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Analysis of Current Possibilities for the Implementation of Practical Training in Surgical Interventions in the Head Area

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Abstract

Introduction: Simulation-based training is a key component of surgical education; however, existing models, such as dry-laboratory and virtual reality simulators, have limitations in terms of realism and accessibility. The use of human cadaveric material is also challenging because of its high cost and limited availability. Objectives: To evaluate the effectiveness of biological models based on large animal cadaveric material, specifically cattle and pigs, for practicing head and neck surgical skills. Materials and Methods: The study included 100 third- and fourth-year students, who were divided into a study group and a comparison group, with 50 participants in each group. The study group practiced surgical skills using animal cadaveric material: a porcine mandible for bone graft harvesting and a bovine head for resection craniotomy. The comparison group practiced using 3D-printed models. The results were assessed using an anonymous 8-item Likert-scale questionnaire, followed by statistical analysis using the Mann–Whitney U test. Results: In the study group, statistically significant increases were observed in satisfaction with participation, fulfillment of expectations, perceived subjective acquisition of manual skills, and overall satisfaction with the training process ($p < 0.001$; median scores: 38.0 and 34.0, respectively). The greatest differences were observed in satisfaction with participation, where 54% of participants rated it as "Excellent" compared with 6% in the comparison group, and in perceived subjective acquisition of manual skills, reported by 80% of participants in the study group compared with 24% in the comparison group. Conclusions. The use of cadaveric specimens from large animals is associated with higher satisfaction and represents an accessible alternative for practicing basic and commonly performed head and neck surgical procedures that do not require fine dissection of neurovascular bundles. This model provides a high degree of tactile realism and anatomical context and is subjectively preferred over non-anthropomorphic simulators.

Keywords: animal cadaveric material; head and neck surgery; maxillofacial surgery; neurosurgery; simulation models; simulation training

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1. Introduction

Surgical treatment of head pathology exemplifies the multidisciplinary nature of modern medicine, as this anatomical region represents an area of overlap among several surgical specialties, including neurosurgery, otorhinolaryngology, and maxillofacial surgery. Simulation-based training is a growing trend in residency education worldwide across all medical specialties, particularly in surgery. Technological advances have significantly expanded both the range and realism of simulation models used in practical training for physicians.

Due to the absence of a unified classification of simulation models in the literature, we use our own classification, which distinguishes between physical models, or dry-lab models; virtual models, including VirtuLab or virtual reality models; and biological models, including animal wet-lab models and human cadaveric models [1].

Dry-lab models are useful for mastering basic surgical skills and are more appropriate for undergraduate training; however, their application in the practical training of residents and practicing physicians is limited. These models may be used primarily for familiarization with the principles of performing specific interventions, such as bone osteosynthesis for facial skeletal injuries or rhinoscopy techniques (Figure 1a). Attempts have been made to overcome these limitations by incorporating mixed reality technologies into the training of neurosurgical residents for technically complex procedures that are difficult to simulate using cadaveric material, such as tumor resection and microsurgical treatment of cerebral aneurysms [2,3].



(**a**) (**b**)

Figure 1. Using dry-lab and virtu-lab models to practice transnasal endoscopic access techniques. SIMONT simulator (**a**), NeuroTouch virtual simulator (**b**).

Practicing complex, multistage manipulations, such as transcranial approaches, using these models remains largely experimental because of the high cost of the models and the technical complexity of their production [4–6]. Virtual reality technology, which was initially used for training military and civil aviation pilots, began its successful implementation in the practical training of physicians in the early 2000s and has since demonstrated its effectiveness. This technology can essentially be divided into three types: immersive virtual reality, augmented or mixed reality, and non-immersive virtual reality, often described as "looking through a window."

The most widely used virtual simulators are those based on the principle of full immersion and are designed to simulate thoracoscopic and laparoscopic interventions [7,8]. VR models are relatively expensive, which remains one of their main disadvantages. Nevertheless, they have become firmly established in simulation-based training for surgeons, urologists, and gynecologists, and their economic feasibility has been demonstrated [9,10].

Virtual simulators are also available for modeling surgical interventions involving the cranial cavity and spine, such as NeuroTouch; transnasal endoscopic access to the paranasal sinuses; and antromastoidectomy, including NeuroTouch, Voxel-Man, and similar systems.

