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Evolution of surgical training from ancient times to the present day

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Abstract

Surgical training has evolved significantly from the first operations in antiquity to modern training methods. Historically, the practice was based on observation andempirical practice, with limitations due to a lack of knowledge about hygiene, pain and infection. Today, training combines theory, practical training and technology, such as simulators and minimally invasive techniques (e.g. laparoscopic surgery), with the aim of ensuring patient safety and developing the skills of trainees. Recognising different learning styles, using learning curves and providing personalised guidance contribute to the effective and targeted training of surgeons. This approach shows that modern surgical training combines historical experience with technological innovation to develop competent and safe professionals.

Keywords: Surgical Training; Technical Skills; Learning Curve; Patient Safety; Medical Innovation

1. Introduction

Surgical training is a cornerstone of medical science, as it directly affects patient safety, the quality of operations, and the professional development of doctors (Aggarwal et al., 2023). This process is not limited to the transmission of theoretical knowledge, but includes the development of technical skills, understanding of anatomy and pathophysiology, and critical decision-making during actual procedures (Maniou, 2024).

From the first surgical procedures recorded thousands of years ago to modern medical practice, education has evolved alongside advances in science and technology. In ancient times, learning was mainly empirical and based on observation and practical training in real-life situations, often on battlefields or in military environments.

Limited knowledge about hygiene, analgesia, and complications from infections determined the level of safety of procedures and the learning process (Maniou, 2024).

Over the centuries, the development of surgical science, the establishment of surgical associations and the introduction of standardised specialisation programmes created more structured and organised training frameworks (Arani, 2012). Today, surgical training utilises modern technologies, such as simulators and virtual environments, allowing trainees to acquire skills in controlled and safe environments before applying them to real patients (Maniou et al., 2025a).

The recognition of different learning styles, the application of the learning curve and the continuous assessment of trainees' performance enhance the effective transfer of knowledge and the development of high-level skills (Maniou et

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al., 2025b). Thus, modern surgical training combines empirical tradition with technological innovation, responding to the ever-changing demands of medical practice and society.

2. Historical Surgery References

The earliest indications of surgical interventions date back to prehistoric times. Paul Broca demonstrated that trepanation (cranial surgery) was performed around 7000 years ago, indicating the presence of rudimentary surgical practices in very early human societies (Stone, 1991). It is likely that basic surgery was applied even before this period, particularly on battlefields, where the care of wounded individuals was crucial. The empirical knowledge acquired by caregivers during this time formed the oundation of early surgical education.

In antiquity, the Roman Empire developed military medical systems that included organised field hospitals equipped with water supply, latrines, and basic hygiene infrastructure. These facilities reflect an understanding of preventive measures and the importance of hygiene in patient care (Cushing, 1999). Despite these early efforts, surgical practice until the 18th century was limited by significant problems such as haemorrhage, infection, and inadequate analgesia, making procedures risky and complex.

During the scientific renaissance of surgery, John Hunter, a renowned 18th-century surgeon without a formal medical degree, is considered the founder of pathological anatomy and a father of modern scientific surgery. His experiences during the Seven Years' War (1756–1763) led him to publish significant studies on gunshot wounds, laying the groundwork for scientific analysis and evidence-based surgical education (Hunter, 1794; Moore, 2005).

In subsequent centuries, surgical societies developed, contributing to the standardisation and structured training of apprentices. In Greece, surgical education faced significant challenges, including the lack of standardised and homogeneous training programmes and hospitals, leading to considerable variation in size, quality, and content. This unequal distribution of educational resources directly affected the development of surgical skills, creating a need for systematic and targeted reorganisation of training (Van Way III, 2016; Arani, 2012).

Table 1 The evolution of surgery and education

Prehistoric era (~5000 BC)	**Unknown caregivers of the injured**	**Early surgery**	**Trepanation (skull drilling)**
Antiquity (Roman Empire, ~1st century BC–5th century AD)	Roman military doctors	Open-air hospitals	Basic hygiene and care for the wounded
18th century John Hunter (1728–1793)	Father of modern scientific surgery	Pathological anatomy	Studies of gunshot wounds
19th–20th century (Europe)	Surgeons' associations (British/European)	Standardization of surgeon training	
19th–20th century (Greece)	Greek surgeons / trainers	-Unequal distribution of educational resources - Diversity in education	Needfor systematic reorganization

