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Review Article

The Importance of Anatomy for Becoming an Effective Surgeon

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ABSTRACT

Anatomy is one of the fundamental subjects taught in the medical curriculum. The knowledge of anatomy helps the student in a later career for clinical diagnosis and treatment. Over the past decades, anatomy teaching has undergone various changes. Students have been exposed to methods that help them learn lifelong. The traditional curriculum has its own merits and demerits. Many institutions have adopted the modern integrated approach. Information technology has been incorporated into teaching and learning. There is a need to look at the curriculum in any institution and make necessary changes. Also, we need to determine which skills to prioritize and which need to be phased out. Artificial intelligence could be incorporated into teaching and learning. Anatomy plays an important role in all surgical fields. The complex subject of anatomy is often quickly forgotten, and young surgeons must revisit the anatomy department to brush up on their knowledge and sharpen their skills. The present review discusses the importance of anatomy in traditional and modern curricula, the challenges faced in the transition, and its importance in the surgical field. We discuss the role of variations, incisions, wound suturing, and dressing, which could benefit the surgical field. We also highlight various teaching tools that could benefit teaching and learning.

KEYWORDS: Anatomy, learning, skills, medical education.

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INTRODUCTION

Human anatomy is the study of the structure of the human body [1]. Despite changes in the curricula through time, its importance remains resolute and fundamental to medical education. To comprehend its significance better, the

World Health Organization and World Federation For Medical Education have mandated anatomy education for subsequent syllabus accreditation in medical schools worldwide [2]. Of the many subjects within clinical medicine, gross anatomy is the most important among surgeons [3].

Anatomy has been a subject of perennial significance in medicine. Nikolay Pirogov, a Russian surgeon in the 19th century, produced a doctoral thesis on the potential of aortic ligation as a treatment for aneurysms in the aorta or iliac artery. Pirogov claimed that exercising anatomy in practice holds greater virtue [4]. Therefore, it is no surprise that despite recent technological advances, anatomical dissections are still highly regarded as one of the most popular means of teaching anatomy [5].

Figure 1 shows how teaching of anatomy subject can be beneficial disciplines.

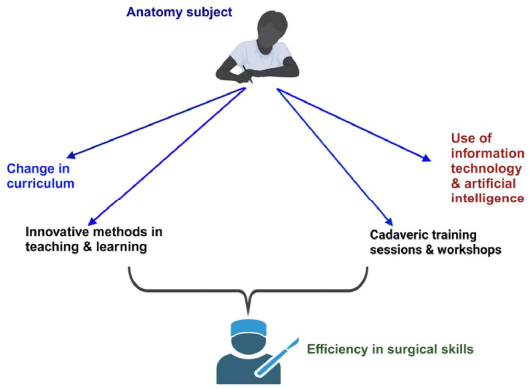

Fig. 1: Schematic diagram showing how the teaching of the anatomy subject can be beneficial for surgical disciplines. The figure is drawn with subscription license from Biorender.com.

METHODOLOGY

An extant search of literature was done to retrieve articles from Pubmed, Scopus and google scholar. All articles from 1978 until 2025 were retrieved. No case reports and letters to the editor were considered and only English written articles were retrieved. Two independent individuals searched the literature. Keywords included “Anatomy,” “Clinical,” “Learning,” Anatomy curriculum” “Surgical anatomy,” “Teaching methods,” “Cadaveric teaching,” “Surgical skills,” “innovative teaching,” and “digital anatomy.”

TRADITIONAL AND MODERN CURRICULA

Traditional curriculum

For centuries, didactic lectures and cadaveric dissections have traditionally taught anatomy [6]. It is interesting to note how the changes in belief in different communities have influenced the teaching of anatomy throughout history.

Despite its long-standing significance, spatial and structural awareness of human anatomy was limited and highly inaccurate, as the standard guides utilized by physicians were drawn by artists at that time, who had inadequate scientific knowledge. This issue remained until 1543 when Vesalius published De Humani Corporis Fabrica, a pinnacle in advancing descriptive anatomy [7].

A study conducted by the University of Zimbabwe has shown that when traditional means of teaching are utilized, students struggle to connect anatomical knowledge to clinical situations [8]. This can partially explain why many graduates have a suboptimal understanding of anatomy [9]. Despite the many plus points of cadaver-based learning, it is growing increasingly difficult to perform dissections due to significant expenses in obtaining and maintaining cadavers [8].

Studies paired with the shortage of anatomy instructors and cadavers globally [10].

