers the bleeding possibility, which is variable depending on whether the cadaver is embalmed or fresh frozen. In-vivo animal simulation is not allowed in some countries and consequently, animal cadaveric simulation can be more accessible.[48–50] The ovine sinus model has allowed the acquisition of endoscopic surgical skills using video endoscopic techniques. This model is cheap, portable, requires reduced equipment, and can be used anywhere.[26] Also, the use of the ex-vivo ovine model for training does not require the approval of an institutional review committee and may raise fewer ethical concerns than the use of live ovine model. The sheep's head model as a sinus simulator for the aim of endoscopic sinus surgery learning proved to have face, content, and construct validation.[26,28]

Physical Bench Models

Physical bench models are low-fidelity trainers with a low level of anatomy with the potential to provide different tasks for training in basic endoscopic sinus surgery.

Nogueira et al showed the development of a physical bench model for training in endoscopic sinus surgery called SIMONT, with the capability to practice basic endoscopic sinus surgery procedures.[15] Stamm et al in their study, used four SIMONT sinus models to determine the feasibility of balloon dilatation of the paranasal sinus ostium, thus one experienced surgeon performed all dilatations. The SIMONT sinus model proved to be feasible in training for sinus ostia balloon dilatation.[16] In another study, Fortes et al evaluated the same SIMONT sinus model, 111 otolaryngologists (60 residents and 51 otolaryngologists with experience) performed uncinectomy, the main ostium of maxillary sinus identification, ethmoidal bulla opening, frontal recess opening, sphenopalatine artery identification, posterior ethmoidal cells opening, sphenoid intersinus septum resection, orbital decompression, and pedicled nasoseptal flap creation. The evaluation included three subjective questionnaires. The SIMONT sinus model proved to bring benefits for the training of otolaryngology surgeons.[27]

A low-cost sinus surgery task trainer was developed by Steehler et al, so 10 otolaryngologists, 15 residents and 52 medical students performed 5 simulated tasks-recess probing, targeted injections, removal of superior sutures, extraction of posterior beads, and antrostomy of an egg with the removal of contents using this low-cost sinus surgery task trainer. 18-question Likert-type scale survey and video records of tasks were used to evaluate this low-cost sinus surgery, task trainer. The model was able to show face, content, and construct validity.[20] Steehler et al in another study, evaluating the same low-cost sinus surgery task trainer with 52 medical students with no experience in sinus surgery, performed each one recess probing, targeted injections, removal of superior sutures, extraction of posterior beads, and antrostomy of an egg with the removal of contents. Training videos, checklists, and global rating scale were used for evaluation. This low-cost sinus task trainer proved that can be a valuable training tool for basic skills in endoscopic sinus surgery.[23]

Wais et al randomized 14 residents into 2 groups. The first group had a pretraining session with 5 different training modules with tasks to complete as quickly as possible with a low number of mistakes. The day after the pretraining, both groups participate in a cadaveric endoscopic sinus surgery training. Video recordings, a global rating scale, and a task-specific checklist 5-point Likert scale were used for evaluation.

The findings of the study suggest that participants who underwent a pretraining session with low fidelity training modules were able to acquire the necessary skills for endoscopic sinus surgery. On the following day, these participants outperformed the group who did not have a pretraining session. The low fidelity training modules proved to be effective in providing basic surgical skills that are essential before transitioning to cadaver training. Furthermore, the use of these low fidelity modules does not raise any ethical concerns, making them a practical and ethical training tool for young doctors. Overall, the study highlights the importance of pretraining sessions and the use of low fidelity training modules for developing basic surgical skills in endoscopic sinus surgery.[22]

Other low-cost endoscopic sinus surgery task trainers showed face, content, construct, and concurrent validity.[33,46]

Three-Dimensionally Printed Model

3D printing technology is increasingly used recently to create surgical simulators useful in training. It offers the possibility to create complex anatomical models of high fidelity, being able to simulate any anatomical or pathological variation based on CT images, so that any surgical maneuver can be simulated on such a model. There are several studies in the literature that have proposed the use of 3D printed models for training in endoscopic rhinosinusal surgery and have benefited from validation in this regard.