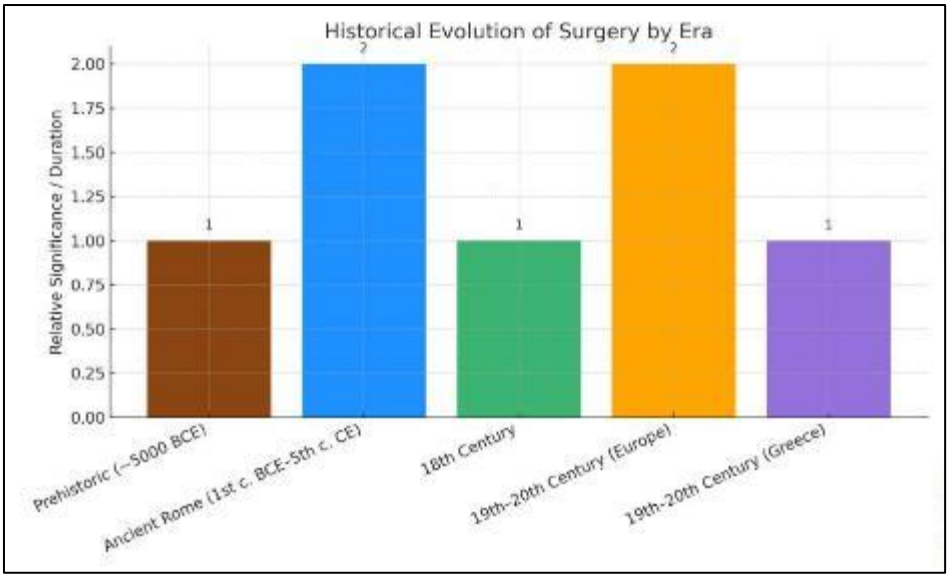

Figure 1 Bar chart showing the historical development of surgery Modern surgical training and learning methods

Modern surgical training has evolved from the traditional "watch and do" practice to a systematic and multidimensional learning framework that focuses on patient safety and the development of technical skills (Aggarwal et al., 2023). Today, training combines theoretical knowledge, practical practice and the use of technological tools, such as simulators and virtual environments, which allow trainees to gain experience without risk to the patient (Kneebone, 2023; Issenberg et al., 2005).

Trainees are continuously assessed using the learning curve, which determines the number of repetitions required to master a skill depending on the difficulty of the procedure (BMC Medical Education, 2024a). In this context, studies on specific techniques have highlighted how experience affects performance and patient safety. For example, the application of the Breast Lesion Excision System (BLES) shows that operators become proficient after a certain number of repetitions, while supervision during the first applications reduces the risk to the patient (Michalopoulos, Maniou & Zografos, 2012; Maniou et al., 2019). Similarly, novice radiologists performing MRI imaging for endometriosis need systematic experience to make a reliable diagnosis (Bruyère et al., 2020). Furthermore, assessment of patients' quality of life after stereotactic vacuum biopsy shows that the technique and experience of the operator significantly affect the results and safety (Maniou et al., 2011). At the same time, the integration of supportive care in complex situations, such as cancer management during pregnancy, highlights the multiple demands on the trainee and the need for organised and guided learning (Zagouri & Maniou, 2016).

Theoretical approaches to learning in surgery include different models. Behaviourism considers that learning results from external stimuli and repetition, shaping the learner's behaviour (Watson, Pavlov, Skinner). Cognitivism focuses on processing information and linking it to pre-existing knowledge, requiring a structured presentation so that theory can be applied in practice (Ericsson, 2004). Constructivism emphasises learning through personal experiences, where the learner actively selects and adapts stimuli under the guidance of the instructor (Piaget, Dewey, Vygotsky). Finally, the synthetic approach connects existing knowledge with new experiences, enhancing active participation and adaptability in a changing environment (Jarvis, Kokkos).

Practical training is the cornerstone of modern education. In the context of surgical procedures, guidance from experienced surgeons allows trainees to practise in real anatomical and pathological conditions, with simultaneous assessment and feedback (Sawyer, 2019). The physical presence of the trainer and trainee in the same space facilitates the direct transfer of knowledge, the resolution of queries and the improvement of skills. Recognising different learning styles and personalizing guidance contributes to the effective training of young surgeons, preparing them to perform complex and minimally invasive procedures with high standards of quality and safety (Ziv et al., 2005).

