의학박사 학위논문

A Study on the Development and Educational Effects of Digital-Based Anatomy Curriculum for Medical Students

의대생을 대상으로 한 디지털 기반 해부학 교육과정 개발과 교육효과에 관한 연구

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Abstract

A Study on the Development and Educational Effects of Digital-Based Anatomy Curriculum for Medical Students

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Traditional cadaver dissection has been drastically reduced for various reasons, and technological advances in recent years have produced a variety of digital devices and software in medical education. This thesis was conducted in two studies to develop curriculums applying digital technologies and compare digital-based anatomy education with traditional anatomy education to find out the learning efficacy and satisfaction.

In the first study, the coronavirus disease 2019 (COVID-19) outbreak weakened medical education and healthcare systems. Therefore, the effect of the modified schedule with the introduction of online classes and a three-dimensional anatomy application on students' academic achievement and satisfaction was analyzed. Anatomy education was divided into three regional units (the upper and lower limbs, trunk, and head and neck) due to COVID-19. The schedule was mixed with simultaneous and rotating schedules. Except for online lectures, cadaver dissections, and written and practical examinations were conducted in three classes of approximately 50 students each. Furthermore, students' performance was assessed using three sets of written and practical examinations, and they completed a questionnaire regarding modified anatomy laboratory schedules. Most of the written and practical examination scores significantly decreased in 2020

compared to 2019. However, in the trunk session that used the virtual anatomy application, the score on the practical examination in 2020 was significantly higher than in 2019. Over 70% (upper and lower limbs and trunk sessions) and 53% (head and neck session) students reported no significant difficulty in the face-to-face anatomy laboratory. In addition, over 50% of students received considerable help with the anatomy application in all sessions.

In the second study, the digital revolution has impacted all medical disciplines. Therefore, the need for digital competencies in medical education and how to incorporate them into undergraduate training using a digital-based anatomy curriculum was addressed. This was a crossover randomized controlled trial. In both Human Anatomy and Neuroanatomy laboratories, there were three classes (class A, B, and C) in the first year of the Department of Medicine, and students were randomized into two groups: the virtual group (virtual dissection → cadaver dissection) and the cadaver group (cadaver dissection → virtual dissection). The virtual dissection laboratory was conducted via head-mounted displays, tablets, and a life-sized touchscreen. Quiz 1 (Q1) was tested following the first virtual or cadaver dissections. Quiz 2 (Q2) and a survey were conducted at the end of the final procedure in each training modality. Regarding the Human Anatomy laboratory, there was no significant difference in the Q1 mean total score. However, in class C, virtual education showed significantly higher academic achievement than cadaver education. Most students felt tablet-based learning was an effective study method among the digital lab resources. Regarding the Neuroanatomy laboratory, virtual education showed significantly higher academic achievement in Q1 than cadaver education. Most students reported that digital-based learning enhanced their understanding of cadaveric anatomy. Students were most satisfied with their experiences of virtual anatomy education through digital lab resources.

These studies demonstrate the potential for digital-based anatomy education in medical education. Digital-based anatomy education can provide innovative learning experiences augmenting traditional cadaver education.

Keywords: Anatomy education, Digital-based anatomy curriculum, Head-mounted display, Virtual dissection tables, Tablets, Cadaver dissection

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

2D: two-dimensional

3D: three-dimensional

ADDIE: analysis, design, development, implementation, evaluation

AR: augmented reality

AV: atrioventricular

COVID-19: coronavirus disease 2019

e-learning: electronic learning

ETL: e-Teaching and Learning

HMDs: head-mounted displays

IRB: Institutional Review Board

LMCA: left main coronary arteries

LMS: learning management system

MR: mixed reality

PPE: personal protective equipment

Q1: quiz 1

Q2: quiz 2

RCA: right coronary artery

SA: sinoatrial

SARS-CoV-2: SARS coronavirus 2

SNUCM: Seoul National University College of Medicine

SNUH: Seoul National University Hospital

VR: virtual reality

XR: extended reality

Chapter 1

The Metaverse:

A New Challenge for Anatomy Education

Challenges Facing Anatomy Education

Since human anatomy is the most fundamental discipline in medicine, and its purpose is to study the structural details of the human body (1, 2), the study of human anatomy has always been related to the use of cadavers. Some studies have suggested that anatomy depends on hands-on experience to fully understand the human body's structures (3, 4). Students can become oriented inside the human body through cadaver dissection, understanding where the prominent topographical landmarks are located, and describing three-dimensional (3D) relations (5). However, there is growing debate over whether cadavers are indispensable. Cadaver is not the only solution for anatomy education. There could be superior alternative methods to learn anatomy than traditional cadavers.

Traditional cadaver dissection can be inaccessible or inadequate to students for various reasons, such as lack of cadavers, cost, exposure to formaldehyde, difficulties imposed by the ethical issues for their use, and the era of infectious diseases (6-8). Over the last several years, universities have been reducing the hours allocated to the anatomy laboratory, and some educational institutions have already eliminated the use of cadavers from their curricula (9-11). In addition, I and others reported that situations such as the coronavirus disease 2019 (COVID-19) pandemic had disrupted higher education worldwide, making it difficult for those who teach and study anatomy to continue their education (12-14). Some publications highlight that anatomy educators pursued innovations and creative instruction in response to COVID-19. Therefore, medical students need to supplement or substitute their anatomy education with plenty of digital resources in response to the decrease in time and availability of cadaveric resources (15).

Figure 1 illustrates the challenges facing cadaver dissection, and the introduced of digital resources.

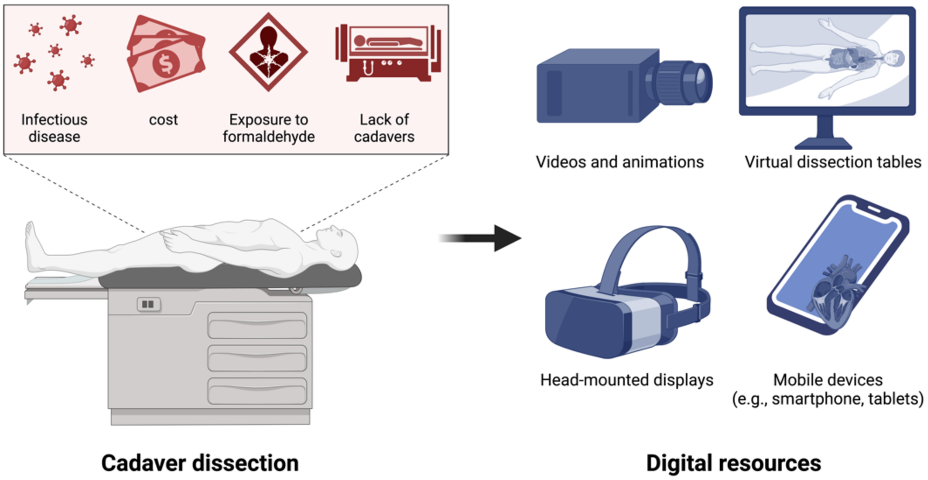

Figure 1. The challenges facing the cadaver dissection and the introduction of digital resources

There are different types of resources via phones, laptops, and tablets. Otherwise, there is a host of different types of resources, including e-Books, Simulators, 3D interactive models, 3D printings, videos and animations, and extended reality (XR) applications across both virtual reality (VR) and augmented reality (AR). Nowadays, medical students use various learning resources; thus, it is crucial to use the most effective teaching resources and approaches to accomplish the necessary learning outcomes (16).

