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SKULL BASE SURGERY (CH SYNDERMAN AND EW WANG, SECTION EDITORS)

Training and Surgical Simulation in Skull Base Surgery: a Systematic Review

Philippe Lavigne[1,2] · **Nathan Yang**[1]

Abstract

Purpose of Review Simulation devices and training protocols are being developed across all surgical fields to teach trainees and optimize learning to improve performance when operating on live patients. This article presents a review of the available literature specific to training and simulation in endoscopic endonasal skull base surgery.

Recent Findings A systematic review of the literature was performed on *simulation* and *training* in endoscopic endonasal skull base surgery. The level of evidence, simulation fidelity, and the level of learning effectiveness (Kirkpatrick scale) were assessed for each available study. Thirty studies were included in the review. One study describes a validated training program for training in skull base surgery. The other included studies of present simulation training using cadaveric models, 3D-printed models, virtual reality trainers, or a combination of these modalities. The overall level of learning effectiveness and level of evidence from these studies are low.

Summary The level of evidence and fidelity of simulators in endoscopic skull base surgery has improved over the years, but high-quality studies are needed to demonstrate the effectiveness of these learning methods on surgical training.

Keywords Cranial base surgery · Simulation · Training · Medical education · Virtual reality

Introduction

Cranial base surgery is constantly evolving, with improved understanding of the pathologies involved, introduction of new technologies, and development of new surgical techniques. Training surgeons for the operative management of these pathologies is a challenge as these procedures are rare, complex, and potentially high-risk [1, 2]. With new constraints on working hours, patient safety concerns, and current work load, training opportunities are limited. As an adjunct to traditional surgical teaching methods, new training strategies and simulation models are being developed across all surgical fields. An increasing body of literature supports simulation and in 2008, the American Residency Review Committee for Surgery mandated all surgical residency programs to facilitate skills acquisition through training laboratories [3, 4]. This article presents a review of the literature on training strategies and the use of surgical simulation models currently available in endoscopic skull base surgery.

Methods

A systematic review of the published literature on training methods and surgical simulation in cranial base surgery was performed for the primary outcome. The MEDLINE and Embase databases were searched for articles published between January 1st 1950 and November 5th 2019. Table 1 presents the MeSH terms that were used in the search strategy. The bibliographies of identified articles were also reviewed for additional relevant articles. Anatomical and radiological studies were excluded if not performed as part of an educational or training protocol. After the search was completed, study selection was performed by abstract review. Only articles published in English and French were included.

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✉ Philippe Lavigne
philippe.lavigne@umontreal.ca

Nathan Yang
nathan.yang@umontreal.ca

[1] Department of Otolaryngology-Head and Neck Surgery, University of Montreal, Montreal, Canada

[2] Montreal, Canada

Table 1 Systematic review search strategy

Themes	MeSH terms used in search strategy
1	Endoscopy, endoscope, skull base surgery, sinonasal, cranial base surgery.
2	Medical education, teaching, graduate education, residency.
3	Simulation training, patient simulation, interactive learning, computer simulation.

The level of evidence for learning effectiveness of the included studies was then classified according Kirkpatrick's training evaluation model (Fig. 1). Fidelity, which describes the extent to which the appearance and generated behaviors of the simulation reflect the ones in the actual setting, was graded between high and low.

Results

Initial database search generated a total of 2405 studies. Title screening for articles on simulation and training in endoscopic endonasal surgery reduced this number to a total of 202 studies. Subsequent abstract review led to the inclusion of 34 articles for the final analysis. The selection process is outlined in Fig. 2. The identified themes pertaining to training in cranial base surgery were training program, learning of surgical skills, and simulation of complications.

One article described a step-wise approach to skull base surgery training over 5 levels based on the complexity of the anatomy, the technical difficulty, the risk to neurovascular structures, and the vascularity of the tumor [5•]. The authors provided evidence for construct validity, as these levels correlate with clinical outcome.

When looking at simulation devices, two major themes were identified: simulation and learning of endoscopic endonasal surgical skills and simulation of complications.

For the simulation of surgical procedure and endoscopic skills learning, several devices and modalities were identified (Table 2). The modality and level of fidelity used in these studies varied on the learning objective: initial learning of endoscope and instrument handling was often taught with low-cost trainer boxes supplemented with 3D-printed components or egg shells that can simulate bone drilling [18, 21, 22, 24, 28, 33]. High fidelity simulation models were developed for advanced surgical training of specific tasks. For example, the chicken wing model covered by a trainer box was used for learning of endoscopic neurovascular structure dissection [34, 36].