Modern surgical training therefore requires a comprehensive approach that integrates theoretical knowledge, technological tools and personalised guidance, ensuring the development of the necessary skills for safe and effective practice.

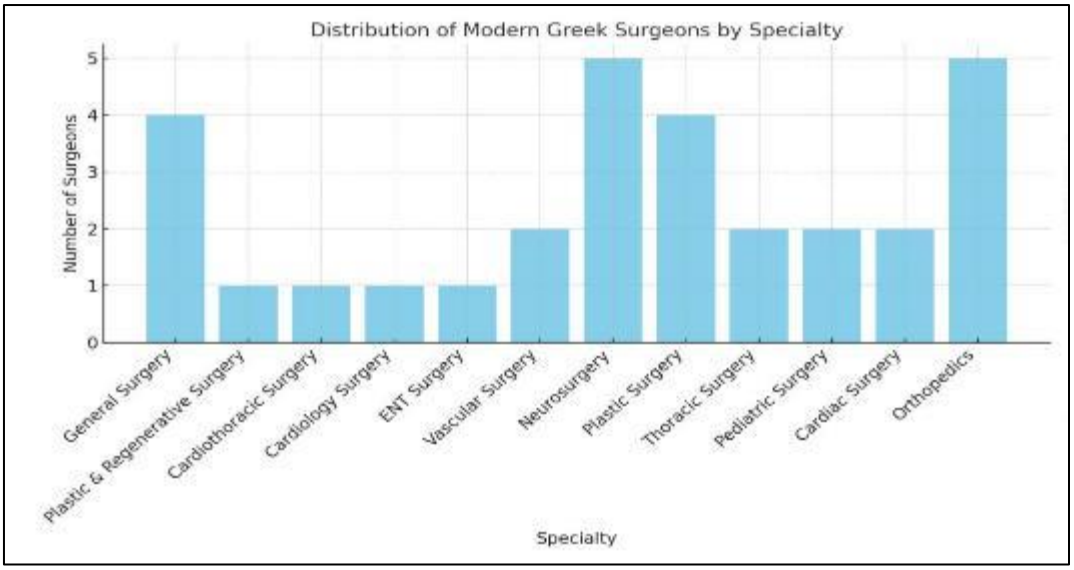

Figure 2 Figure showing the distribution of modern Greek surgeons by specialty

3. Surgical training today: Greece and international developments

Surgical training internationally is undergoing a period of intense development. The emphasis is no longer only on the number of cases, but also on the development of specific skills through competency-based training (Budak et al., 2020). The use of simulators, VR/AR and robotic technology is a key part of training in most developed countries (Rahimi et al., 2024). At the same time, artificial intelligence is being introduced as an assessment and feedback tool, offering new possibilities for personalised training (Khan et al., 2024).

In Greece, education continues to face problems. Limited access to technological resources (robotic systems, simulators) and the difficulties brought about by the economic crisis have had a negative impact on the quality of training (Skandalakis et al., 2008). In several specialties, such as ophthalmology, the lack of sufficient surgical cases hinders the practical training of trainees (Skandalakis et al., 2008).

In contrast, in the international context, there are structured training programmes with clear levels of progress and objective evaluation criteria. In EU countries, trainees are selected through specific procedures (competitions, structured interviews), which leads to a more organised distribution of candidates (Dimitriou et al., 2021).

The COVID-19 pandemic has affected education worldwide, with a reduction in interventions and a limitation of the surgical experience of trainees (Di Saverio et al., 2020). This has highlighted the need for alternative training methods, such as the use of online programmes and simulations (Nguyen, Thomas and Rahman, 2025).

Overall, surgical training in Greece lags behind international standards, mainly due to a lack of infrastructure. However, the integration of new technologies and the adoption of objective assessment systems, as applied abroad, can be important steps towards improvement (Budak et al., 2020; Rahimi et al., 2024; Khan et al., 2024).

4. Proposals for improving surgical training in Greece

Surgical training in Greece is at a critical juncture, as challenges related to limited infrastructure, financial difficulties and slow adoption of international standards continue to create a significant gap compared to practices in other countries (Skandalakis, Androulakis and Mirilas, 2008). In order to improve the quality of education, a series of complementary interventions are required.