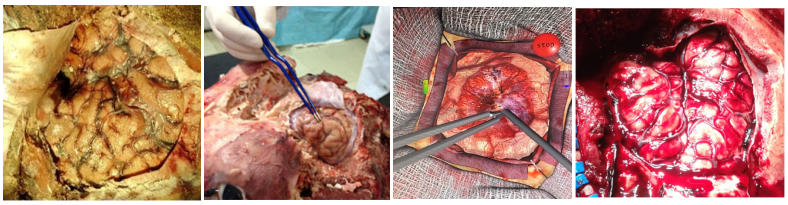
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However, their functionality is considerably lower than that of general surgical simulators. They allow only individual stages of surgical procedures to be practiced and do not provide sufficient representation of anatomical variability [11,12] (Figure 1b).

Today, virtual reality technologies are capable of accurately reproducing various anatomical regions and tissue properties, allowing their use in educational settings without the need for substantial material resources, including financial costs and anatomical dissection material. However, VR currently lacks the tactile feedback provided by biological tissues. This limitation is particularly important in surgery, especially in the head and neck region, where skin texture, complex craniofacial anatomy, and tissue resistance are essential for safe surgical performance.

Thus, even at the current level of development of training technologies, the use of biological models appears to remain indispensable. J. Gasco [13] concluded that the highest training effectiveness for neurosurgical residents was achieved using cadaveric material, with an effectiveness rate of 71.5%, compared with physical models at 63.8% and virtual simulators at 59.1%.

Human cadaveric material has served as the principal biological simulation model for hundreds of years. It remains relevant because it is superior to other models for practicing dissection techniques involving neurovascular bundles, layered surgical approaches to various anatomical structures of the head and neck, and manipulations within the cranial cavity. Human cadaveric material is superior to wet-lab models in terms of anatomical similarity to the human body, whereas VR models offer a more favorable cost-effectiveness ratio and the ability to reproduce all stages of surgical intervention, except hemostasis (Figure 2).



(**a**) (**b**) (**c**) (**d**)

Figure 2. Simulation of intracranial surgery (craniotomy, intradural stage). Human cadaver material (**a**), animal cadaver material (cow head) (**b**), NeuroTouch virtual simulator (**c**), for comparison, surgery on a patient with traumatic brain injury (**d**).

However, simulation-based training for head and neck surgery using human cadaveric material is limited by its availability and high cost. Animal cadaveric material does not have these disadvantages. This model retains many of the characteristics of living tissue and allows for the reproduction of tactile sensations.

The aim of this article was to analyze our own experience of surgical simulation in the head area using biological models based on cadaveric material of large animals.

2. Materials and Methods

For the simulation, we selected common cranial bone procedures in head and neck surgery: harvesting a graft for bone grafting from the mandibular ramus, as well as resection craniotomy.

To teach the technique of harvesting a graft for bone grafting from the mandible, we used native cadaver material—porcine mandible with soft tissues. Using a specimen fixed to a fixed base, the following steps were performed sequentially: (1) a vertical incision to the bone in the retromolar region in the projection of the mandibular ramus; (2) dissecting the soft tissue from the bone with a rasp; (3) cutting the cortical bone layer along the intended

graft boundaries using a fissure bur and an angled handpiece (Figure 3a); (4) separating the bone graft with a chisel; and (5) suturing the soft tissue. A native cadaveric specimen—a head specimen from an adult cow—was used as a model for practicing craniotomy techniques. The following steps were performed sequentially on a pre-prepared cow head specimen (removal of the anterior wall of the frontal sinuses covering the cranial portion of the skull): (1) a burr was used to create a hole in the area roughly corresponding to the squama of the temporal bone on the human skull (Figure 3b); (2) a resection trepanation of the skull was performed using rongeurs (Figure 3b); (3) the dura mater was opened with an arcuate incision (Figure 3c); (4) the dura mater was closed with a continuous suture (Figure 3d).