Several models have been developed to simulate an entire endoscopic endonasal approach using either cadaveric models, 3D-printed models, or virtual simulators. Interestingly, the development and accessibility of 3D printing have led to an increase in studies using this modality over the last 3 years (see Table 2). This model eliminates the need for cadaveric heads and their preparation and it can allow incorporation of variations to the experience such as presence of tumors or anatomical variations. Similarly, virtual reality

Fig. 1 Kirkpatrick levels of evidence

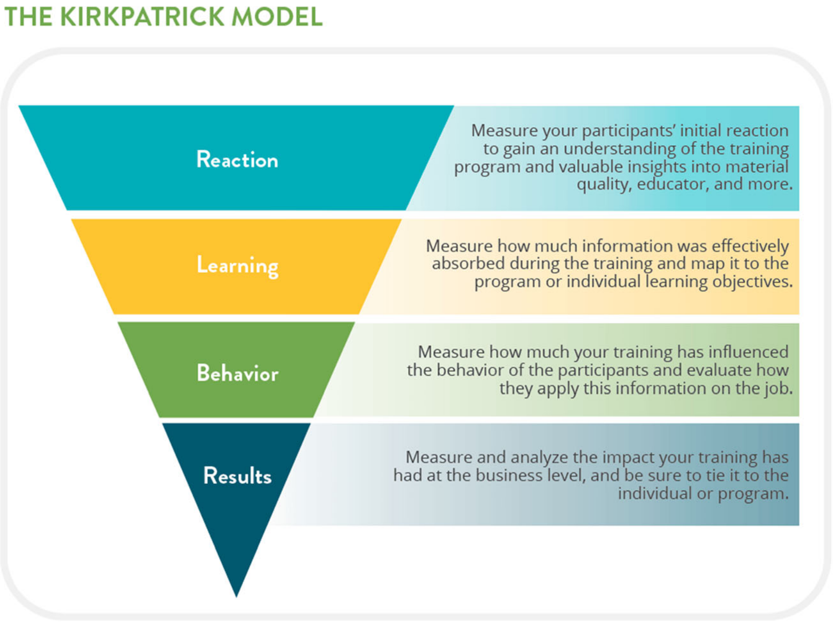
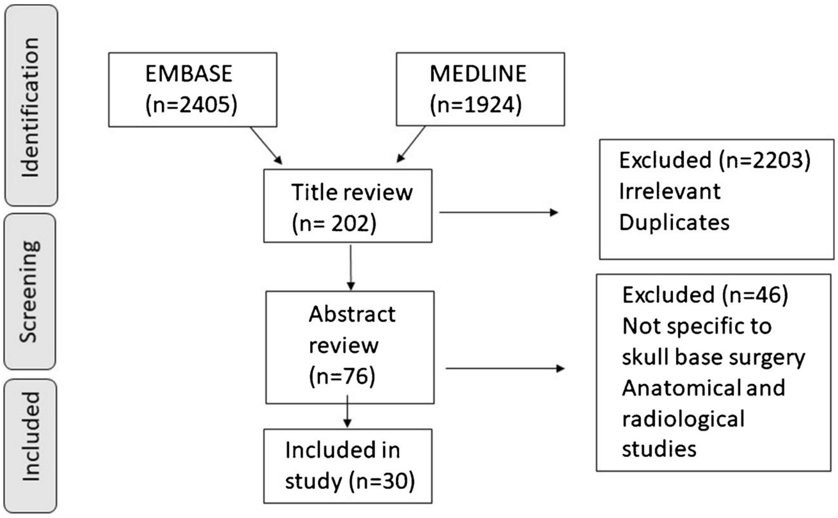


Fig. 2 Article selection process



simulators have the benefit of being customizable to a specific task or case, and can also be used for otologic training. Varshney et al. found improved performance (efficiency measures—like distance traveled within the nasal cavity) when a cohort of novice surgeons were trained with the McGill Simulator for Endoscopic Sinus Surgery (MSESS) [35]. Stephenson et al. used the PHACON sinus trainer and compared training on the virtual reality trainer to traditional study materials. In this randomized control trial, the authors found improved psychomotor endoscopic skills and increased confidence in the intervention group [33].

For the simulation of complications, two surgical situations were identified: cerebrospinal fluid (CSF) leak and vascular injury. Three studies investigated CSF leak repair simulation and used a cadaveric model [10, 17, 36]. The goal of the simulation for these studies was training for endoscopic watertight closure of skull base defects after the dural space is pressure-infused with CSF-like fluids. All studies showed that such training was feasible, but the educational outcomes that were assessed were limited to Kirkpatrick levels I and II.

