Indian Journal of Surgical Oncology
https://doi.org/10.1007/s13193-021-01360-2

ORIGINAL ARTICLE

Graduating from Laboratory to Operating Rooms—the Way Forward for Future Surgeons!

Rajnish K. Arora[1] · Radhey S. Mittal[1] · Meenakshi Khapre[2] · Santosh Kumar[2] · Brijendra Singh[3] · Satya P. Aggarwal[4] · Poonam Arora[5]

Received: 20 August 2020 / Accepted: 31 May 2021

Abstract

Background Changing healthcare and social scenarios are reducing the learning opportunities of surgical postgraduates in our country. Majority of surgical training centers in the developed world use laboratory training as an integral part of their curricula. However, in India, most of surgical residents are still trained by traditional apprenticeship model.
Aims To describe the role of laboratory training in improving the competency of surgical postgraduates.
Settings and Design Laboratory dissection was used as an educational intervention for postgraduates in tertiary care teaching hospital.
Methods and Material Thirty-five (35) trainees from various surgical subspecialties performed cadaveric dissection led by senior faculty members. The perceived knowledge and operative confidence of trainees were assessed before and three weeks after the course using a five-point Likert scale. A structured questionnaire was administered to explore the experience of training. Results were tabulated in percentage and proportion. Wilcoxon signed-rank test was applied to find any difference between pre and post perception of knowledge and operative competence of participants.
Results Thirty four (34/35; 96%) were males; 65.7% (23/35) trainees demonstrated improvement in knowledge level after dissection ($p < 0.0001$) and 74.3% (26/35) in operative confidence ($p < 0.0001$). Majority believe that cadaveric dissection helps to improve knowledge of procedural anatomy (33/35; 94.3%) and enhances technical skill (25/35; 71.4%). Thirty participants (86%) rated cadaveric dissection as the best tool for surgical training of postgraduates better than operative manuals, surgical videos, and virtual simulators.
Conclusions Laboratory training including cadaveric dissection is feasible, relevant, effective, and acceptable to postgraduate surgical trainees with few disadvantages, which can be taken care of. Trainees felt it should be made part of curriculum.

Keywords Postgraduate surgical curriculum · Cadaveric dissection · Surgical skills

Introduction

"For one to be a skillful and erudite surgeon, one must first be an anatomist":
Sushruta (600 BC)

Indeed, when one tries to enumerate attributes of a good surgeon, a thorough knowledge of anatomy is an indispensable one. Morton [1] in his famous article about qualities of a successful surgeon, has written, "The surgeon must be well informed about the anatomy, physiology, pathology, and pharmacology of surgical disease. Understanding the scientific basis for an operation separates the surgeon from the skilled technician." How can a surgical trainee improve his learning, in terms of in-depth anatomical knowledge and

✉ Rajnish K. Arora
rajnish.nsurg@aiimsrishikesh.edu.in

1 Department of Neurosurgery, AIIMS Rishikesh, 249203 Rishikesh, India

2 Department of Community and Family Medicine, AIIMS Rishikesh, Rishikesh, India

3 Departemt of Anatomy, AIIMS Rishikesh, Rishikesh, India

4 Departent of Surgical Oncology, AIIMS Rishikesh, Rishikesh, India

5 Department of Trauma and Emergency, AIIMS Rishikesh, Rishikesh, India

Published online: 05 June 2021

other technical skills? Traditionally, these core competencies are acquired directly in operating rooms, where a trainee learns from master by first assisting and later performing a surgical procedure under supervision (Halstedian apprenticeship model). Although it is followed widely, practicality of this model is being challenged by factors such as ethical issues of practicing on patients, ever-increasing patient satisfaction demands, cost constraints, limitation of resident work hours, and medico-legal concerns. Society, particularly in our country, is very intolerant and hostile to surgical mishappenings and our operating rooms (ORs) are under continuous social, legal, and ethical surveillance. At some private institutes in India and west, resident autonomy is also being challenged by outcome-based reimbursements and reporting of surgeon specific outcome data [2, 3]. These attributes practically lead to qualified faculty members performing major part of surgical procedures themselves, limiting the learning opportunities for surgical residents, and therefore, reducing their competency. Hence, need of better training to produce competent surgeons is evident. Training in laboratory using various simulation techniques can help in improving competency and shortening the learning curve. By practicing a procedure using laboratory simulation, one can develop skills in a controlled environment without risking a human life. This type of training can be used to train surgical postgraduates during the early part of the learning curve of acquiring technical skills (e.g., during residency program) [2]. Many institutes, particularly in the west, have adopted these strategies of laboratory training as an integral part of their curricula [4]. More than 70% of medical schools in the USA use laboratory training in one or another form [5]. However, Indian medical teaching institutes lag behind considerably in this aspect and majority of surgical residents in our country are still trained by following the traditional model. Though simulation training is not a new idea and some institutions have established simulation labs, but overall, its actual utilization as a part of training curriculum is very low in India.