Several studies have been conducted to investigate the students' preference for the various possible approaches to teaching anatomy in different situations (17-21). One study reported that most students thought the classic teaching methods might not be very helpful in learning anatomy and recommended combining multiple techniques, especially cadaver dissection and multimedia sessions (18). According to a study by Jaiswal Rashmi et al., 54.26% of students favored multimedia teaching methods as the best anatomy teaching method (21). The importance of the potential effects of incorporating digital technologies into medical education for the future of learning and assessment has been highlighted in several earlier studies (22-24). Additionally, according to some studies, many technological solutions help reduce the disruption to medical education during the COVID-19 pandemic (25-27). Owolabi and Bekele also reported that blended learning and multiple learning modalities may make COVID-19's adaptation process easier (28). This study offered a variety of resources, including audio and video files, computer-based learning software, simulations, and other media. Another study found that students favor synchronous (45%) and asynchronous (55%) modes of communication; therefore, it is crucial to maintain a balance between the two modes (29). These results demonstrated that virtual technologies are an effective and potent tool for medical education. Accordingly, digital resources can improve students' anatomical learning skills and are suitable alternatives to traditional methods if cadavers and mannequins are unavailable.

Applications of a Metaverse in Medical Education

The Metaverse ("meta" meaning beyond, transcendence, or reality, and "verse" meaning universe or world) concept has been frequently debated since 2021. It is the next-generation mobile computing platform expected to become popular in the near future; it is the internet accessed through VR and mixed reality (MR) glasses (30). The rise of the Metaverse has brought infinite possibilities to the broad scope of applications, including general settings, such as social activities, education, gaming, and payments, and special fields, such as medicine (31). Metaverse applications in medical education and training provide VR and AR to examine the anatomy of a human body in a laboratory setting. This technology holds potential opportunities for creating a new educational environment. As shown in Figure 2, there is a difference between MR, and VR technologies.

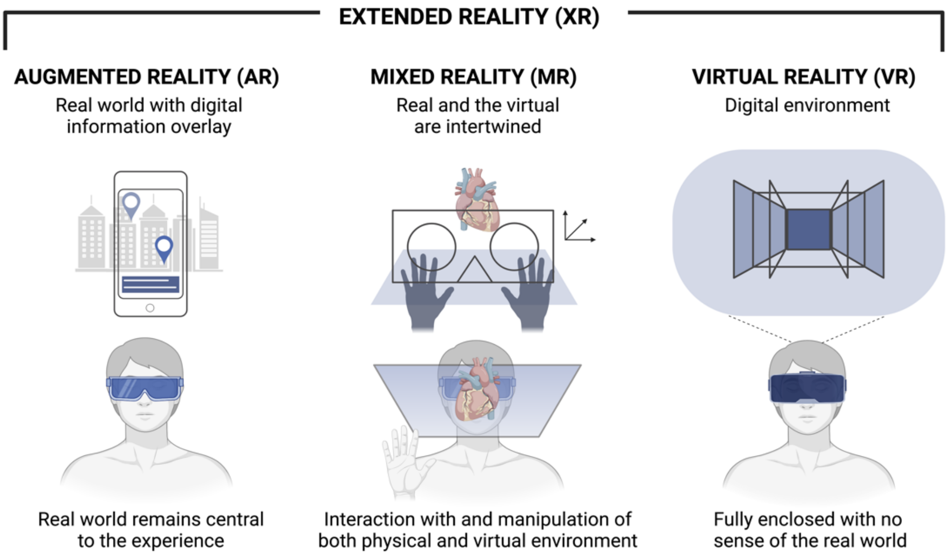

Figure 2. The difference between virtual reality, augmented reality, and mixed reality

AR overlays digital objects or information over real surroundings, creating a hybrid experience that is both real and digital. By integrating physical and virtual information, AR can improve well-established procedural simulation methodologies (32). Using mobile devices or HoloLens, AR has been used in anatomical teaching tools, classroom study aids, image training simulators, and clinical skills interaction simulators at all levels of medical education.

In comparison, VR is a technology that creates a fully immersive digital world. In VR experiences, the physical or actual surroundings are completely blocked out. This technology can be used in two different areas of medical education. The first is using VR to improve technical competencies such as procedural skills or those that need powerful 3D visualization. Examples of its applications have been in areas such as the teaching of anatomy, resident surgical training, and skills such as cardiopulmonary resuscitation (33-35). A second, less well-researched area involves using avatars that respond in a certain way for users to communicate. Considering the vast diversity of skills that can be practiced with VR and the widespread reach and convenience of digital education, this could be a potent educational tool for medical students. It has been shown that immersive VR is associated with learners being more engaged and acquiring better practical skills (36, 37).

MR refers to any combination of VR and AR in which a user is able to interact with a digitally created object in the real world while wearing an MR headset (38) and is utilized in anatomy education. Furthermore, learning skills on a training model or completing a practical activity for the first time in a clinical context, an MR system seems ideal for delivering a direction to students. According to Gnanasegaram et al., they compared the use of MR headsets and traditional lectures to deliver ear anatomy education and demonstrated much-improved engagement and student motivation (39). XR is an umbrella term for any technology that modifies reality by adding digital aspects to the physical or real-world environment, blurring the boundaries between the physical and digital worlds. Therefore, XR includes AR, MR, VR, and any technology at any point in the virtuality continuum. Numerous studies demonstrate the utility of XR technology in medical education (40-42).

The List of Devices for Anatomy Education

Mobile devices

Mobile learning devices, such as smartphones and tablets, allow for wireless communication, constant Internet access, sending and receiving emails and text messages, and holding virtual conferences (43). Due to their versatility and multi-functionality, these devices have become incredibly popular in recent years and are now a natural part of every person's daily life. Some reports reported that almost medical students own tablets or smartphones, and this trend is increasing (44-46). Mobile learning through these devices is a new trend in medical education. Especially, mobile AR is becoming more popular and gives students the chance to learn when and where they want, based on their own learning styles and rates (47). In addition, these devices can be used with AR to create an immersive, highly stimulating learning environment. An AR-based mobile learning including examples of mobile devices, is presented in Figure 3.

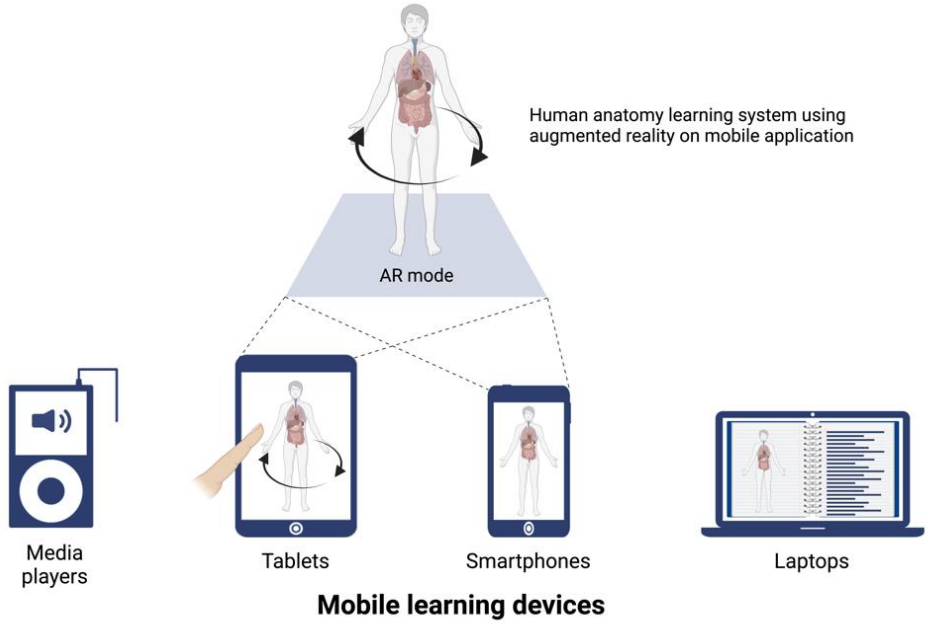

Figure 3. Mobile learning devices and an augmented reality-based mobile learning

Some studies focused on the development process of mobile-based applications for learning bone anatomy and the larynx utilizing AR (48-50). Therefore, the role of mobile learning has been perceived as an appropriate complement to traditional learning.