Using cadavers as a source of teaching dramatically benefits those who prefer visual learning; seeing the structures in person enhances the theoretical understanding of anatomy. Dissections allow students to develop teamwork skills, as it is primarily a group-based activity [11].

This is a competent trait necessary in medicine, especially in surgery, where timely coordination and clear communication between professionals are of utmost priority.

Modern curriculum

In recent years, teaching anatomy methods have been modified to match the developments in modern technology. One of the inventions includes endoscopy, which makes it possible to view joint cavities and other hollow regions of the body. There is an avid

Table 1: Comparison of traditional and modern medical curricula.

Aspect	Traditional Curriculum	Modern Curriculum	Reference
Teaching Method	Didactic lectures	Interactive, focusing on doctor-patient experiences and student-centred approaches such as PBL.	[18,19]
Use of Technology	Limited to human cadaveric dissection and textbooks	Extensive use of AR, VR, radiology, 3D printing, and live surgical streaming.	[18,20]
Cadaver Dissection	Central and primary method for learning anatomy	Complemented with or replaced by prosections and computer-based learning.	[21]
Assessment	Reliance on multiple-choice written and short-answer practical exams	Includes computer-based testing with interactive and adaptive questioning.	[22]
Cost	Less expensive to develop and maintain	More costly due to the need for advanced technologies.	[22]
Learning Resources	Standard textbooks and limited cadaver availability	Wide range of interactive content, including dynamic 3D virtual environments and comprehensive digital resources.	[18,23]
Student Engagement	Mostly passive learning with limited interaction.	Active learning emphasizes collaboration and discussion and fosters students' creativity, curiosity, and intelligence.	[24]

incorporation of imagery such as magnetic resonance imaging (MRI), computed tomography (CT), and ultrasound in medical education and clinical practice [1].

However, intricate and long-lasting models are expensive to produce and have limited accessibility. It has been shown that 3D models assist students in comprehending anatomy better than traditional methods, especially in small group tutorials [12]. Augmented reality (AR), as well as plastination, two-dimensional (2D) and 3D imaging, also pose as other alternatives to live cadaver dissections [13].

Furthermore, virtual AR cadaver dissections offer the opportunity to dissect tissue layers in any order without necessarily going from superficial to deep. Minute or deep structures that are hard to dissect can be isolated and studied independently, improving the learning experience and comprehension quality [13]. Another advantage of this resource includes the prevention of any damage to actual tissue, as no cadaver is used, which eliminates any ethical issues. This is a significant advancement in anatomy teaching, as ethical concerns regarding cadaveric material have always persisted throughout history.

With the emergence and easy access to the Internet, the utilization of online resources in medical education has become inevitable. Videos are a popular source of information amongst students, increasing engagement and boosting comprehension of anatomical structures. In the US, 44% of medical colleges integrated virtual video dissections to teach students [14]. Another immersive technology that was recently developed was dissection audio-visual resources (DAVR) as an adjunct to prepare for dissections. A survey evaluated that 90% of students agreed that DAVR strengthened their anatomy learning [15].

Therefore, it is evident that online resources have significantly benefited a student's learning.

Interactive environments are pivotal to modern medical education, as it is shown that students who are immersed in such settings have stronger problem-solving skills than those following conventional curricula [16]. Also, technology has successfully augmented anatomy teaching; for example, computer-assisted learning (CAL) is a good educational tool that enhances students' and instructors' knowledge of complex concepts in anatomy through its flexibility and highly resourceful nature [17]. Embedding CAL, medical imaging, and other technology offers a clinically oriented approach to teaching anatomy, which aligns more with today's medical discipline. Table 1 compares various aspects of the traditional vs the modern anatomy curriculums.

Table 2: Impact of anatomical variants on surgical procedures.