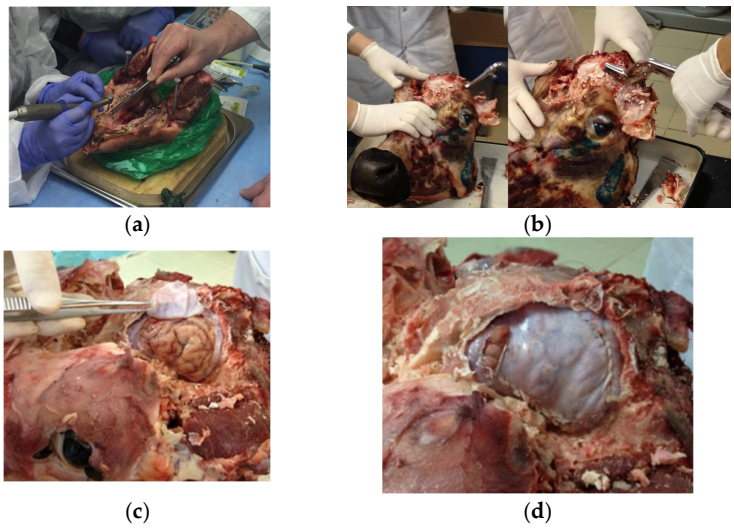


Figure 3. Using wet-lab models. Practicing the technique of harvesting a graft for bone grafting on a pig's jaw (**a**); practicing the technique of craniotomy on a cow's head: craniotomy (**b**), opening the dura mater (**c**), suturing the dura mater (**d**).

2.1. Study Design and Participant Allocation

Students were divided into groups based on their individual educational trajectories. Formal randomization was not conducted.

The two groups (the study group, n = 50, trained on cadaveric animals; the control group, n = 50, trained on 3D-printed models) were matched at baseline for year of study (all were third- or fourth-year students), previous experience with simulator training (none had previously used cadaveric models; all had limited experience working with models in a "dry lab"), and basic knowledge of surgical disciplines and anatomy (mean anatomy exam scores: study group 4.2 $\pm$ 0.5, control group 4.1 $\pm$ 0.6, $p > 0.05$). Instructors were not informed about the type of model used in advance, as it was obvious during the lesson and required no further explanation.

Participants' participation in the study survey was anonymous; no personal data were collected. All animal cadaveric material was handled and disposed of in accordance with standard biohazard waste sanitation protocols, including collection, disinfection, and cremation after completion of the study.

To assess the effectiveness of the simulation training and satisfaction with its aspects, we used an anonymous questionnaire developed using a modified Likert scale. The questionnaire was administered immediately after the practical training session, along with a post-test.

Participants were asked to rate eight key parameters of the training course:

- Satisfaction with program participation.
- Meeting training expectations.
- Satisfaction with the organization of the training.
- Satisfaction with the teaching methodology.
- Meeting expectations with the teaching methodology.
- Educational value of the methodology.
- Perceived (subjective) formation of manual skills thanks to the methodology.
- Satisfaction with the teacher (tutor) job.

5—"Excellent";
4—"Good";
3—"Satisfactory";
2—"Bad";
1—"Terrible".

Additionally, an integrated overall satisfaction score was calculated by summing the scores for all eight questions. The minimum overall satisfaction score was 8 points (the most negative assessment), and the maximum was 40 points (the most positive assessment).

The study involved 100 students, divided into two equal groups:

(1) The main group (n = 50)—participants who practiced their skills on biological material (cow cadaver heads and pig mandibles).

(2) The comparison group (n = 50)—participants who performed the same procedures on 3D-printed skull and mandible models (dry-lab models).

The study was conducted on a small educational group (100 students) majoring in general medicine, in which students are taught an individualized educational trajectory that allows for a flexible choice of lesson type. This sample is a pilot sample for translating the results to the main dataset.

The study protocol, including the use of animal cadaveric material (bovine heads and porcine mandibles) for surgical simulation training, was reviewed and approved by the Biomedical Ethics Committee of the Federal State Budgetary Institution 'National Medical Research Center of Oncology' of the Ministry of Health of the Russian Federation (extract from the minutes of meeting No. 118 dated 2 June 2022). The study did not involve human cadavers, live vertebrate animals, or human subjects.

2.2. Statistical Processing

Data distribution was assessed using the Shapiro–Wilk test. For normally distributed data, the mean and standard error (MSE) are presented; for non-normally or ordinal data, the median and interquartile range (IQR) are used. To compare independent groups by ordinal indicators (individual Likert scale items and the overall satisfaction score), the Mann–Whitney U test was used. Results for individual items and the total score are reported as median (interquartile range, IQR). The Hodges–Lehmann estimator with a 95% confidence interval was calculated for the median difference between groups. To adjust for multiple comparisons, the Bonferroni correction was applied. A corrected significance threshold of $\alpha = 0.00625$ (0.05/8) was used. All p-values < 0.001 remained significant after correction. There was no formal randomization in this study.