Virtual dissection tables

Virtual dissection tables, such as Sectra Table™ (Sectra AB, Linkhöping, Sweden), Anatomage Table™ (Anatomage Inc., San Clara, CA), or MDBOX™ (MEDICALIP Co., Ltd., Seoul, Republic of Korea) are large multi-touch screens that enable visualization and improves accessibility in anatomical structures through interactivity (5, 51, 52) and are shown in Figure 4.

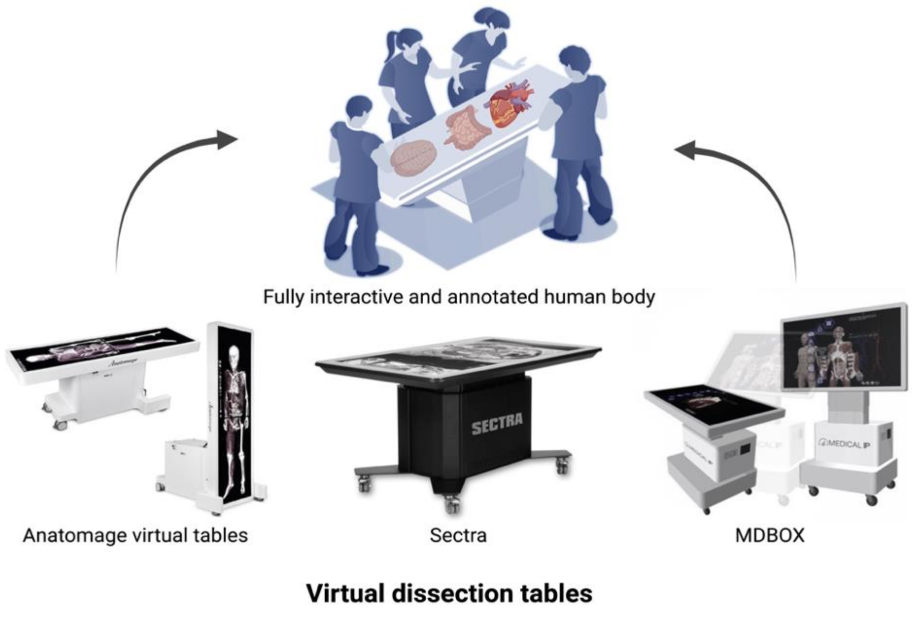

Figure 4. Examples of virtual dissection tables[1) - 3)]

1) https://www.cabrini.edu/about/media-hub/news/2019/anatomage-table
2) http://m.bokuennews.com/m/m_article.html?no=213989
3) https://www.3bscientific.com/kr/index.html

Sectra™ virtual dissection table is based on a design of other virtual anatomical tables, with touchscreen displays allowing interaction with the 3D structures. In addition, Sectra and the Anatomage Tables™ have a built-in DICOM viewer for displaying CT and MRI scans on the system (53). Boscolo-Berto et al. conducted a randomized controlled trial with 23 medical students who were taught anatomy using either the Anatomage Table™ or textbooks (54). Following that, both groups completed cadaver dissection. Seventy percent of all the students in the group who got taught using the Anatomage Table™ said it helped them learn, on average. Although the Anatomage group did not statistically outperform the control group on the exam given following the cadaver dissection, the tendency was clear. MDBOX™ makes team-based multidisciplinary learning and has an interactive smart board that allows images from a computer screen to be displayed on the board. The educator or a student can interact with the images directly on the screen using a tool and take notes while moving and rotating each anatomical structure. A real patient's contents and the form factor, similar to an operating table, perfectly depict the anatomical realism of a living human. The user can dissect and peel off the skin of the digital human body to reveal muscles, the skeleton, internal organs, blood vessels, and nerves (55). These technologies have become more prevalent, and research studies that support the specific use of visualization tables (56, 57) and other 3D visualization technologies (58) have also contributed to this trend. Those virtual dissection tables may also have been affected by several diseases, allowing users to investigate both normal and abnormal anatomy.

Head-mounted displays

Rapid computer technology advancements have also led to many different forms of digital anatomy simulations (59). VR, AR, and MR have grown into a viable option for medical education programs to supplement anatomy learning (60). These technologies provide students with educational near-real-life experience and introduce them to anatomical structures in 3D instead of the two-dimensional (2D) images from textbooks that are difficult to understand the structures.

VR is a broad concept that has many different devices and applications. Some examples of VR technology are Oculus Quest 2™ (Meta Platforms, Inc., Menlo Park, CA), HTC Vive™ (HTC, Taoyuan City, Taiwan), Samsung Gear VR™ (Samsung, Seoul, ROK), and Xiaomi Mi VR™ (Xiaomi, Beijing, China). Any basic commercially available VR simulation system is made up of hardware, which includes a headset and two controllers, one on each hand, as well as simulation software (61). The headset is a head-mounted display that enables the user to view the 3D environment from all angles. The controllers are used to manipulate the virtual objects on display and select different configurations from the menu.

In contrast, MR, a subset of these cutting-edge technologies, combines real and virtual objects via a head-mounted, see-through display. This subsection of type of modality contains the HoloLens 2™ (Microsoft, Redmond, WA), Magic Leap One™ (Magic Leap, Plantation, FL), Google Glass™ (Google, Mountain View, CA), and Vuzix Blade 2™ (Vuzix, Rochester, NY) devices (62). Unlike VR headsets, MR headsets enhance users' existing worlds. Objects can be projected as holograms in 3D space in front of the user's eyes, eliminating the need to hold a screen or camera. Some head-mounted displays (HMDs) have built-in cameras and video recording capabilities, making them a potentially more helpful tool for remote teaching and monitoring, information sharing, real-time consultation, and surgical education (63-65). Objects can be manipulated using hand and finger gesture controls or a more conventional keyboard or handset. It is currently being researched in an educational setting, and its potential to allow multiple students to visualize the same structure if the headsets communicate with one another is extremely promising. Therefore, although both headsets enable users and professionals to explore the virtual world, they belong to distinct categories. Examples of VR and MR headsets are shown in Figure 5.