The objective of present study was to examine the perception regarding the utility of laboratory training in form of cadaveric dissection in improving procedural knowledge, technical skills, and surgical competency and assess its acceptability among surgical residents.

Subjects and Methods

Setting

Our institute is a budding tertiary care institute, which has a large modern dissection room that was primarily used for undergraduate dissection. This dissection room is not only having facilities for cadaveric dissection but has facilities for virtual dissection and synthetic simulation models. Students can use both cadaveric dissection and virtual dissection in an interactive manner.

Study Design

Educational intervention study.

Intervention

Dissection laboratory was used for training residents of various subspecialties of surgery. We conducted cadaveric training sessions of surgical oncology, urology, neurosurgery, traumatology, and pediatric surgery. Faculty members with more than 5 years of experience as independent consultants led these sessions. Trainees were postgraduate students of these subspecialties and had at least 3 years of experience in general surgery before they joined in any subspecialty. Initially, a senior faculty member demonstrated the technique on cadaver, and relevant details were also shown on virtual dissection platform. This was followed by hands-on experience session. The dissections were performed on soft embalmed (using modified Thiel's solution) and formalin-fixed cadavers depending on the need of procedures undertaken. They were conducted in small batches of residents (3–4/per cadaver) and for an average of 5 h per day over seven working days. Procedures like trans-nasal and trans-basal endoscopy for skull base, exposures of infratemporal fossa, laryngectomy, brachial plexus exposures, carpel tunnel release, transplant kidney retrieval, ureteric reimplantaion, pedicled myocutaneous flaps, free flaps, and arterio-venous anastomosis were practiced. Participants also used virtual dissection facilities in form of endotrainers (Absolute fidelity solutions, New Delhi, India) Sectra virtual dissection system (Sectra AB,Stockholm Sweden); Anatomage virtual dissection platform (Anatomage Inc. San Jose CA, USA); Synthetic cadaver model VINNY (SynDaver corp. Tempa FL, USA).

After obtaining the informed consent, participants were asked to complete the structured and validated questionnaire. It consisted of perceived improvement on knowledge and operative confidence after training in cadaveric dissection (self-reported), advantages and disadvantages of cadaveric dissection, and opinion related to utility of cadaveric dissection as a part of surgical training curriculum. The knowledge level and operative confidence of a trainee were assessed before and 3 weeks after practice dissection sessions using a 5-point Likert scale (for knowledge 1 = poor, and 5 = excellent; for operative confidence 1 = not confident, 5 = extremely confident). Data was presented in proportion. Wilcoxon signed-rank test was used to compare perceived knowledge level and operative confidence before and after intervention. The analysis was performed in SPSS version 23 (IBM Corp. Armonk, NY, USA).