3. Results

The null hypothesis was rejected with a high degree of confidence ($p < 0.001$). The alternative hypothesis that training on animal cadaveric material is associated with higher overall satisfaction and better skill perceived (subjective) formation was supported. In the main group (biological material), the proportion of respondents who rated "Excellent" was

statistically significantly higher for 7 of the 8 criteria ($p < 0.001$). This indicates that learning with biological material elicits a significantly stronger positive response from participants (Table 1). After applying the Bonferroni correction for eight comparisons ($\alpha = 0.00625$), all seven parameters with $p < 0.001$ remained statistically significant. The only non-significant parameter (satisfaction with organization of training, $p > 0.05$) was unaffected.

Table 1. Results of the survey of students in the comparison group and the main group.

Parameter	Comparison Group (n = 50)	Main Group (n = 50)	Exceeding Factor	*p*-Value
Satisfaction with participation in training	3 (6%)	27 (54%)	9 times higher	<0.001
Meeting learning expectations	5 (10%)	32 (64%)	6.4 times higher	<0.001
Satisfaction with the organization of training	19 (38%)	23 (46%)	1.2 times higher	>0.05
Satisfaction with the teaching methodology	18 (36%)	25 (50%)	1.4 times higher	<0.001
Expectations from the teaching methodology	20 (40%)	42 (84%)	2.1 times higher	<0.001
Educational value of the methodology	20 (40%)	37 (74%)	1.85 times higher	<0.001
Formation of manual skills	12 (24%)	40 (80%)	3.3 times higher	<0.001
Satisfaction with the teacher	21 (42%)	42 (84%)	2 times higher	<0.001

Satisfaction with training participation: 54% of the participants in the main group gave excellent grades, compared to only 6% in the comparison group (a 9-fold difference). Students working with biomaterials enjoyed the process significantly more, perceiving it as a real surgical procedure. This is confirmed by the criterion for manual skill development: 80% of participants in the main group rated this aspect as "Excellent", compared to 24% in the 3D-model group (a 3.3-fold difference), emphasizing the importance of tactile feedback for the perceived subjective acquisition of fine motor skills.

The survey data also reveals the value of the teaching methodology for working with biomaterials. No one in the main group gave grades lower than satisfactory, demonstrating high tolerance and a positive perception of working with biological material, even among those participants experiencing it for the first time. An analysis of the frequency of top ratings convincingly demonstrates that students perceive learning with biological material (animal cadavers) as a fundamentally higher-quality, more valuable, and more realistic experience compared to 3D-printed models. The greatest increase in satisfaction occurred for criteria related to tactile sensations, practical value, and emotional engagement ("participation," "skills," "expectations met"). The lack of differences in the organization's assessments confirms that the identified benefits are due specifically to the biological nature of the simulator.

A comparative analysis of the median values presented in Table 2 revealed that participants in the main group (training using animal cadaver material) rated all key aspects of the training significantly higher ($p < 0.001$), apart from satisfaction with the organization of the process, which was comparable in both groups ($p > 0.05$). This is evident, as the organization (schedule, preparation of materials, explanations) was the same for all participants. This fact strengthens the reliability of the remaining results—the differences arise specifically from the type of model, not from differences in course organization.

The most pronounced differences in favor of biological models were recorded for the criteria of "satisfaction with methodology," "educational value," and "perceived development of manual skills." The overall satisfaction score (sum of 8 items, range 8–40) in the main group was median 38.0 (IQR 36.0–39.0) versus 34.0 (IQR 32.0–36.0) in the comparison group. The Hodges-Lehmann difference in medians was 4.0 points (95% confidence interval: 2.5–5.5), $p < 0.001$. Analysis of the data in the presented tables shows that the alternative hypothesis is confirmed: training in head surgery on cadaveric animal material is associated with higher overall satisfaction with the training.

Table 2. Mean satisfaction scores for various aspects of training in the comparison group and the main group, assessed using a 5-point Likert scale.