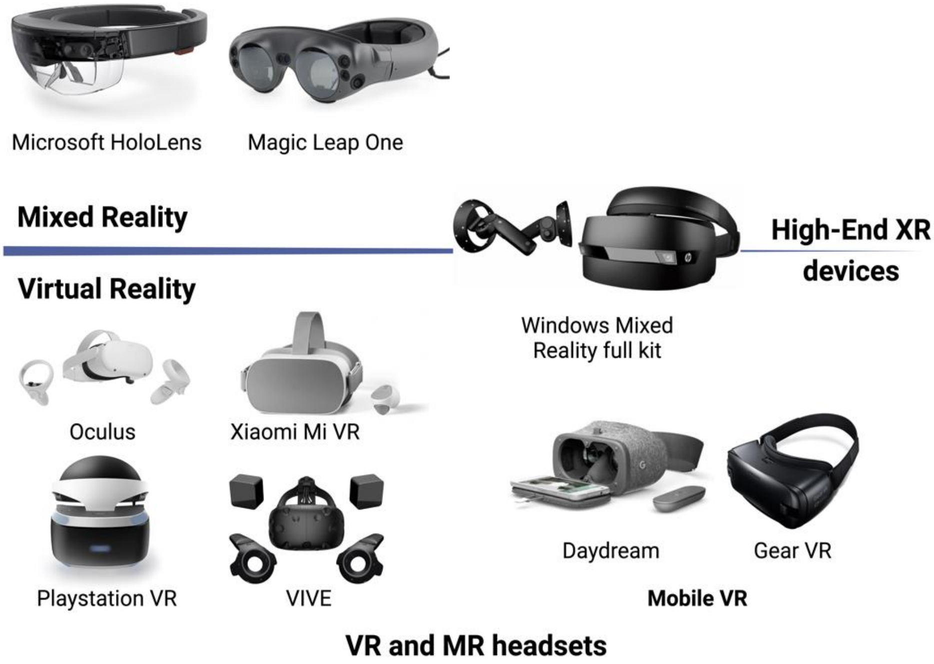

Figure 5. Examples of virtual reality and mixed reality headsets[4) - 12)]

4) https://learn.microsoft.com/ko-kr/hololens/hololens1-hardware
5) https://www.ifixit.com/Device/Magic_Leap_One
6) https://www.legendshop.ng/collections/vr-headsets/products/oculus-quest-2-advanced-all-in-one-virtual-reality-headset-256-gb
7) https://www.11st.co.kr/products/pa/3899803704
8) https://korean.alibaba.com/product-detail/Xiaomi-Mi-VR-Standalone-Virtual-Reality-1600194390310.html
9) http://itempage3.auction.co.kr/DetailView.aspx?ItemNo=C550056880&frm3=V2
10) http://itempage3.auction.co.kr/DetailView.aspx?itemno=B463904101
11) https://www.used.plus/products/hp-windows-mixed-reality-full-kit
12) https://www.bodnara.co.kr/bbs/article.html?num=139452

Digital Anatomy Applications

As applications via smartphones and tablets have become more common, anatomy software that corporate 3D visualization technologies are also being developed in anatomy education (66). The utilization of mobile technology and accompanying 3D anatomy software is one such way that may have great educational potential. Digital anatomy applications in three dimensions can effectively supplement more conventional learning methods. Novel commercial anatomy applications such as Complete Anatomy®, Visible Body®, and Pocket Anatomy® allows students to visualize and manipulate anatomical structures from 3D models (67). Students can view complex anatomical structures at their own pace and rotate structures from various angles (58, 68).

As highlighted in the article by (69), most students believe that 3D anatomy software is more beneficial than a 2D atlas for matching simple anatomical structures. Many students are interested in using 3D anatomy software to learn anatomy (70). One study evaluated students' academic achievement and anxiety levels learning genital system anatomy using traditional methods versus mobile learning applications (71). Regarding anxiety levels, students who conducted cadaver dissection showed a higher level than those using the mobile application. These results indicate that using mobile applications when teaching anatomy may be an effective method to enhance learning and reduce anxiety levels compared to traditional teaching methods.

Previous studies reviewed features of the most used digital anatomy applications to guide selecting an anatomy application and the development and integration of future mobile applications (67, 72, 73). Only one study compared 13 non-commercial and seven commercial anatomy applications on realism, general software details, and program functionality (72). Others reviewed the features and shortcomings of two or three anatomy applications (73). There are more anatomical applications on the market, many of which were made by individuals or small companies and focused on making more realistic 3D models than the ones. Thus, a more thorough review of various 3D goods is required to create even better and more comprehensive guidance for selecting a suitable anatomy application.

Contents’ Scenarios for Digital Anatomy Education

Educators worldwide have searched for engaging and interactive teaching tools and methods, along with the decline in cadaver teaching (58, 74, 75). Current challenges in the field of anatomy education include the lack of information about the long-term effectiveness of various teaching approaches and 3D data (76). Effective digital anatomy education requires content redesign. Digital anatomy education should not be considered a simple technical transition from a cadaveric to a digital approach. When designing a scenario of digital anatomy contents, the scenarios must be under the supervision of an anatomist specialist (77).

Digital learning scenarios take learners on a learning journey in a digital environment. Designing an effective scenario requires careful planning and can be broken into several steps, which include understanding the target learners, goals, objectives, intended outcomes, and context (78). Learning from these educational scenarios offers several advantages to both learners and educators, whether viewed from their respective perspectives. Additionally, these educational scenarios can be tailored to the specific needs of each student, and educators can be included to provide the additional support some students may require to complete a given learning object. Users can easily create and save content preset views to efficiently integrate gross anatomy into lectures or lab practical. Depending on digital resources, many tools can effectively visualize anatomical structures. Users can show, hide, or make entire systems transparent or a different color. For example, users can color code blood vessels or the nervous system and make surrounding organs or structures transparent to make sense of anatomical relationships.

In both academic and clinical contexts, scenario-based simulations are increasingly used as a teaching tool in medical education (79). However, most previous scenario-based learning studies were limited by only focusing on clinical education (80-82). Scenario-based learning provides students with the opportunity to be active and build skills for daily living (83). This instructional strategy bridges the gap between theory and practice (72, 84). Learning through situations not only promotes efficient and realistic learning but also makes the process more enjoyable and the learning activities more successful. This feature also encourages motivation.

Chapter 2

Exploring Medical Students' Performance and Satisfaction of the Modified Anatomy Schedules and a Digital Software During COVID-19 Pandemic

Introduction

COVID-19 first appeared in late December 2019 in Wuhan, Hubei Province, China, and quickly spread worldwide (85). COVID-19 is a new virus that belongs to the same family as SARS coronavirus 2 (SARS-CoV-2) and some types of the common cold (86). The unprecedented outbreak of COVID-19 has caused significant confusion not only in politics, economy, society, and culture but also in education around the world and has become a turning point for introducing a new teaching system (87, 88). Despite the fact that there have been transformational movements in medical education, such as the use of online education and VR technology (89), COVID-19 has accelerated this change by forcing students to exercise social distancing (90). Due to the virus's high transmissibility, it has been difficult to continue with classes as usual (91).

In South Korea, an academic year is divided into two semesters: the spring semester from March to June and the fall semester from September to December. In March 2020, first-year medical students at Seoul National University College of Medicine (SNUCM) began a human anatomy course. In March, it was predicted that the pandemic would be under control in a few weeks and that face-to-face classes would be available by June. The pandemic situation, however, has not improved, and many Korean universities have decided that all lectures should be delivered online throughout the semester. Due to the temporary closure and suspension of medical schools, medical schools began to convert medical education from face-to-face lecture-based teaching and cadaver dissection to digital formats (92, 93). Some of the most proposed methods are online learning platforms, mobile applications, and 3D anatomy models (94). Anatomy education is important for medical students in terms of knowledge and skills for an accurate understanding of human anatomical structures but it also requires much more than dissection and learning (1, 95). Through cadaver dissections, students can learn about the essential characteristics and virtues of physicians. As a result, I intended to continue providing students with adequate exposure to cadaveric dissections.