Results

Total 35 participants were trained and responded to questionnaire. Thirty-four (97.1%) were males. Ten (28.6%) were from sub specialty of surgical oncology, nine (25.7%) from urology, eight (22.8%) from neurosurgery, six (17.1%) traumatology, and two (5.7%) from pediatric surgery. Eighty-six percent (30/35) of trainees considered laboratory cadaveric dissection as good educational tool for learning procedural anatomy, rating it superior to reading operative texts, watching surgical videos and practice on virtual simulators or their combination (Fig. 1). Majority (32/35; 91.4%) felt that the most of the steps performed during cadaveric dissection were similar to those performed in real operating rooms (ORs) scenario. Twenty-six participants (74%) responded that cadaveric dissection has changed their way of handling tissues in real cases and 88% (31) gained new knowledge about usage of surgical instruments. The knowledge level and operative confidence were assessed before and 3 weeks after practice on cadavers. Median pre-dissection score for knowledge domain was 3, while post procedure was 4. Applying Wilcoxon signed-rank test, this difference was found to be statistically significant ($p < 0.0001$). Twenty (57.1%) trainees reported at least 1-point improvement on Likert scale and 3 (8.6%) reported a 2-point improvement. The self-reported pre dissection operative confidence also showed a similar trend, i.e., median pre-test and post-test score was 3 and 4 respectively. This difference was also statistically significant ($p < 0.0001$). Here 74.3% (26/35) trainees reported at least one-point improvement on Likert scale (Table 1). Over half of the participants (57.1%; 20/35) opined that cadaver training should be made a mandatory part of resident curriculum; a further 28.6% (10/35) highly recommended its utility in training but not as a mandatory inclusion (Fig. 2). Twenty-three out of thirty-two (71.87%) trainees responded that simulation training should be utilized for all years of resident training with frequency of at least one session per month. 15.6% (5/32) were of opinion that it should be used in the first year of training only. Few opined that it is preferable to start such a training after initial 6 months of starting their residency course. Trainees also reported a few disadvantages like time-consuming and lack of bleeding which does not resemble real scenario. However, majority did not see these as deterrents to inclusion of cadaver dissection into training. Overall, 80% (28/35) reported these sessions as very useful.

Discussion

> "Today's residents in surgery are learning their anatomy on sick patients for the first time in the middle of the night: operating without a firm knowledge of anatomy leads to increased mortality and morbidity"

Oliver Beahrs, first President of American Association of Clinical Anatomists [6]

Though real operating room is ideal learning environment, above statement made by an academician of international repute highlights an important facet of traditional

Fig. 1 Opinion of participants regarding appropriate method of technical training for surgical postgraduates ($n = 35$)

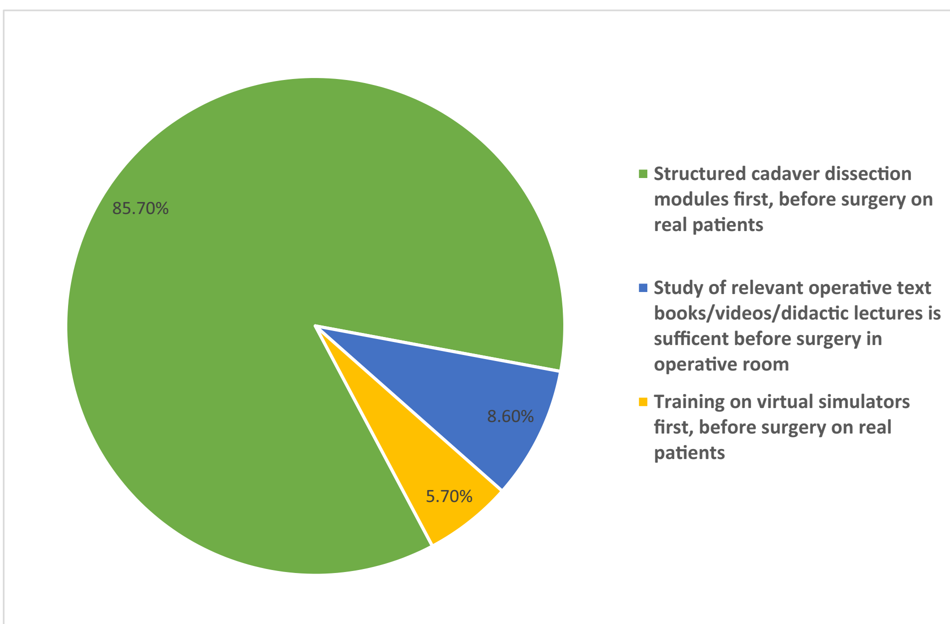

Table 1 Comparison of pre-/post-practice knowledge level and operative confidence

Domain	Score	Pre- practice *n* (%)	Post-practice *n* (%)	Wilcoxon rank sum test
Knowledge level	5 (excellent)	1 (2.9)	1(2.9)	
	4 (very good)	8 (22.9)	24 (68)	
	3 (satisfactory)	18 (51.4)	8 (22.9)	
	2 (fair)	7 (20)	2 (5.7)	
	1 (poor)	1 (2.9)	0 (0)	
	Median (range)	3 (1–4)	4 (1–5)	$Z = -3.714$ (***p* < 0.0001**)[a]
Operative confidence	5 (extremely confident)	2 (5.7)	1 (2.9)	
	4 (very confident)	5(14.3)	23 (65.7)	
	3 (confident)	21 (60)	10(28.6)	
	2 (low in confidence)	6 (17)	1(2.9)	
	1 (not confident)	1(2.9)	0(0)	
	Median (range)	3 (1–4)	4 (1–4)	$Z = -4.271$ (***p* < 0.0001**)[a]