Alrasheed et al developed an anatomical model of the osteomeatal complex and frontal sinus based on CT images of a patient that they segmented using 3D visualization software, then printed this model using a different material for the mucosa and bone tissue. Certain endoscopic procedures were simulated on this model, being evaluated by 20 participants with different levels of training, receiving content and construct validation.[34]

Hsieh et al created a specific patient, 3D printed sinus and skull base model for which he demonstrated anatomical accuracy and a good haptic sense with participants of different degrees of training.[39]

Zhuo et al developed a model using CT data of a pediatric patient without rhinosinusal changes, which was printed using a desktop-level 3D printer. Subsequently, a series of tasks were performed by a group of rhinologists and residents for validation. This is according to the authors the first study to evaluate a pediatric rhinosinusal anatomical model for surgical training in endoscopic sinus surgery.[42]

In another study by Alwani et al,12 residents performed uncinectomy, maxillary antrostomy, anterior ethmoidectomy, posterior ethmoidectomy, sphenoidotomy, and frontal sinusotomy on the PHACON Sinus Trainer (Leipzig, Germany), then they performed the same maneuvers on a cadaver head.[43]

A five-item Likert scale questionnaire, a modified fifteen-item questionnaire, a modified global rating scale and video recordings were used for evaluation. This 3D printed model demonstrated face, content, concurrent, and construct validity.

Dong et al used a simulated secretion that mimics mucus and blood that accumulates at the rhinosinusal level during endoscopic surgery and a dissolvable dressing pack. Using a 3D printed head model, simulated secretion was injected in paranasal sinuses and the simulated dressing was also injected in the nasal cavity. 46 residents performed pledget insertion, nasal packing, and postsurgical debridement on this 3D printed head model. A checklist and global rating scale were used for evaluation and face, content, and construct validity were proved.[44]

Gallet et al evaluated 30 participants (10 beginners, 11 intermediate, and 9 expert level) by stability and the accuracy of endoscopic camera handling, train accuracy, dexterity and workspace, precision in the use of the surgical instrument and dissection abilities, using a 3D printed head model as a support for learning modules. These learning modules were able to show face, content, and construct validity with good relevance in endoscopic sinus surgery training.[45]

Other studies have evaluated low-cost 3D printed models with good results and have shown that they are useful tools in acquiring basic surgical techniques in endoscopic rhinosinusal surgery without raising ethical issues.[32,40,41]

Vegetable Model-Capsicum and Tomato Model

Also, a vegetable model useful in rhinosinusal surgical training has recently been described in the literature. In a study conducted by Tikka et al, Capsicum and tomato were introduced as models for basic endoscopic sinus surgery training. The study involved 10 fellows from the same academic year, who were tasked with performing the proposed maneuvers on these models. The results of the study showed that the participants were able to acquire basic surgical skills, such as hand-eye coordination and maneuvering instruments specific to endoscopic rhinosinusal surgery, with good results.

The participants reported that the exercises on the Capsicum and tomato model helped improve their abilities to begin training on the cadaveric model and subsequently on human patients. The use of these models in training has the potential to enhance the learning process, allowing trainees to become more comfortable and proficient with surgical instruments and techniques before operating on actual patients.

Notably, the use of Capsicum and tomato models in surgical training is an innovative approach that has gained attention in recent years. These models offer a safe and cost-effective way to provide hands-on experience to trainees, allowing them to gain confidence and familiarity with the instruments used in endoscopic sinus surgery. Additionally, the use of these models in training can potentially reduce the risk of complications and improve patient outcomes by ensuring that trainees are well-prepared and proficient in their surgical skills.

Overall, the study conducted by Tikka et al highlights the potential benefits of using Capsicum and tomato models in basic endoscopic sinus surgery training. As such, it is a promising option that warrants further exploration and consideration in the development of surgical training programs.[47]

Discussion

For aspiring doctors, becoming competent in endoscopic sinus surgery can be an immense challenge, as it requires mastering a variety of complex skills and knowledge beyond the proper surgical procedures. In addition to these procedures, young doctors must also gain a deep understanding of the complex 3D anatomy of the nasal cavity and paranasal sinuses. This knowledge is critical to successfully performing endoscopic sinus surgery, as it enables the surgeon to navigate the anatomical structures, avoid damaging vital tissues, and achieve optimal surgical outcomes.