Several publications have documented the immediate reactions to COVID-19, highlighting the innovations and creative instruction pursued by anatomy educators. There have been several studies on anatomy education, including distance learning but excluding in-person instruction (66, 96, 97). However, previous studies were descriptive and did not include inferential statistics comparing practical examinations and surveys involving the upper and lower limbs, trunk, and head and neck during COVID-19, despite the fact that they shed light on the early adaptations to gross anatomy education at the time. Furthermore, to the best of my knowledge, no publications have been published that provide a detailed example of the modified schedules and methods of teaching anatomy in the early stages of the epidemic, as well as their impact on academic achievement and student satisfaction. The goal of this study was to overcome the limitations of previous studies and determine whether the altered anatomy education schedules caused by the COVID-19 pandemic affect students' outcomes and satisfaction in the gross anatomy course. Figure 6 depicts the graphical summary of the chapter 2 study.

Study Goals and Questions

Graphical summary and specific research questions guided chapter 2 study:

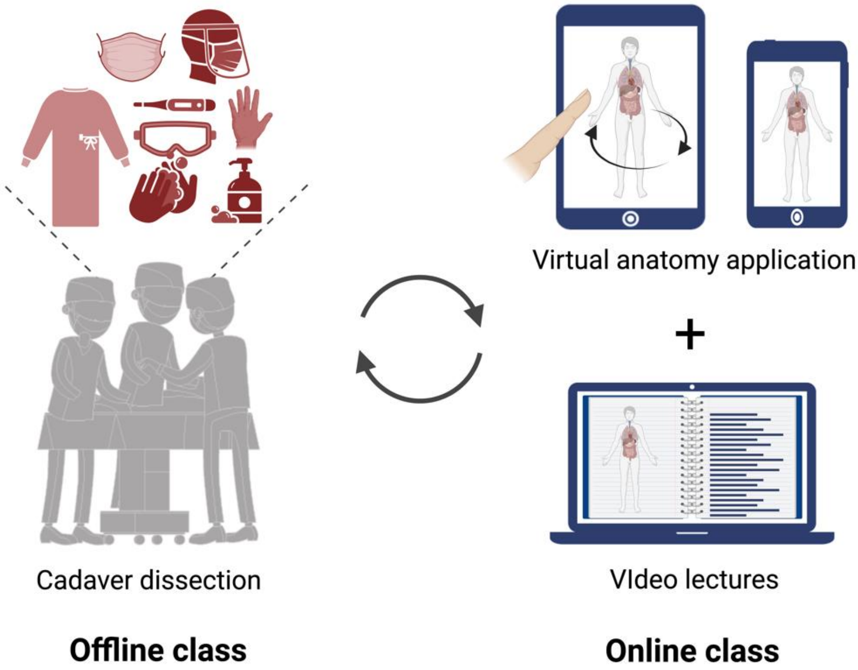

Figure 6. Graphical summary of chapter 2 study

- Are there differences in students' academic achievement between the 2019 and 2020 classes?
- What factors contribute to students' academic achievement?
- What is the level of student satisfaction with the modified schedules of anatomy education?

Materials and Methods

Subjects

All participants were Seoul National University College of Medicine (SNUCM) first-year medical students who took a Human Anatomy course. In 2020, 145 students were enrolled in their first year of medical courses.

Change in the Schedules and Methods of Teaching for "Human Anatomy" Lecture

In 2020, the total number of class hours (48 hours, divided into three regional units: upper and lower limbs, trunk, and head and neck) remained similar to 2019, although all lectures were changed to online lectures. The COVID-19 pandemic influenced the reorganization of schedules and teaching methods in several ways, including using prerecorded video lectures and online platforms. Following a two-week curriculum suspension due to the COVID-19 pandemic, first-year students were provided gross anatomy electronic learning (e-learning) materials from March 20, 2020, to May 1, 2020 (Table 1). Professors provided e-learning materials such as slides, videos, and lecture note at least a week before they were posted online on Seoul National University's e-learning service, e-Teaching and Learning (ETL). The SNUCM e-learning system provides students with access to e-learning materials. Learning through video lectures lasted approximately one hour. According to the cadaver dissection schedule, students were obliged to attend online lectures before conducting a cadaver dissection in person. The table of contents contains all of the Human Anatomy courses available at SNUCM. From March 20, 2020, to March 23, 2020, a general overview of ways to study anatomy, including regional, systemic, and clinical anatomy, was presented (Table 1). Furthermore, the examination was divided into three parts: upper and lower limbs, trunk, and head and neck. Written and practical examinations were given one at a time over two days.

Table 1. Table of contents and schedule for the Human Anatomy course according to the restrictions of the COVID-19 pandemic, SNUCM, 2020.

Contents	**Deadline for e-learning Materials**	**Upload date of e-learning Materials**	**Anatomy Laboratory (face-to-face)**
General overview I	Mar 13	Mar 20	-
General overview II	Mar 13	Mar 20	-
Introduction to anatomy laboratory	-	-	May 04
General overview III	Mar 16	Mar 23	-
Upper and lower limbs			
Superficial structure of lower limb	Mar 16	Mar 23	May 04
Organization of thigh muscles	Mar 17	Mar 24	May 06
Gluteal region	Mar 19	Mar 26	May 07
Knee and poster thigh muscles			
Leg	Mar 19	Mar 26	May 08
Foot	Mar 20	Mar 27	May 11
Joints of lower limb	Mar 20	Mar 27	
Shoulder	Mar 25	Apr 01	May 12
Axilla	Mar 25	Apr 01	May 13
Thorax	Mar 30	Apr 06	
Arm	Mar 31	Apr 07	May 14
Forearm	Mar 31	Apr 07	
Hand	Apr 01	Apr 08	
Joints of upper limb	Apr 01	Apr 08	
1st written and practical examinations			
Trunk			
Thoracic wall and mediastinum	Apr 02	Apr 09	May 18
Pleurae and lung			
Heart	Apr 03	Apr 10	
Fascia, muscles, vessels, and nerves of back	Apr 06	Apr 13	May 19

Anterolateral abdominal wall	Apr 06	Apr 13	May 19
Pelvic cavity, pelvis, and perineum	Apr 07	Apr 14	
Peritoneum and abdominal viscera	Apr 09	Apr 16	May 20
Esophagus, stomach, small intestine, and large intestine	Apr 09	Apr 16	
Liver, pancreas, and spleen	Apr 10	Apr 17	
Posterior abdominal wall	Apr 10	Apr 17	May 20
Pelvic cavity, and perineum	Apr 14	Apr 21	May 21
Vessels, nerves, and lymph of pelvic cavity	Apr 14	Apr 21	
Rectum and anal canal	Apr 15	Apr 22	May 21
Male internal genital organs	Apr 16	Apr 23	May 22
Female internal genital organs	Apr 16	Apr 23	
Medical imaging of abdomen	Apr 15	Apr 22	
2nd written and practical examinations			
Head and neck			
Cranium	Apr 17	Apr 24	May 25
Scalp, and cranial meninges	Apr 17	Apr 24	May 26
Face	Apr 17	Apr 24	May 25
Vasculature of brain	Apr 20	Apr 27	May 26
Brain and cranial nerves	Apr 20	Apr 27	
Orbit, and orbital contents	Apr 21	Apr 28	May 27
Eyelids and lacrimal apparatus	Apr 21	Apr 28	
Superficial structures of neck	Apr 22	Apr 29	May 28
Triangles of neck	Apr 22	Apr 29	
Arteries, veins, and nerves in root neck	Apr 22	Apr 29	
Salivary glands, and temporomandibular joint	Apr 22	Apr 29	May 29
Nose, and larynx	Apr 24	May 01	Jun 01
Ear	Apr 24	May 01	
Oral region	Apr 24	May 01	
Medical imaging of head and neck	Apr 24	May 01	
3rd written and practical examinations			