[a] statistically significant

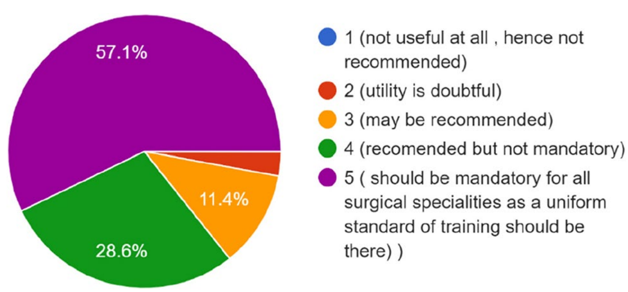

Fig. 2 Recommendation given by trainees for cadaveric dissection as a part of surgical curriculum (pie chart)

model of clinical training. Indeed, there are some inherent disadvantages of this system, particularly in current times such as ethical issues of practicing on patients. Often, the high caseload in India due to large number of patients is cited as the reason that there are enough learning opportunities for surgical residents to learn with in operating room itself. However, there are some valid questions raised by Harrop et al., such as how many cases does a resident need to perform before he/she is competent? Do all individuals learn at same fixed rate? How can we best measure technical skills? It is obvious that training programs should have defined educational objectives, but in traditional Halstedian apprenticeship model, there is no standardization of training protocols and there are no objective criteria established to measure educational outcomes [7]. Furthermore, in India, which is a large country, case load is not the same across all centers (both in numbers as well as type). There is a difference in hands on experience for residents between government and private centers and surgical training is not uniform. One of the most important goals of any surgical residency program is to produce a competent surgeon, who is capable of independently performing certain procedures safely. Simulation training is an adjunct that improves technical competency and can provide uniformity to training. We have started using regular laboratory training of surgical subspecialty residents at our institute and their feedback is encouraging. We shall discuss here, in brief about various laboratory simulation models along with our initial experience of starting laboratory training in form of cadaveric dissection.

Currently available simulation models for laboratory training can be classified into following types.

1. Physical simulation
2. Biological models (cadavers; animal models ex vivo, e.g., chicken wings for vascular anastomosis/ sheep scapula/pig heads; in vivo animal training, e.g., Rats)
3. Synthetic physical models, e.g., endotrainers/mannequins/saw bone models/3D printed models
4. Virtual simulation devices and web based simulators
5. Hybrid models or a combination of above.

Cadaver Models

Cadaveric dissections have historically been considered the ultimate anatomic simulators and continue to play an indispensable role in current surgical training at many centers. They provide definitive anatomic detail and permit demonstration of elegant surgical approaches [8]. Cadaveric courses have been documented to have positive effect on enhancing anatomical knowledge and may provide a higher level of autonomy to perform procedures independently in nearly all surgical specialties, e.g., surgical oncology, head and neck surgeries, gynecology, urology, vascular surgery, laparoscopic surgery, plastic surgery, and neurosurgery [9–14]. Our participants were from various subspecialties and their evaluation revealed significant improvement in knowledge as well as operative confidence. This is similar to other studies [12, 15–18]. Cadaveric training is not only beneficial for postgraduate trainees but even experienced surgeons prefer to practice new techniques on cadavers. Eighty-five percent (85%) of trainees in this study also rated cadaveric training as best method of resident training. In fact, 20/35 opined about mandatory inclusion of dissection as a part of training. Out of these nine were from surgical oncology, eight from neurosurgery, two from traumatology, and one from urology. Among all subspecialties, surgical oncology trainees were most captivated by dissection practice. This was followed by neurosurgical trainees. Surgical oncology trainees felt that cadaveric dissection helped them to gain confidence in achieving R0 resections and performing vascular anastomosis with confidence. We believe that trainees who liked the dissection training most were those performing procedures having steep learning curve, e.g., minimally invasive approaches, microsurgical/vascular techniques, and procedures that include involvement of multiple specialities.

We have assessed our participants 3 weeks after their dissection course, which gave them time to observe any effect of laboratory training on their work in real ORs also. Their feedback was encouraging. It has been shown that skills acquired by such courses are retained up to 18 months [19]. We plan to assess them later also, for long-term assessment.