Another significant challenge in mastering endoscopic sinus surgery is the need to translate 2D views into 3D anatomical space. This requires an understanding of how the instruments are positioned in relation to the anatomy, as well as spatial orientation and bimanual dexterity in working with endoscopes and surgical tools. In addition, the surgeon must have the ability to make the right choice in choosing the surgical instruments that are best suited to complete the intended task.

Overall, the demands of endoscopic sinus surgery training are multifaceted and require a comprehensive approach to achieve competency. Mastery of these skills requires a combination of didactic education, hands-on training, and experience in surgical procedures. With proper training and guidance, young doctors can acquire the necessary skills and knowledge to become proficient in endoscopic sinus surgery and provide high-quality care to their patients.[48]

The use of surgical simulators has become increasingly important for young doctors to acquire and practice the necessary skills for endoscopic sinus surgery. This is because surgical simulators offer a safe and controlled environment for trainees to repeatedly practice procedures and techniques without putting patients at risk. By providing opportunities for hands-on experience and repetition, surgical simulators have become a valuable tool for young doctors to gain confidence and proficiency in performing complex endoscopic sinus surgeries. This ultimately leads to better patient outcomes and a higher quality of care.[51] Moreover, the trainee can objectively evaluate surgical skills achieved and the progress in a measurable way.[52] As a new state of the art, surgical simulators are developed continuously, so they can be used to learn basic endoscopic surgery skills by repetitive maneuvers, permitting detection of surgical error and incidents without risk for the patient.[53]

All of these simulators apply themselves to learning endoscopy skills and hand-eye coordination. The capacity of task achievement ameliorates with exercise. They do not support surgical decision-making and do not have the quality to learn surgical anatomy. Given the relief of construction, low cost, and total performance element, these low-fidelity physical simulators may be brought into practice for learning the basic skills in endoscopic sinus surgery.[48]

While non-virtual reality simulators have been used for a very long time, they are still popular because they may have several good features. The ideal surgical simulator is accessible, safe, available, reusable, realistic in the handling of surgical instruments, and has the ability to show progress with repetition.

Several studies demonstrate that the surgical skills developed on low-fidelity physical simulators might confer the same manner of profit as high-fidelity surgical simulators, such as cadavers. This is possible because the teaching method was considered to be superior to the physical substrate.[25]

Endoscopic sinus surgery simulation on cadavers is better than physical models, but it depends on cadaver availability and ethical considerations. The main advantage is that the cadaver constitutes the only true anatomical model of human paranasal sinuses.[48,50]

Cadaveric simulators, despite being considered as the gold standard over physical and virtual reality surgical simulators, are yet to establish if their use increases operating efficiency. Nevertheless, novices considered the experience of learning on cadavers to be highly useful in everyday practice.[54]

Animal tissue is one of the popular non-virtual simulators because of the realistic tissue feel and anatomy likeness. Despite that, it is the growing difficulty in using human cadavers for learning that has driven the quest for other possibilities.

Conclusion

Moreover, it is worth noting that the ovine model has been extensively utilized in various research studies and surgical training programs, and has demonstrated promising results in preparing trainees for actual surgical procedures. As a result, it has become a popular choice for medical institutions and rhinology centers worldwide.

One of the key advantages of the ovine model is its cost-effectiveness. Compared to other training models, such as cadavers or computer simulations, the ovine model is significantly less expensive, making it accessible to a wider range of medical trainees. Additionally, the ovine model is readily available in many countries, making it an excellent option for aspiring rhinology doctors worldwide.

Furthermore, the ovine model offers a safe and controlled environment for trainees to practice surgical procedures. Since the model is not a live human patient, there are fewer risks associated with the training process. Additionally, the ovine model enables trainees to focus on specific surgical techniques, such as endoscopic navigation, dissection, and hemostasis, without the added stress of operating on a human patient.

In conclusion, while the ovine model is not a perfect replica of human rhinosinusal anatomy, it offers a cost-effective and safe training option for aspiring rhinology doctors to hone their surgical skills. With its widespread availability and ability to simulate real-life surgical scenarios, the ovine model remains a valuable asset in the training and education of future endoscopic sinus surgeons.

Disclosure

The authors report no conflicts of interest in this work.

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