Anatomical Variant	Procedure	Impact on Surgery	Study evidence	Reference
Cystic duct, cystic artery, and subvesical bile duct.	Cholecystectomy	Damage to the cystic duct, artery, or subvesical bile duct may cause bleeding or a bile leak.	Inexperienced surgeons caused 30% of bile duct injuries, but the risk decreased with experience.	[27,31]
Hepatic artery, portal vein and fissures of the liver.	Hepatobiliary surgery (e.g., Hepatectomy, Liver transplantation).	Variations may complicate liver tumour resection, risking improper hepatectomy and bleeding.	Experienced surgeons ensured tumour-free margins and minimal liver dissection in Klatskin tumour cases.	[32,33]
Branching patterns of mesenteric vessels and the gastrocolic trunk.	Colon surgery (e.g., laparoscopic colorectal surgery)	Injury to these variations may impair blood supply and lead to haemorrhage.	Knowledge of anatomical variants can help reduce critical errors by 6.8% in laparoscopic colorectal surgery.	[34,35]
Lateral femoral cutaneous and other inguinal region nerves.	Inguinal hernia repair	Damage to regional nerves due to iatrogenic injury could result in persistent severe pain.	Around 30% of inguinal hernia patients risk postoperative pain from nerve injury, but better knowledge of nerve variation reduces this risk.	[36,37]
Recurrent laryngeal nerve (RLN) extra branches.	Thyroid surgery	Unilateral RLN injury may cause vocal cord paralysis and hoarseness, while bilateral injury can result in dyspnea and laryngeal obstruction.	RLN injury and voice changes have been reported, post-thyroidectomy, stressing the need to understand anatomical variations.	[38]

Challenges with transition

Despite the significant advancements in the anatomy curriculum, it has been under pressure lately due to reduced time available to teach larger student populations and overworked faculty members. Consequently, inadequate knowledge of anatomy has become a reason for increasing surgical malpractice [9]. Many clinicians criticized junior doctors' inadequate anatomical knowledge to further this statement. Of the respondents, 97% of surgeons expressed concerns that their juniors' anatomical knowledge was substandard [5].

Numerous studies have shown that despite the countless advantages of technology, students still prefer traditional learning methods, such as cadaveric dissections [25]. One primary limitation of 3D models is that they cannot recreate the exact texture of actual human tissue. Hence, it can be a supplementary resource, not necessarily a direct substitute for cadavers. Likewise, for surgeons, though cadaveric models pose a popular option for practice, they cannot replicate the same experience in real life.

Importance of anatomy in mastering surgical skills

Knowledge of variations/anomalies of structures

While not always indicative of pathological conditions, anatomical variations can present significant challenges during surgery if not correctly identified and addressed. Inadequate exposure and understanding of these variations can lead to misinterpretation of clinical scenarios and poor treatment outcomes, particularly for surgeons unfamiliar with such anomalies [26].

In laparoscopic and traditional cholecystectomy procedures, early recognition of variations in the common hepatic artery is crucial. The common hepatic artery is a primary target for clipping or ligation, and its variations can complicate surgical management, leading to risks such as haemorrhage or hepatobiliary injury [27]. Common variations include atypical cystic artery locations or the presence of multiple cystic arteries, which can significantly impact the surgical approach and outcomes [28].

Advanced imaging techniques and detailed anatomical knowledge are crucial in improving surgical precision and minimizing complications associated with these variations [29]. In renal surgeries, particularly in donor nephrectomy, awareness of vascular variations is vital for minimizing complications and reducing ischemia time during laparoscopic procedures [30].

Table 2 summarizes the major anatomical variants, including the procedures they affect and their impact on the surgical outcomes.

Table 3: Comparison of surgical incisions: uses, advantages, and disadvantages.

Type of Incision	Common Uses	Advantages	Disadvantages	Reference
Midline	Emergency exploratory laparotomy	Quicker in emergencies with minimal risk to the blood supply and nerves.	Increased risk of wound dehiscence and postoperative hernia.	[41,42]
Paramedian	Abdominal procedures targeting pathology in the lateral abdomen.	Lower risk of wound disruption and infection with easy access to lateral abdominal structures like the spleen or kidney.	Longer procedures with higher risks of vascular injury, hematoma, and nerve damage, potentially causing permanent rectus abdominis paralysis.	[41,43]
McBurney's	Appendectomy.	Low risk of incisional hernia, avoids injury to ilioinguinal and iliohypogastric nerves.	It can leave an unappealing surgical scar, potentially unpleasant for the patient.	[44,45]
Pfannenstiel	Gynecological pelvic surgery.	Rare dehiscence and hernias with improved cosmetic outcomes.	Limited upper abdomen exposure and extensibility, with increased risks of inguinal hernias near the external inguinal ring and femoral nerve injury.	[43]

Incisions

To address visible scarring, many surgeons continue to utilize Langer's "cleavage lines," which were first described in 1861 and represent the natural orientation of skin tension [39]. A clinical trial comparing midline and transverse incisions during cholecystectomy found that transverse incisions resulted in a significantly lower incisional hernia rate (2%) compared to midline incisions (14%). Transverse incisions were also shorter and aesthetically more pleasing, with patients experiencing less postoperative pain than those with midline incisions [40].