There are some disadvantages of cadaver dissection, e.g., practical difficulties in cadaver supply, requirement of dedicated setup, and hence cost, the characteristics of embalmed tissues may be not similar to what is natural, one is likely not to encounter pathology, and there is no bleeding in cadavers. We used both formalin-fixed and soft embalmed cadavers. For soft embalming, modified Thiel's solution (mixture of 4- chloro-3- methylphenol, ammonium nitrate, potassium nitrate, ethylene glycol,boric acid, and 2% formalin) was used at our center. This helps to provide excellent softness and flexibility to cadavers. After complete embalming cadavers are kept in same solution for 4–6 weeks and later after use kept in sealed plastic bags. Such cadavers can be used to 6 months–1 year for training teaching purposes depending on climatic conditions and storage facilities. Participants in our study quoted lack of bleeding (42.9%), smell of preservatives, and risk of biohazards (17.1% each) as shortcomings of cadaveric dissection (Table 2). Virtual reality simulators may fill these voids [2]. Furthermore, in a cadaver, tissues once dissected, usually cannot be reused, which is not the case with virtual simulators.

Table 2 Advantages and disadvantages of cadaveric dissection as perceived by trainees

	Key points	*n* (%)
Advantages	Improves knowledge of procedural anatomy	33 (94.3)
	Enhances technical skill	25 (71.4)
	Bloodless field	15 (42.9)
	No stress of loss of blood/life	19 (54.3)
Disadvantages	Time constraints	16 (45.7)
	Lack of bleeding during dissection	15 (42.9)
	Smell of preservatives	6 (17.1)
	Biohazards	6(17.1)

Other Physical Models and Virtual Reality Simulation

The technological advances in imaging, computation, virtual reality, and 3D printing along with the imitations of cadaver models have led to the development of other avenues of laboratory training including synthetic physical models and computer-based virtual reality simulators [20]. There are few skills like endoscopy/laparoscopy, which require hand–eye coordination; the simulators and endotraniers work best for developing such skills. Indeed, general surgery was the first specialty to embrace simulation and laparoscopy has largely demonstrated clinical benefits from simulation training [7, 21]. Realistic physical models for other surgical trainees have been developed, which do bleed on dissection or demonstrate leak of CSF [22]. These can be combined with computer simulation to practice emergency scenarios also [23]. Though advancements in virtual simulators are challenging the "gold standard status" of cadaver training [24], and there is a general belief that virtual reality (VR) simulators will ultimately replace all other forms of simulation training. Still, a high quality virtual simulator, which has realistic deformation of tissues and a good haptic feedback, requires a heavy investment in terms of initial cost, and as of now, they are yet not freely available outside few institutes in west. Middle-income and low-income countries will have to wait for some time until their wider availability and costs reductions. Cadaver training will continue to help in a big way in the resource-limited countries as these dissections are already being used for undergraduates within most of their institutes. However, there are few teaching hospitals in country, where there are no cadavers and students learn only by various means of virtual dissection/simulation. We do have virtual dissection systems in our clinical anatomy department. It is believed that dissection is superior to simulation in terms of better anatomic and psychomotor fidelity. Only 2/35 (5.7%) of our trainees preferred a virtual simulator, while majority of them 30/35(85.7%) rated cadaveric dissection as the best tool for surgical training of postgraduates. Trainees from our cohort spent about 10 h on virtual dissection platform, while synthetic model was least preferred with only 3 h. They reported lack of fidelity to be reason for this. Three participants (12%) felt that operative books, videos, and lectures only are sufficient for surgical trainees before they operate on real patients. (Fig. 1).

Based on existing evidence that spaced simulation training is better than massed training [25] and considering the logistics involved in setting up simulation facility, we believe that simulation training should be for all years of residency training, with approximately one session per month, for a period of 2–3 days for each speciality. For subspecialty training, it may be started even during initial 6 months also, as trainees who have already come from a general surgery background can rehearse their basic surgical skills during initial sessions.