‡Modified from article 'The impact of the modified schedules of anatomy education on student's performance and satisfaction: Responding to COVID-19 pandemic in South Korea' of Young Hyun Yun; Abbreviation: COVID-19 = coronavirus disease 2019, SNUCM = Seoul National University College of Medicine, e-learning = electronic learning

Change in the Schedules and Methods of Teaching for "Human Anatomy" Laboratory Sessions

SNUCM planned face-to-face laboratory sessions for medical students when the government reduced the degree of social distancing in early May 2020. When the number of new COVID-19 cases in Seoul reached zero on May 4 (Figure 7), the face-to-face anatomy laboratory implemented simultaneous and rotating schedules (98) through June 1, 2020. Twenty-four rotating dissections (3 h each, three classes) and 21 rotating reviews were conducted (3 h, three classes). The schedule was modified to accommodate an average of fifty students per laboratory session to increase social distance. The 154 students who participated in the anatomy laboratory were divided into three classes, and each class dissected a cadaver for three hours. Only one-third of the students participated in a hands-on dissection at any given time. Approximately 50 students were divided into 10 groups of five per cadaver for a three-hour laboratory dissection session. Each group was separated by 3 m from the others. Human Anatomy, 7th Edition, guidelines (Korea Medical Book Publishing Company, Seoul, Korea) was used as the main textbook for cadaver dissection. SNUCM also offers educational 3D anatomy platforms e-Anatomy® (Panmun Education, Seoul, Korea) and Complete Anatomy® (Elsevier, Amsterdam, Netherlands).

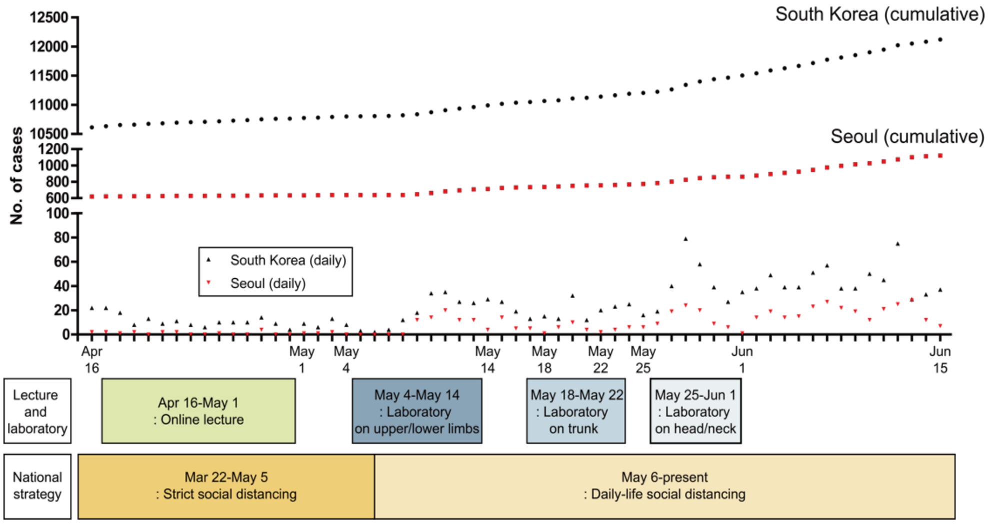

Figure 7. Timeline of cases with COVID-19 (South Korea and Seoul) and schedules of anatomical education in SNUCM. ‡Modified from article 'The impact of the modified schedules of anatomy education on student's performance and satisfaction: Responding to COVID-19 pandemic in South Korea' of Young Hyun Yun; Abbreviation: COVID-19 = coronavirus disease 2019, SNUCM = Seoul National University College of Medicine

Written and Practical Examinations

The performance of the students was evaluated through three sets of written and practical examinations on three regional units: the upper and lower limbs, the trunk, and the head and neck. The assessment consisted primarily of a written examination in the morning and a practical examination in the afternoon. The written examination was designed to be administered simultaneously in three separate classrooms, with approximately 50 students separated by at least 2 meters to prevent contagion. After the written examination, all students had lunch. After lunch, the students returned to their written examination sites before moving to the practical examination waiting room. It was supervised by teaching assistants so that students who had already taken the practical examination would not encounter those who had yet to take the examination. The entrance and exit to the practical examination were separated in order to prevent students from overlapping with other students. When students exited the laboratory, they discarded the masks they wore during the exam and received new masks and hand sanitizer.

Instruments

A survey was conducted online at the end of the spring 2020 semester. Regarding the modified anatomy laboratory schedules, students were required to respond using 3- and 5-point Likert scale scores. The following items were included in the questionnaire: (1) overall satisfaction with face-to-face anatomy laboratory sessions; (2) preference for modified anatomy schedules; (3) utilization of allotted time for cadaver dissection; (4) preference for 3D digital anatomy educational software; (5) difficulty learning the human anatomy course; and (6) difficulty taking practical examinations.

Actions for COVID-19 Prevention and Control in SNUCM

At the entrance of the education building, all the students were checked for symptoms (cough and sputum) using a questionnaire and body temperature using non-contact infrared thermometers. If students reported symptoms or the body temperature was above 37.5°C, they were referred for testing for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) by reverse transcriptase-polymerase chain reaction at a COVID-19 screening center in Seoul National University Hospital (SNUH). Personal protective equipment (PPE) provided by the university included hand sanitizers, disposable isolation gowns, surgical gowns, KF94 masks (which filter out 94% of 0.4 μm microparticles), nitrile gloves, goggles, and face shields. From the first day of the face-to-face anatomy laboratory, students wore PPEs and attended the introduction to the anatomy laboratory. Not all students wore the same size of PPE. All Gowns were sized to each student to ensure there were no gaps. Additionally, face shields and goggles were reused in good condition by handling and cleaning adequately. Except for goggles and face shields, most PPEs were discarded after use in each anatomy laboratory and practical examination.

Statistical Analysis

All statistical analyses were conducted using SPSS software, version 26 (IBM Crop). I analyzed the differences in examination scores between 2019 and 2020 using the Student's t-test and considered a 2-tailed $P < 0.05$ to be statistically significant.

Ethical Approval

The Institutional Review Board (IRB) of SNUH approved the present study (IRB number: E-2202-034-1298). It was completely retrospective (using existing student surveys and grades), and the IRB allowed a consent waiver.

Results

Three students reported symptoms (cough, fever/myalgia, and fever) during anatomy dissection sessions and were referred for SARS-CoV-2 testing. They were denied access to the laboratory until negative results were obtained. Despite the ongoing pandemic events in Seoul and South Korea during the laboratory sessions (see Figure 24), no confirmed cases were identified among the students, faculty, or staff.

Academic Achievement

The written and practical examination results for the 2019 and 2020 classes' anatomy assessments were compared (Figure 8 and 9). In 2020, the total mean scores, including both written and practical examinations, were significantly lower than in 2019 ($p < 0.05$). The upper and lower limb sessions on the written examination in 2020 had significantly lower mean scores ($p < 0.0001$), whereas there was no difference between the trunk and head and neck sessions (Figure 8). The scores for the upper and lower limbs ($p < 0.0001$) and head and neck ($p < 0.001$) sessions of the 2020 practical examination were significantly lower than those of 2019 (Figure 9). In contrast, the 2020 class scored significantly higher on the trunk session than the 2019 class ($p < 0.01$).