Table 3 summarizes the commonly used incisions in surgeries, including the surgeries they are used for and their advantages and disadvantages.

Sutures

A thorough understanding of deep anatomical structures, physiological processes, and wound healing mechanisms is crucial for surgeons to achieve optimal surgical outcomes and select the most appropriate suturing techniques and materials based on the wound's location and depth [46]. The choice of suture materials significantly affects tissue approximation, wound healing, and scar aesthetics, making it essential to select materials that minimize ischemia, excessive tension, and tissue damage [47].

Wound dressing

Risk factors for assessing postoperative complications in surgical wounds can be categorized into three primary domains: trauma-related factors such as soft tissue injury or fracture type, surgical factors including incision placement, surgical site contamination, technique, operative duration, and estimated blood loss, and patient-related factors such as morbid obesity, significant comorbidities, and medication use [48].

Anatomical knowledge is pivotal in effective wound management and significantly impacts the selection of appropriate dressing techniques that promote optimal healing. Insights into the anatomical characteristics of various wound sites, such as tissue type, vascularity, and mechanical stress, are crucial for choosing suitable dressings and treatments [49].

How anatomy knowledge can be improved for surgeons

Changes in preclinical curriculum and shortcomings to be removed

When considering changes to a preclinical medical education curriculum, it is crucial to address existing programs' strengths and weaknesses. A review of various curricula reveals a common shortcoming: the lack of hands-on experience in anatomy. A study conducted in Malaysia found that during the preclinical year, most students learned anatomy primarily through rote memorization. A smaller group of students highlighted that early clinical integration, PBL, and using animations in anatomy instruction helped improve their understanding [50].

Table 4: Specialty-specific anatomy innovations and their impact on surgical outcomes.

Surgical Specialty	Advances in Clinical Anatomy Curriculum	Impact on Specific Surgeries	References
General Surgery	Simulation-based laparoscopic training modules 3D digital models of the biliary tree	Inexperienced surgeons disproportionately associated with bile duct injuries; simulation reduces risks	[58-61]
Plastic Surgery	3D-printed simulators for flexor tendon repair Cadaveric + 3-D model flap-dissection workshop	Mean skills-score rose from 61% to 82.5%; all trainees reported higher confidence with tendon repair	[62]
Otorhinolaryngology	3D-printed sinus models & VR-based endoscopic simulations Focused modules on Recurrent Laryngeal Nerve (RLN) anatomy	RLN injury occurs in 0.5–5% of thyroid surgeries; targeted training reduces complications	[63-65]
Orthopedics	Virtual reality arthroplasty simulators Augmented reality for complex fracture mapping	VR-based reverse shoulder arthroplasty improved procedural precision by 67% and saved ~47 minutes of OR time	[57]
Ophthalmology	AR-based modules for orbital and ocular microanatomy Digital microsurgery simulators	Enhances hand–eye coordination during corneal transplant; virtual approaches improve learner engagement	[66, 67]
Obstetrics and Gynecology	Integrated pelvic anatomy sessions emphasizing Pfannenstiel incisions Cadaveric workshops for layered closure	Transverse incisions (e.g., Pfannenstiel) lower incisional hernia rates (~2-6% vs. midline ~11-14%)	[43, 68]
Vascular Surgery	3D reconstructions of vascular variants Simulation-based vessel anastomosis & stent placements	Portal or hepatic arterial variations appear in up to 30% of individuals; recognition reduces complications	[29]
Cardiothoracic	3D-printed heart models for congenital/valvular anomalies Imaging-based AR to guide coronary bypass	Coronary anomalies affect ~1–2% of individuals; advanced training improves recognition	[69, 70]
Neurosurgery	VR-based skull-base approach simulators Cadaveric microvascular decompression labs	Improves spatial orientation and reduces operative errors in complex cranial procedures	[71]
Urology	AR-guided inflatable penile prosthesis placement Laparoscopic kidney dissection simulations	Multiple renal arteries occur in 20–30% of donors; detailed training lowers complications	[72-74]
Hepatobiliary	Detailed 3D modeling of hepatic artery and portal vein Biliary variant recognition in resection training	Hepatic/biliary variations occur in ~30–40% of patients; structured curricula reduce misidentification	[75]
Pediatric Surgery	3D modeling & simulation for congenital anomalies (e.g., AAOCA) Neonatal laparoscopic technique modules	AAOCA occurs in ~1% of children with congenital heart disease; advanced imaging reduces complications	[76]
Trauma Surgery	High-fidelity simulators for chest tube insertion & cricothyroidotomy Anatomy modules on surface landmarks	10% of malpractice claims result from anatomical variation misunderstandings; advanced training is critical	[77]

Innovative methods in teaching and learning

Traditional methods often lead to passive learning, making it challenging for students to stay engaged. Innovative approaches, such as interactive models and digital tools, can make learning more dynamic and engaging. The new methods can accommodate a range of learning styles, increasing the likelihood of success for all students. Vertical integration, which introduces clinical education early in the curriculum while continuing the teaching of basic sciences during later phases, is one way to bridge the gap between preclinical and clinical education [51].