Simulation for vascular injury was assessed in 6 studies [15, 19, 20, 23, 25]. Of these, two used the SIMONT synthetic sinus model (Sinus Model Otorhino Neuro Trainer) positioned over the exposed cervical carotid artery of an anesthetized sheep [23, 30]. The study by Padhye et al. was the only study from this review that was found to assess the impact of training on medical outcomes (Kirkpatrick level IV - results). The authors identified surgeons who had previously attended their training course and investigated the outcomes after having had a vascular injury in a live patient. They found that all 9 patients treated with the technique taught at the course, the muscle patch repair, had survived the event. The 4 other studies investigated knowledge acquisition in a carotid injury event on perfusion-based models [15, 19, 20, 25]. Of these, 3 used a cadaveric model connected to a pressure pump, and one used a 3D-printed connected to a pressure pump. These studies included 5 to 37 participants and assessed satisfaction questionnaires as well at time to vascular control and the amount of blood loss. They then compared the results between groups of differently experienced surgeons and validated the model based on increasing performance with experience.

Overall, 9 studies evaluated the Kirkpatrick level of *Reaction* and 17 assessed *Learning*. One study assessed *Behavior* changes, but only included 3 trainees in each group [26] and one study assessed *Results* impact and had 9 participants in its cohort [30]. The six remaining studies had no measures for assessment of training.

Discussion

From a learning perspective, separating practice from performance in the real environment is an expected part of preparation in many fields other than medicine, such as sports, music, and aviation. Training through simulation provides the opportunity for trainees to practice and learn in a controlled environment, without the possibility of adverse consequences. Moreover, the current literature suggests that simulation facilitates enhancement of psychomotor skills, hand-eye coordination, and ambidextrous surgery, elements that are especially important in endoscopic endonasal surgery [40]. At this time, none of the available models can simulate every aspect of an endoscopic endonasal surgery, and prepare a novice trainee for a live case. However, each model can provide learning of a specific task. Cadaveric dissection provides drilling sensory feedback similar to a live situation. 3D-printed models can incorporate anatomical variations and tumor components that can replicate neurovascular structure displacement or encasement. New virtual reality trainers have improved haptic feedback and allow trainees to have repeated attempts at a specific task over a single training

Table 2 Simulation in cranial base surgery

Year	Authors	Simulation type	Fidelity	Validation (Kirkpatrick)	Study design
2019	Mattavelli et al. [6•]	Cadaveric - CSF leak/reconstruction	High	None	Exploratory study
2019	Stephenson et al. [7••]	Virtual reality	High	Leaning	2 groups randomized – adjuvant training
2019	Huang et al. [8]	3D-printed model	High	Leaning	Single group pretest-posttest
2019	Maza et al. [9]	3D-printed model	High	Leaning	Single group pretest-posttest
2018	Christian et al. [10]	Cadaveric CSF - leak/reconstruction	High	Leaning	Cohort
2018	Lin et al. [11]	3D-printed model	High	Reaction	Cohort
2018	Shinomiya et al. [12]	3D-printed model	High	Reaction	Cohort
2018	Zheng et al. [13]	3D-printed model	High	Reaction	Cohort
2018	Zhang et al. [14]	3D-printed model	High	Reaction	Cohort
2018	Shen et al. [15]	Cadaveric - vascular injury	High	Leaning	Cohort
2018	Hsieh et al. [16]	3D-printed model	High	Reaction	Cohort
2018	AlQahtani et al. [17]	Cadaveric - CSF leak	High	None	Exploratory study
2017	Harbison et al. [18]	Trainer box	Low	Leaning	Cohort
2017	Pacca et al. [19]	Cadaveric - vascular injury	High	Reaction	Cohort
2017	Ciporen et al. [20]	Cadaveric - vascular injury	High	Leaning	Cohort
2017	Chang et al. [21]	Trainer box	Low	Reaction	Cohort
2017	Alvarez et al. [22]	Trainer box	Low	Leaning	Cohort
2016	Valentine et al. [23]	Animal model + synthetic model vascular injury	High	Leaning	Cohort
2016	Wen et al. [24]	3D-printed model + egg	Low	Leaning	Cohort
2016	Muto et al. [25]	3D-printed model - vascular injury	High	Leaning	Cohort
2016	Thawani et al. [26]	Virtual reality	High	Behavior	2 groups randomized – adjuvant training
2016	Tai et al. [27]	3D-printed model	High	Reaction	Cohort
2016	Singh et al. [28]	Trainer box	Low	Leaning	4 groups with different experiences
2016	Fortes et al. [29]	Synthetic thermosensible rubber (Neoderma)	High	Leaning	Cohort
2015	Padhye et al. [30]	Animal model + synthetic sinus model vascular injury	High	Results	Retrospective multicenter case series of outcomes in surgeons that completed training
2015	Narayanan et al. [31]	Trainer box	High	Reaction	Cohort
2015	Oyama et al. [32]	Selective laser sintering (3D-printed model)	High	None	Exploratory study
2014	Okuda et al. [33]	3D-printed model + egg	Low	Leaning	Cohort
2014	Kaplan et al. [34]	Animal model (chicken wing)	High	Leaning	Randomized single-blind study – no adjuvant training
2014	Varshney et al. [35]	Virtual reality	High	Leaning	4 groups with different experience
2013	Jusue-Torres et al. [36]	Animal model (chicken wing) + trainer box	High	Leaning	Cohort
2013	Berhouma et al. [37]	Cadaveric + polymer	High	None	Exploratory study
2010	Tolsdorff et al. [38]	Virtual reality	High	None	Exploratory study
2003	Caversaccio et al. [39]	Virtual reality	Low	None	Exploratory study