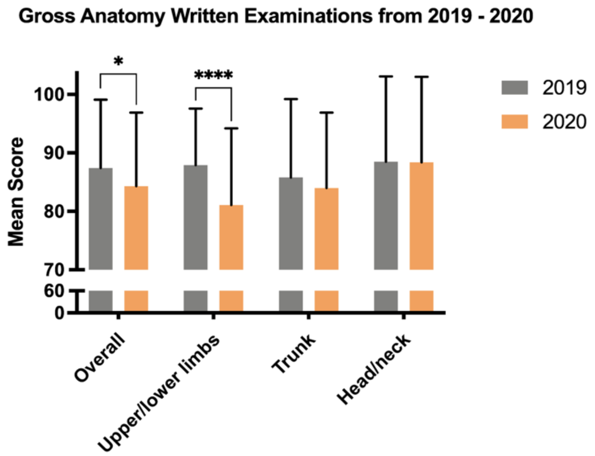

Figure 8. Comparison of written examination scores between 2019 and 2020 at SNUCM. The performance of students was evaluated using three written examinations on three regional units: the upper and lower limbs, trunk, and head and neck. Students' academic performance on written examinations was assessed using t-test. The statistical significance is indicated by the following symbols: * p < 0.05, ** p < 0.01, ***p < 0.001, ****p < 0.0001 to indicate statistical differences. ‡Modified from article 'The impact of the modified schedules of anatomy education on student's performance and satisfaction: Responding to COVID-19 pandemic in South Korea' of Young Hyun Yun; Abbreviation: COVID-19 = coronavirus disease 2019, SNUCM = Seoul National University College of Medicine.

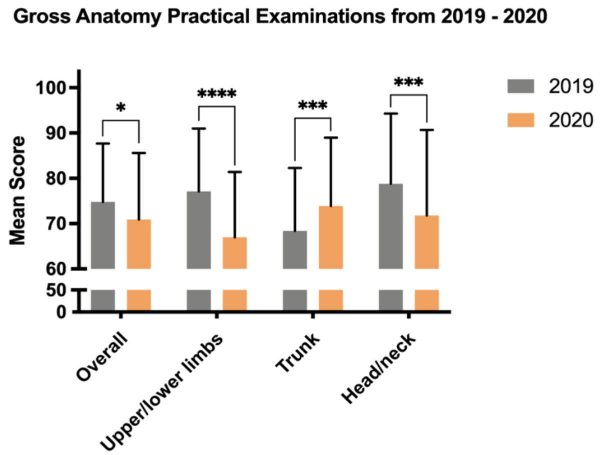

Figure 9. Comparison of practical examination scores between 2019 and 2020 at SNUCM. The performance of the students was evaluated using three sets of practical examinations on three regional units: the upper and lower limbs, the trunk, and the head and neck. Students' academic performance on written examinations was assessed using t-test. The statistical significance is indicated by the following symbols: * p < 0.05, ** p < 0.01, ***p < 0.001, ****p < 0.0001 to indicate statistical differences. ‡Modified from article 'The impact of the modified schedules of anatomy education on student's performance and satisfaction: Responding to COVID-19 pandemic in South Korea' of Young Hyun Yun; Abbreviation: COVID-19 = coronavirus disease 2019, SNUCM = Seoul National University College of Medicine.

Survey Results

The survey's students (n = 105) were asked how satisfied they were with the face-to-face anatomy laboratory sessions (Figure 10). Over fifty percent of students were satisfied with the upper and lower limbs (75.3%), trunk (77%), and head and neck (53.3%). In addition, the students assessed the outcomes of the modified laboratory schedules and instructional strategies. The modified schedule had many advantages. Students preferred three classes with approximately 50 students per session for upper and lower limbs (extremely likely: 28.6%, very likely: n = 46.7%), trunk (extremely likely: 21.9%, very likely: 51.4%), and head and neck (extremely likely: 18.1%, very likely: 35.2%). In addition, more than half of the students utilized the allocated time for self-directed learning in each session (upper and lower limbs: 69.5%, trunk: 65.7%, and head and neck: 63.5%). The majority of students utilized the 3D atlas Complete Anatomy® and received significant help with upper and lower limbs (n = 67), trunk (n = 64), and head and neck (n = 56). In contrast, the session on the head and neck was the most difficult for students to learn about anatomical structures (42.9%) and perform well on practical examinations (32.4%).