New innovative methods, such as hardware-accelerated laparoscopic simulations and the upcoming intraoperative MRI monitoring, are being introduced in select institutions [52]. However, maintaining a cadaver laboratory in most medical schools remains a significant challenge due to the high costs and required infrastructure.

Additionally, body donations and environmental concerns present further obstacles. In response, some universities have experimented with large touch screens to replicate anatomy labs, but the lack of a 3D element proved insufficient for effective teaching.

Changes in residency programs with basic sciences being incorporated

Incorporating basic sciences into residency programs is essential for producing

well-rounded, competent physicians who can deliver high-quality patient care. This integration not only enhances individual learning experiences but also contributes to the overall advancement of healthcare. A spiral, integrated curriculum is a particularly compelling model, as it revisits core concepts multiple times throughout the curriculum in different contexts. Students who understand the basic science behind a disease do not experience any decline in knowledge retention, even a week after learning about the disease [53].

Cadaveric training sessions

In anatomical and surgical education, cadaveric training remains a staple that has been used as a teaching method throughout theages. Cadaveric dissections are referred to as the dissection of a human cadaver for educational purposes. Training sessions using cadavers involve performing several procedures as suited to the surgical specialty, including surgical skills such as practicing incisions and sutures, surgical maneuvers, and instrument handling [54].

Technology advances and simulated learning

New and emerging technologies are rapidly appearing within surgical residency training, as many workshops and training methods include simulation models through virtual reality (VR) and AR. These simulation models offer a realistic representation of the human body, providing a medium for applying surgical techniques with minimal consequences for any technical errors during training [55]. This allows the residents to practice their surgical skills in a safer, low-cost environment, improving their multisensory techniques through continuous trials [56].

A study conducted by Lohre *et al*. (2020) explored whether VR improves surgical skills and the transferability of those skills in real-world performance [57]. Furthermore, AR provides a mixed reality that utilizes virtual projections of the real world, enabling users to visualize digital objects and display them alongside physical surroundings. Table 4 highlights the advances in surgical anatomy with its impact.

CONCLUSION

The levels of Bloom's Taxonomy, i.e., knowledge, comprehension, application, analysis, synthesis, and evaluation, should be incorporated into teaching and learning. Future directions should aim at innovative learning skills in anatomy. There is a need to shift from traditional learning to a modern, integrated learning method. Traditional learning is more lecture-centered, where the student may be passive. The participation of the students in teaching activities, as well as motivation and stimulation, is important. The student needs to learn anatomy with clinical correlates. We need to train the students to be more skillful rather than theory-oriented. Modern electronic gadgets, virtual methods, and artificial intelligence-laden tools have proved to be beneficial for surgeons who can develop their operative skills. The present review was a humble attempt to highlight the importance of anatomy in the surgical field.

Abbreviations

MRI – Magnetic Resonance Imaging
CT – Computed Tomography
3D – Three-Dimensional
AR – Augmented Reality
2D – Two-Dimensional
PBL – Problem-Based Learning
TBL – Team-Based Learning
DAVR – Dissection Audio-Visual Resources
CAL – Computer-Assisted Learning
CHA – Computer Human Anatomy
USMLE – United States Medical Licensing Examination
RLN – Recurrent Laryngeal Nerve
MRCS – Membership of the Royal College of Surgeons
PGY – Postgraduate Year
VR – Virtual Reality
UK – United Kingdom
USA – United States of America

Author Contributions

Abdullah Al Lawati (AAL); Syeda Heyam (SH); Tahlil Waladwadi (TW); Majid Al Lawati (MAL); Ahmed Kifah Hassan (AKH); Ayman Alhabsi (AA); Hanan Al Lawati (HAL)- Literature search, manuscript preparation, manuscript editing. Srijit Das (SD)- Concept, design, literature search, manuscript preparation, manuscript editing.

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