Parameter	Comparison Group (n = 50) Median (IQR)	Main Group (n = 50) Median (IQR)	*p*-Value
Satisfaction with participation in training	4.0 (3.0–4.0)	5.0 (4.0–5.0)	<0.001
Meeting learning expectations	4.0 (4.0–4.0)	5.0 (4.0–5.0)	<0.001
Satisfaction with the organization of training	4.0 (4.0–5.0)	5.0 (4.0–5.0)	>0.05
Satisfaction with the teaching methodology	5.0 (4.0–5.0)	5.0 (5.0–5.0)	<0.001
Expectations from the teaching methodology	4.0 (4.0–5.0)	5.0 (4.0–5.0)	<0.001
Educational value of the methodology	4.0 (4.0–5.0)	5.0 (5.0–5.0)	<0.001
Formation of manual skills	4.0 (4.0–5.0)	5.0 (4.0–5.0)	<0.001
Satisfaction with the teacher	5.0 (4.0–5.0)	5.0 (5.0–5.0)	<0.001

4. Discussion

The use of animal cadaveric material in practical surgical training is limited by its anatomical discrepancy with human anatomy and, consequently, by the substantially lower anatomical validity of this model [14].

Surgeries on live animals, the most popular of which are minipigs, despite their anatomical differences, also allow for the perceived (subjective) formation of hemostasis skills. These techniques provide the opportunity to "feel living tissue," but have an obvious drawback: the high cost of organizing the training process. Furthermore, this type of training is more suitable for teaching laparoscopic surgery to abdominal surgeons and is practically useless for mastering surgical techniques on organs of the head and neck due to the pronounced anatomical inconsistency. Exceptions include the use of live laboratory rats for practicing vascular microanastomosis techniques, which represents a basic training skill for specialists who use microsurgical techniques [15].

Attempts to use bovine, ovine, caprine, and porcine cadaveric specimens as training models for various head and neck surgical procedures have been reported since the 2000s, including complex interventions such as dissection of the arachnoid cisterns at the skull base and clipping techniques for cerebral arterial aneurysms. However, these studies have not gained widespread acceptance due to significant discrepancies between the microanatomy of the base of the brain in animals and humans [16–18].

Considering the literature indicating the limited appropriateness of animal cadaveric specimens for modeling complex head surgeries requiring dissection of neurovascular structures, the present study focused on training in simpler but more commonly performed procedures. Our experience shows that bovine heads can be used to teach the technique of resectional craniotomy performed for traumatic brain injury, and porcine jaws can be used to teach the technique of jawbone grafting, which is relevant in preparation for dental implantation.

In Russia, there remains a shortage of anatomical material due to local legislation and the lack of a donation program. Therefore, it cannot be ruled out that the higher satisfaction in the biological material group is partly due to the novelty of working with cadaveric animal specimens. This, in turn, may have increased emotional engagement compared to familiar 3D-printed models. Our results demonstrate a clear preference among trainees for biological models, but future studies should consider the retention of acquired skills for their potential transfer to clinical work.

Limitations

An additional limitation of this study is the use of exclusively subjective questionnaires; objective measures of surgical competence, such as time to task completion, error rate, or blinded expert assessment, were not performed. Therefore, conclusions regarding actual skill acquisition should be considered preliminary.

Students were allocated to groups according to their individual educational trajectories rather than by individual randomization. The groups were comparable in terms of curriculum volume, previous experience with simulation-based training, and basic knowledge of surgical disciplines and anatomy. The absence of formal randomization and instructor blinding, due to the evident nature of the models used, is acknowledged as a limitation of the study.

5. Conclusions

Practical training in surgical specialties using simulation-based technologies has been successfully implemented in routine educational practice. However, the use of dry-lab models in head and neck surgical training remains limited because of their insufficient realism.

The structured practical training of residents in neurosurgery and maxillofacial surgery requires the use of cadaveric specimens. Given the organizational and legislative difficulties associated with training using human cadaveric material, cadaveric specimens from large animals, such as pigs and cattle, may be used to practice procedures that do not require dissection of neurovascular bundles.

Based on our subjective outcome assessments, the use of cadaveric specimens from large animals is associated with significantly higher trainee satisfaction and greater perceived development of manual surgical skills compared with non-biological simulators.

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Institutional Review Board Statement: All procedures involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments. The study protocol was approved as described in Section 2.1. The study did not involve the use of human cadaveric material or live vertebrate animals.

Data Availability Statement: Data available on request due to local law reasons.

Conflicts of Interest: Dr. Irina Smilyk is employed by Institute of Anatomy LLC. The authors declare no conflicts of interest.

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