It must be emphasized that a laboratory training module should be well structured and associated with an evaluation process. The latter not only improves trainee performance but also can objectively document proficiency in technical skills [2, 26–28]. However, it requires significant input in terms of manpower (faculty/supervisors), time, and cost to implement both these schema, i.e., development of structured programs with their regular updates and evaluation. Computer-based simulators usually have in-built assessment tools for evaluation, which means reduced dependency on manpower and time, thus making them cost-effective in long run. Nevertheless, the expert verbal feedback, as is possible with an interaction with mentors at dissection table, results in greater retention than simple computer printouts [29]. Thus, it is evident that various models of laboratory training (cadaveric dissection/synthetic physical models/virtual simulation) have both advantages and disadvantages. Hence, these models should be used as complementary to each other and can be used in tandem as per need of a specialty and resource setting.

Nearly half of our participants (16/35; 45.7%) pointed out time constraints as a factor, which hinders them in utilizing laboratory training fully. Setting up of a standalone laboratory, with dissection as well as simulation facilities and dedicated for postgraduates only, will require a large space, cost, manpower, and time. Presently, in India, most of medical teaching institutes have cadaveric dissection as an integral part of undergraduate curriculum, but when it comes to its utilization in surgical postgraduate teaching, the numbers of centers are disappointing. The reasons of above may be multifold, such as cost constraints in setting up laboratories, practical difficulties in cadaveric supply, increase in number of students, and decreasing number of faculty members interested in laboratory/simulation teaching. As an initial step to overcome some of these barriers, surgical departments in teaching institutes can collaborate with anatomy and start using dissection rooms meant for undergraduates in different time slots.

We feel that inclusion of structured cadaveric/laboratory training modules into postgraduate curriculum of surgery and its subspecialties is the way forward for ensuring surgical competency among residents of our country. Teaching institutes should plan to develop permanent facilities that will be equipped with not only various adjuncts like microscope, endoscopes/laparoscopes, drills, and various kinds of instruments for surgical approaches on cadaver, but along with facilities of synthetic models and virtual simulators. Permanent dissection facility/laboratory should be such so that it mimics a real OR. Aim is to develop and induct structured cadaveric + simulation modules for postgraduate and super specialty surgical curricula. Mentors and trainees should prepare as if they are performing in OR. The modules can be recorded and used for telecast as well as later analysis. We, at our institute, are on the way to develop such a facility.

Limitations of Study

This was a single-center study where laboratory training in form of cadaveric dissection was started as novel initiative; thereby, only 35 were trained until date. As number of residents in surgical subspecialties is usually limited at any given institute, multi-centric and long-term studies with large number of participants may be required to further support our findings.

Conclusions

Laboratory training including cadaveric dissection is feasible, relevant, effective, and acceptable to postgraduate surgical trainees with few disadvantages, which can be taken care of. Trainees felt it should be made part of curriculum. In changing health care scenarios, simulation training can help to improve technical competency of surgical postgraduates and may provide uniformity to training.

Acknowledgements We are also thankful to residents and support staff of Anatomy, Surgical oncology and Neurosurgery for their help during simulation sessions.

Declarations

Consent to Participate Informed voluntary consent was obtained from study participants.

Competing Interests The authors declare no competing interests.