CSF, cerebrospinal fluid; *3D*, three dimension session. These models provide environments that simulate surgical decision-making and force trainees to develop strategies to navigate through the different steps of a surgery. Overall, the fidelity is improving across all simulation models and most training programs have incorporated mandatory simulation training outside of the operating room in their curriculum.

The available literature on training and simulation in skull base surgery is limited, and the level of evidence for learning effectiveness according to Kirkpatrick's training evaluation model rarely exceeds the *Learning* level (Fig. 1). This remains a challenge for simulation training across all medical specialties as studies with higher evidence for learning effectiveness are costly and challenging to design. Moreover, the methodology used to provide evidence for learning effectiveness should be evaluated. Of the identified studies, only one provided evidence of *knowledge acquisition* using a blinded randomized controlled trial of sizeable groups [33]. Most of the other articles described small cohort studies in which a specific task was assessed prior to and after a training intervention using a non-validated scale. Overall, it is expected that most training interventions, whether using traditional methods or simulation, will provide improved outcomes over no training interventions. Future studies should aim at comparing outcomes with validated scales between groups with different training modalities, instead of comparing groups with and without training interventions.

Conclusion

Cranial base surgery is complex and challenging, and risks should be minimized through appropriate training. For live surgery, an incremental training program based on the complexity of the anatomy, the technical difficulty of the procedure, and the risks to neurovascular structures was previously published and validated [2]. For training outside of the operative room, several types of simulation models have been described: live, synthetic, or virtual reality models. All of these models have their strengths and weaknesses, but trainees must take advantage of each learning opportunity to perfect their understanding of cranial base surgery.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Singh R, Siddiqui SH, Choi Y, et al. Morbidity and mortality associated with ventral skull base surgery: analysis of the National Surgical Quality Improvement Program. Int Forum Allergy Rhinol. 2019;9:1485–91.
2. Wang EW, Zanation AM, Gardner PA, Schwartz TH, Eloy JA, Adappa ND, et al. ICAR: endoscopic skull-base surgery. Int Forum Allergy Rhinol. 2019;9(S3):S145–s365.
3. Kurashima Y, Hirano S. Systematic review of the implementation of simulation training in surgical residency curriculum. Surg Today. 2017;47(7):777–82.
4. Cook DA, Hatala R, Brydges R, Zendejas B, Szostek JH, Wang AT, et al. Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. Jama. 2011;306(9):978–88.
5.• Lavigne P, Faden D, Gardner PA, Fernandez-Miranda JC, Wang EW, Snyderman CH. Validation of training levels in endoscopic endonasal surgery of the skull base. Laryngoscope. 2019;129(10):2253–7 **The authors from this study validated a training program in cranial base surgery to facilitate safe learning through case of incremental complexity.**
6.• Mattavelli D, Ferrari M, Rampinelli V, et al. Development and validation of a preclinical model for training and assessment of cerebrospinal fluid leak repair in endoscopic skull base surgery. Int Forum Allergy Rhinol. 2019;10(1):89–96 **The authors from this study found a simple and innovative technique to simulate dynamic endoscopic endonasal CSF leak reconstruction on a cadaver model.**
7.•• Stephenson ED, Farquhar DR, Masood MM, et al. Blinded evaluation of endoscopic skill and instructability after implementation of an endoscopic simulation experience. Am J Rhinol Allergy. 2019;33(6):681–90 1945892419860973. **This blinded randomized controlled study suggests that training on a virtual reality simulator improves task performance on cadaver dissection.**
8. Huang X, Liu Z, Wang X, et al. A small 3D-printing model of macroadenomas for endoscopic endonasal surgery. Pituitary. 2019;22(1):46–53.
9. Maza G, VanKoevering KK, Yanez-Siller JC, Baglam T, Otto BA, Prevedello DM, et al. Surgical simulation of a catastrophic internal carotid artery injury: a laser-sintered model. Int Forum Allergy Rhinol. 2019;9(1):53–9.
10. Christian EA, Bakhsheshian J, Strickland BA, Fredrickson VL, Buchanan IA, Pham MH, et al. Perfusion-based human cadaveric specimen as a simulation training model in repairing cerebrospinal fluid leaks during endoscopic endonasal skull base surgery. J Neurosurg. 2018;129(3):792–6.
11. Lin J, Zhou Z, Guan J, Zhu Y, Liu Y, Yang Z, et al. Using three-dimensional printing to create individualized cranial nerve models for skull base tumor surgery. World Neurosurg. 2018;120:e142–52.
12. Shinomiya A, Shindo A, Kawanishi M, et al. Usefulness of the 3D virtual visualization surgical planning simulation and 3D model for endoscopic endonasal transsphenoidal surgery of pituitary adenoma: technical report and review of literature. Interdiscip Neurosurg. 2018;13:13–9.
13. Zheng JP, Li CZ, Chen GQ, Song GD, Zhang YZ. Three-dimensional printed skull base simulation for transnasal endoscopic surgical training. World Neurosurg. 2018;111:e773–82.