Firstly, it is necessary to strengthen infrastructure and invest in technological equipment. The creation of more centres with robotic platforms, virtual and augmented reality simulators, and digital feedback systems would offer trainees the opportunity to develop skills outside the operating theatre. Internationally, simulators have been shown to improve the safety and confidence of young surgeons before they engage with real patients (Rahimi et al., 2024).

Secondly, an assessment model based on skills rather than solely on the number of cases or years of training should be adopted. Most countries abroad use a competency-based system, which includes objective measurements such as time analysis, movement analysis and standardised tests, with the aim of achieving a more objective assessment (Budak et al., 2020).

Thirdly, structured robotic surgery programmes need to be developed. Internationally, these programmes include theoretical training, practice on simulators, laboratory application in experimental models and, finally, participation in surgeries under close supervision, with gradual certification of skills (Rahimi et al., 2024). Such a structure would ensure that trainees gain sufficient experience in a safe and systematic manner.

Fourth, the integration of artificial intelligence and virtual or augmented reality technologies can act as a catalyst in education. Artificial intelligence has the ability to analyse surgical movements, identify errors and provide personalised feedback, while VR/AR technologies enable realistic, safe and repeatable practice (Khan et al., 2024; Nguyen, Thomas and Rahman, 2025). Although cost and the need for specialized trainers remain obstacles, this direction is considered inevitable internationally.

Fifth, it would be useful to centralise the selection and allocation of trainees. In Greece, the process remains fragmented and often leads to an uneven distribution of human resources in hospitals. , in contrast, the European Union has adopted structured selection systems with competitions, interviews and assessments, which ensure greater transparency and fairness (Dimitriou et al., 2021).

Finally, the experience of the COVID-19 pandemic has highlighted the need for alternative training models. The reduction in surgical procedures has had a negative impact on the training of trainees internationally, and Greece is no exception (Di Saverio et al., 2020). To avoid a complete interruption of the educational process in future crises, it is necessary to develop online courses, virtual laboratories and simulators that will serve as backup solutions.

Overall, improving surgical training in Greece requires investment in infrastructure, the adoption of modern assessment methods, the exploitation of innovation and better organisation of the education system. Only in this way will it be possible to bridge the gap with international standards and ensure a high level of training for future surgeons.

Concluding, we emphasize the significance of all digital technologies in all domains of education and in surgical training, which is highly effective and productive and facilitates and improves assessment, intervention, and educational procedures via mobile devices that bring educational activities everywhere [23-25], various ICTs applications that are the main supporters of education [26-30], and AI, STEM, and ROBOTICS that raise educational procedures to new performance levers [31-34]. Additionally, the development and integration of ICTs with theories and models of metacognition, mindfulness, meditation, and the cultivation of emotional intelligence [35-48], accelerates and improves more the educational practices and results, especially in surgical training

5. Conclusions and prospects

The course of surgical training from antiquity to the present day reflects the gradual transition from empirical learning to scientifically documented and technologically supported training. From early surgical practices, such as craniotomy in prehistoric times, to the development of simulators, robotic platforms and minimally invasive techniques, education has constantly adapted, with patient safety and the systematic acquisition of high-level skills as its core focus.

Today, surgical training internationally is based on a combination of theoretical knowledge, practical training and the use of technological tools, with an emphasis on personalised learning, continuous assessment through the learning curve and ongoing feedback. This integrated approach equips young surgeons with the skills to perform complex and minimally invasive procedures safely and with high quality.

The future prospects for education increasingly rely on the integration of innovations such as virtual and augmented reality, as well as artificial intelligence, which promise more accurate assessment, safe practice, and personalised training. At the same time, international cooperation and knowledge sharing can contribute to the establishment of uniform standards and the creation of a more equitable and effective educational environment worldwide.

In the case of Greece, the above developments highlight specific needs and priorities. Strengthening infrastructure with robotic systems and simulators, transitioning to assessment systems based on skills and not just training time, the creation of structured robotic surgery programmes, the use of AI and VR/AR technologies, and a more centrally organised distribution of trainees are key steps towards modernizing the system. In addition, the experience of the

COVID-19 pandemic has demonstrated the need for alternative training scenarios, such as online courses and virtual laboratories, so that the educational process is not interrupted in times of crisis.

Overall, surgical training, both internationally and in Greece, continues to evolve, combining empirical tradition with technological innovation. For our country, the adoption of these strategic changes is not only a prerequisite for modernisation, but also an investment in the quality of healthcare and patient safety.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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