References

1. Morton JH (2000) The qualities of a successful surgeon. Arch Surg 135:1477

2. Kshettry VR, Mullin JP, Schlenk R, Reckons PF, Benzel EC (2014) The role of laboratory dissection training in neurosurgical residency: results of a national survey. World Neurosurg 82:554–559
3. Suri A, Roy TS, Lalwani S, Deo RC, Tripathi M, Dhingra R et al (2014) Practical guidelines for setting up neurosurgery skills training cadaver laboratory in India. Neurol India 62:249–256
4. Memon I (2018) Cadaver dissection is obsolete in medical training! A misinterpreted notion. Med Princ Pract 27:201–210
5. Singh H, Kalani M, Acosta-Torres S, El Ahmadieh TY, Loya J (2013) Ganju A (2013) History of simulation in medicine: from resusciannie to the Ann Myers Medical Center. Neurosurgery 73:S9-14
6. Green NA (1998) Anatomy training for surgeons – a personal viewpoint. J R Coll Surg Edinb 43:69–70
7. Harrop J, Lobel DA, Bendok B, Sharan A, Rezai AR (2013) Developing a neurosurgical simulation-based educational curriculum: an overview. Neurosurgery 73:S25–S29
8. Limbric DD, Dacey RG (2013) Simulation in neurosurgery: possibilities and practicalities: foreword. Neurosurgery 73:S1–S3
9. Selcuk I, Tatar I, Huri E (2019) Cadaveric anatomy and dissection in surgical training. Turk J Obstet Gynecol 16:72–75
10. Ozcan S, Huri E, Tatar I, Sargon M, Karakan T, Yagli OF et al (2015) Impact of cadaveric surgical anatomy training on urology residents' knowledge: a preliminary study. Turkish Journal of Urology 41:83–87
11. Mitchell EL, Sevdalis N, Arora S, Azarbal AF, Liem TK, Landry GJ et al (2012) A fresh cadaver laboratory to conceptualize troublesome anatomic relationships in vascular surgery. J Vasc Surg 55:1187–1195
12. Sharma G, Aycart MA, Najjar PA, van Houten T, Smink DS, Askari R et al (2016) A cadaveric procedural anatomy course enhances operative competence. J Surg Res 201:22–28
13. Cundiff GW, Weidner AC, Visco AG (2001) Effectiveness of laparoscopic cadaveric dissection in enhancing resident comprehension of pelvic anatomy. J Am Coll Surg 192:492–497
14. Rhoton AL Jr (2003) Cranial anatomy and surgical approaches. Lippincott Williams & Wilkins, Baltimore
15. Kim SC, Fisher JG, Delman KA, Hinman JM, Srinivasan JK (2016) Cadaver- based simulation increases resident confidence, initial exposure to fundamental techniques, and may augment operative autonomy. J Surg Educ 73:e33–e41
16. Anastakis DJ, Regehr G, Reznick RK (1999) Assessment of technical skills transfer from the bench training model to the human model. Am J Surg 177:167–170
17. Gilbody J, Prasthofer AW, Ho K, Costa ML(2011) The use and effectiveness of cadaveric workshops in higher surgical training: a systematic review *Ann R Coll Surg Engl* 93**:**347–352.
18. James HK, Chapman AW, Pattison TR, Griffin DR, Fischer JD (2019) Systematic review of the current status of cadaveric simulation for surgical training. BJS 106:1726–1734
19. Mackenzie CF, Garofalo E, Puche A, Chen H, Pugh K, Shackelford S et al (2017) Performance of vascular exposure and fasciotomy among surgical residents before and after training compared with experts. JAMA Surg 152:581–588
20. Rehder R, Abd-El-Barr M, Hooten K, Weinstock P, Madsen JR, Cohen AR (2016) The role of simulation in neurosurgery. Childs Nerv Syst 32:43–54
21. Vanderbilt AA, Grover AC, Pastis NJ, Feldman M, Granados DD, Murithi LK, Mainous AG 3rd (2014) Randomized controlled trials: a systematic review of laparoscopic surgery and simulation-based training. Glob J Health Sci 7:310–327. https://doi.org/10.5539/gjhs.v7n2p310
22. Bohl MA, Zhou JJ, Mooney MA, Repp GJ, Cavello C, Nakaji P et al (2019) The Barrow Biomimetic Spine: effect of a 3-dimensional-printed spinal osteotomy model on performance of spinal osteotomies by medical students and interns. J Spine Surg 5:58–65
23. Cleary DR, Siler DA, Whitney N, Seldon NR (2017) A microcontroller-based simulation of dural venous sinus injury for neurosurgical training. J Neurosurg 128:1553–1559
24. Bohl MA, McBryan S, Spear C, Pais D, Preul MC, Wilhelmi B, et. Al, (2019) Evaluation of a novel surgical skills training course: are cadavers still the gold standard for surgical skills training? World neurosurg 127:63–71
25. Spruit EN, Band GP, Hamming JF, Ridderinkhof KR (2014) Optimal training design for procedural motor skills: a review and application to laparoscopic surgery. Psychol Res 78:878–891
26. Faulkner H, Regehr G, Martin J, Reznick R (1996) Validation of an objective structured assessment of technical skill for surgical residents. Acad Med 71:1363–1365
27. Martin JA, Regehr G, Reznick R, MacRae H, Murnaghan J, Hutchison C et al (1997) Objective structured assessment of technical skill (OSATS) for surgical residents. Br J Surg 84:273–278
28. Regehr G, MacRae H, Reznick RK, Szalay D (1998) Comparing the psychometric properties of checklists and global rating scales for assessing performance on an OSCE-format examination. Acad Med 73:993–997
29. Porte MC, Xeroulis G, Reznick RK, Dubrowski A (2007) Verbal feedback from an expert is more effective than self-accessed feedback about motion efficiency in learning new surgical skills. Am J Surg 193:105–110