14. Zhang XD, Li ZH, Wu ZS, et al. A novel three-dimensional-printed paranasal sinus-skull base anatomical model. Eur Arch Oto-Rhino-Laryngol: official journal of the European Federation of Oto-Rhino-Laryngological Societies (EUFOS): affiliated with the German Society for Oto-Rhino-Laryngology - Head and Neck Surgery. 2018;275(8):2045–9.
15. Shen J, Hur K, Zhang Z, et al. Objective validation of perfusion-based human cadaveric simulation training model for management of internal carotid artery injury in endoscopic endonasal sinus and skull base surgery. Oper Neurosurg (Hagerstown, Md). 2018;15(2):231–8.
16. Hsieh TY, Cervenka B, Dedhia R, Strong EB, Steele T. Assessment of a patient-specific, 3-dimensionally printed endoscopic sinus and skull base surgical model. JAMA Otolaryngol– Head Neck Surg. 2018;144(7):574–9.
17. AlQahtani AA, Albathi AA, Alhammad OM, Alrabie AS. Innovative real CSF leak simulation model for rhinology training: human cadaveric design. Eur Arch Otorhinolaryngol. 2018;275(4): 937–41.
18. Harbison RA, Johnson KE, Miller C, Sardesai MG, Davis GE. Face, content, and construct validation of a low-cost, non-biologic, sinus surgery task trainer and knowledge-based curriculum. Int Forum Allergy Rhinol. 2017;7(4):405–13.
19. Pacca P, Jhawar SS, Seclen DV, et al. “Live cadaver” model for internal carotid artery injury simulation in endoscopic endonasal skull base surgery. Oper Neurosurg (Hagerstown, Md). 2017;13(6):732–8.
20. Ciporen JN, Lucke-Wold B, Mendez G, Cameron WE, McCartney S. Endoscopic management of cavernous carotid surgical complications: evaluation of a simulated perfusion model. World neurosurgery. 2017;98:388–96.
21. Chang DR, Lin RP, Bowe S, Bunegin L, Weitzel EK, McMains K, et al. Fabrication and validation of a low-cost, medium-fidelity silicone injection molded endoscopic sinus surgery simulation model. Laryngoscope. 2017;127(4):781–6.
22. Sanroman-Alvarez P, Simal-Julian JA, Garcia-Pinero A, Miranda-Lloret P. Multitask box trainer for endoscopic endonasal skull base surgery: ENDOtrainer. World Neurosurg. 2017;101:304–7.
23. Valentine R, Padhye V, Wormald PJ. Simulation training for vascular emergencies in endoscopic sinus and skull base surgery. Otolaryngol Clin N Am. 2016;49(3):877–87.
24. Wen G, Cong Z, Liu K, et al. A practical 3D printed simulator for endoscopic endonasal transsphenoidal surgery to improve basic operational skills. Child’s Nerv Syst: ChNS: official journal of the International Society for Pediatric Neurosurgery. 2016;32(6): 1109–16.
25. Muto J, Carrau RL, Oyama K, Otto BA, Prevedello DM. Training model for control of an internal carotid artery injury during transsphenoidal surgery. Laryngoscope. 2017;127(1):38–43.
26. Thawani JP, Ramayya AG, Abdullah KG, Hudgins E, Vaughan K, Piazza M, et al. Resident simulation training in endoscopic endonasal surgery utilizing haptic feedback technology. J Clin Neurosci: official journal of the Neurosurgical Society of Australasia. 2016;34:112–6.
27. Tai BL, Wang AC, Joseph JR, Wang PI, Sullivan SE, McKean E, et al. A physical simulator for endoscopic endonasal drilling techniques: technical note. J Neurosurg. 2016;124(3):811–6.
28. Singh R, Baby B, Damodaran N, Srivastav V, Suri A, Banerjee S, et al. Design and validation of an open-source, partial task trainer for endonasal neuro-endoscopic skills development: Indian experience. World Neurosurg. 2016;86:259–69.
29. Fortes B, Balsalobre L, Weber R, Stamm R, Stamm A, Oto F, et al. Endoscopic sinus surgery dissection courses using a real simulator: the benefits of this training. Braz J Otorhinolaryngol. 2016;82(1): 26–32.
30. Padhye V, Valentine R, Sacks R, Ooi EH, Teo C, Tewfik M, et al. Coping with catastrophe: the value of endoscopic vascular injury training. Int Forum Allergy Rhinol. 2015;5(3):247–52.
31. Narayanan V, Narayanan P, Rajagopalan R, et al. Endoscopic skull base training using 3D printed models with pre-existing pathology. Eur Arch Oto-Rhino-Laryngol: official journal of the European Federation of Oto-Rhino-Laryngological Societies (EUFOS): affiliated with the German Society for Oto-Rhino-Laryngology - Head and Neck Surgery. 2015;272(3):753–7.
32. Oyama K, Ditzel Filho LF, Muto J, et al. Endoscopic endonasal cranial base surgery simulation using an artificial cranial base model created by selective laser sintering. Neurosurg Rev. 2015;38(1): 171–8 discussion 178.
33. Okuda T, Yamashita J, Fujita M, Yoshioka H, Tasaki T, Kato A. The chicken egg and skull model of endoscopic endonasal transsphenoidal surgery improves trainee drilling skills. Acta Neurochir. 2014;156(7):1403–7.
34. Kaplan DJ, Vaz-Guimaraes F, Fernandez-Miranda JC, Snyderman CH. Validation of a chicken wing training model for endoscopic microsurgical dissection. Laryngoscope. 2015;125(3):571–6.
35. Varshney R, Frenkiel S, Nguyen LH, Young M, del Maestro R, Zeitouni A, et al. Development of the McGill simulator for endoscopic sinus surgery: a new high-fidelity virtual reality simulator for endoscopic sinus surgery. Am J Rhinol Allergy. 2014;28(4):330–4.
36. Jusue-Torres I, Sivakanthan S, Pinheiro-Neto CD, Gardner PA, Snyderman CH, Fernandez-Miranda JC. Chicken wing training model for endoscopic microsurgery. J Neurol Surg Part B Skull Base. 2013;74(5):286–91.
37. Berhouma M, Baidya NB, Ismail AA, Zhang J, Ammirati M. Shortening the learning curve in endoscopic endonasal skull base surgery: a reproducible polymer tumor model for the trans-sphenoidal trans-tubercular approach to retro-infundibular tumors. Clin Neurol Neurosurg. 2013;115(9):1635–41.
38. Tolsdorff B, Pommert A, Hohne KH, et al. Virtual reality: a new paranasal sinus surgery simulator. Laryngoscope. 2010;120(2): 420–6.
39. Caversaccio M, Eichenberger A, Hausler R. Virtual simulator as a training tool for endonasal surgery. Am J Rhinol. 2003;17(5): 283–90.
40. Agha RA, Fowler AJ. The role and validity of surgical simulation. Int Surg. 2015;100(2):350–7.