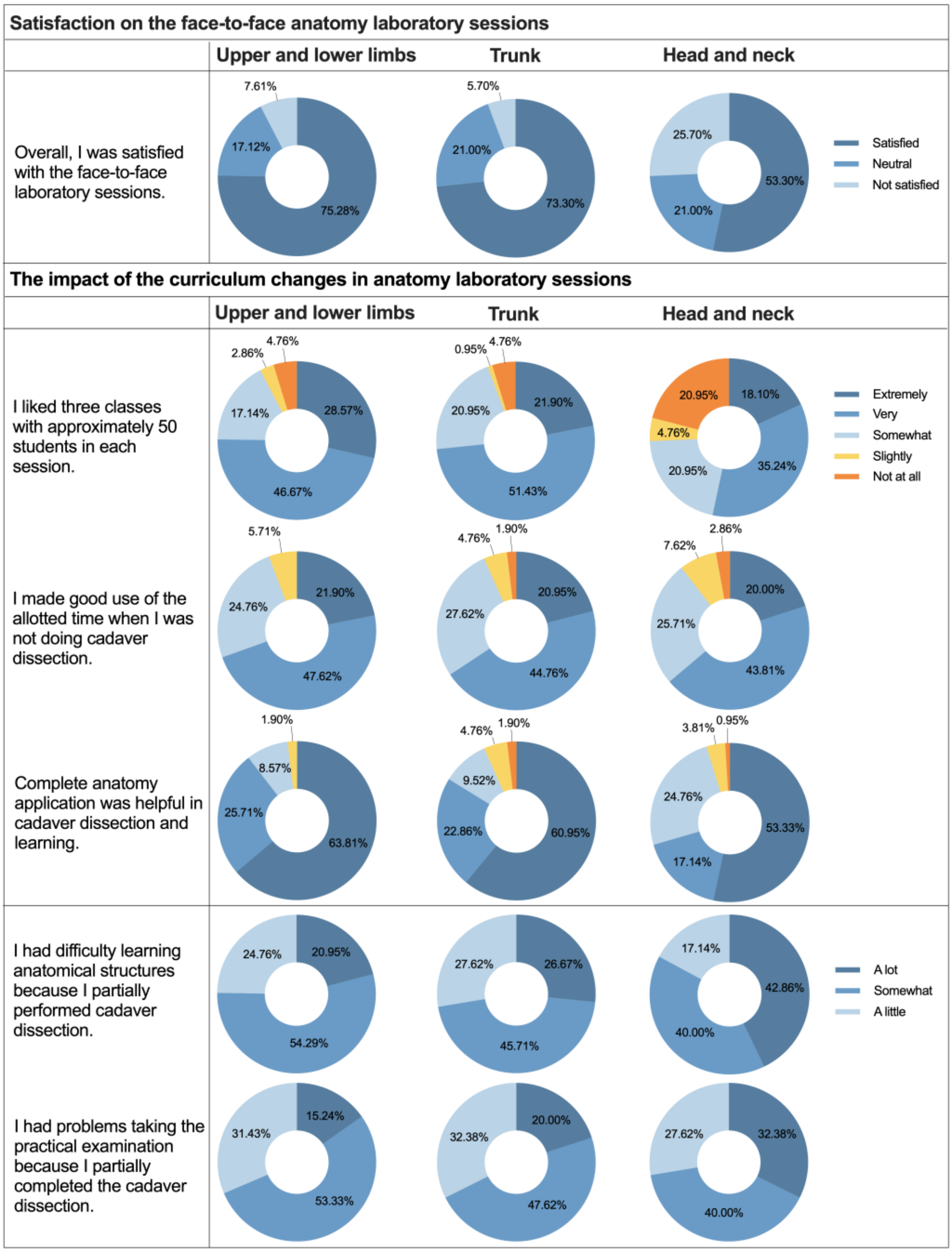

Figure 10. Students' satisfaction on face-to-face anatomy laboratory sessions. Students' (n = 105) satisfaction on face-to-face anatomy laboratory sessions was ranked on a 3-point Likert-type scale (1 = satisfied and 3 = not satisfied). Students were asked about the impact of the modified schedules and methods of teaching in anatomy laboratory sessions they experienced after the COVID-19 pandemic, as represented by pie graphs. The 3- and 5-point Likert scale scores are shown in percentage. ‡Modified from article 'The impact of the modified schedules of anatomy education on student's performance and satisfaction: Responding to COVID-19 pandemic in South Korea' of Young Hyun Yun; Abbreviation: COVID-19 = coronavirus disease 2019.

Discussion

This study aimed to provide educational schedules and methods for teaching anatomy education in the COVID-19 era and to investigate the research outcomes related to students' academic performance, satisfaction, and factors affecting them. I successfully offered a detailed example of a modified educational schedule and teaching method for responding to infectious diseases or similar calamities that may occur in the future and preparing for the future of anatomy education.

Educational Schedule and Methods of Teaching Anatomy

In terms of anatomy education in the COVID era, this study provided a detailed education schedule and methods of teaching anatomy that can be utilized globally in the future. Although several studies have reported online anatomy teaching throughout the pandemic era (22-27, 92-94), none have offered a thorough schedule and content allocation. Furthermore, during the pandemic, an alternate dissection strategy (three teams rotating) could be another option for face-to-face anatomy laboratories (98). In fact, the strategy alleviated the crowding problem in the dissection laboratory while having an impact on student learning outcomes. As a result, the face-to-face dissection strategy and detailed educational schedule information of this study can play a complementary role in the COVID-19 era.

Academic Achievement

This study's results revealed that students' achievement scores on written and practical examinations in 2020 were significantly lower than those in 2019 (see Figure 25 and 26). To the best of my knowledge, these results are the first to provide quantitative evidence of the risk of decreased academic performance in anatomical education due to the COVID-19 pandemic, even with efforts such as continuing face-to-face anatomy laboratories. The analysis of this survey revealed that students had difficulty learning anatomical structures and taking practical examinations due to the time limitation of the anatomy laboratory that each student could experience. However, most previous studies on anatomy education have reported that academic achievement was higher or similar to that before the COVID-19 pandemic (99-101). These studies suggested positive factors that influence students' academic achievement but did not provide evidence of the pandemic's negative impact on academic achievement.

3D Digital Anatomy Educational Software

This study provides novel evidence that adequate supplementation has the potential to enhance academic performance in anatomy education. Although overall performance in 2020 was lower than in 2019, an interesting finding was that there was no statistically significant difference in scores between 2020 and 2019 on the written examination for the trunk and head and neck sessions (see Figure 25). In addition, the practical examination score in the trunk session was significantly higher in 2020 than in 2019 (see Figure 26). All medical students were given access to 3D digital anatomy educational software, but only professors in charge of the trunk session utilized it to make lecture materials. In addition, according to the survey, cadaver dissection and anatomy learning were aided by the software, even though participation in laboratory sessions was reduced to one-half (see Figure 27). This study focuses on the advantages of integrating digital anatomy educational software with traditional anatomy laboratories in medical education. This result is consistent with previous studies indicating that digital anatomy educational software provides a positive experience (102) and improved exam performance (103). Therefore, I propose that digital anatomy software aids students in rapidly comprehending anatomical structures and their adjacent relationships. The advantages of integrating 3D atlas applications and face-to-face anatomy laboratories in medical education have been demonstrated in this study. Although cadaveric dissection is a useful tool for anatomy education in many medical schools (104), the inevitable change in medical education brought on by COVID-19 is still in the process of occurring (89). Traditional cadaveric dissection cannot be replaced, but it can be supplemented with advanced high-tech innovations, particularly in the pandemic era.

Survey on Students' Satisfaction and Preference by Each Session

This is the first study to survey students' satisfaction and preferences in anatomy education during the COVID-19 pandemic with respect to each session covering the upper and lower limbs, trunk, and head and neck (see Figure 26). Previous studies have investigated students' satisfaction with and preference for learning anatomy in a more comprehensive manner but have not analyzed the causes of satisfaction (66, 96, 97, 99). One study revealed students' perceptions of the difficulty of dissecting anatomical regions (105). However, this study lacked situational elements such as class hours, teaching methods, and schedules, indicating that students' perceptions of anatomical regions were limited. In this study, different results were obtained for each situational element survey. The satisfaction levels of the three anatomical regions varied. Therefore, it is necessary to conduct separate surveys for each anatomical region. Student satisfaction is influenced by multiple factors. I believe the continuation of cadaver dissection laboratory sessions, even after the COVID-19 pandemic, has contributed to high overall student satisfaction. In addition, the provision of PPE and adherence to social distancing guidelines may have contributed to high levels of employee satisfaction. In addition, the duration of the laboratory dissection experience may have contributed to satisfaction. High satisfaction was reported for upper and lower limbs, as well as trunk sessions, which lasted the same amount of time as in 2019. However, low satisfaction was observed for head and neck sessions, which were shorter than those in 2019. Due to a lack of time, there was no opportunity for a preview or review, and it would have been challenging to adapt to the schedule changes.

Limitations

While the results of this study are extremely encouraging, there are some limitations that must be considered. This study was conducted at a single institution and a single center. The modified schedules of anatomy education and outcomes may not be applicable to other schools because the circumstances of each medical school are unique. Due to time constraints following the COVID-19 outbreak, it was impossible to validate the instruments utilized in this study. I measured the level of student satisfaction with the human anatomy course through a limited number of questionnaire items. In this regard, additional research is required.

Chapter 3

Virtual Anatomy Laboratory Education: A Crossover Randomized Controlled Trial Compared to Cadaver Dissection

Introduction

The goal of medical school is to take intelligent medical students and develop them into physicians who are ready to begin residency training. Thus, first-year medical students must have anatomical knowledge. Understanding the structures and functions of normal human anatomy is vital for medical students' future careers, facilitating the integration of upcoming information and building a critical awareness of anomalous structures and functions in relation to illness management (106). Students are required to absorb a lot of knowledge and concepts quickly and to employ cadaver dissection skills, which many are unfamiliar with.

Furthermore, the human anatomy has evolved in recent years to keep up with changing teaching and learning techniques (107). Modern technology and learner-centered pedagogy are used to teach anatomical knowledge. Digitization expands prospects in medicine and has an impact on every aspect of medicine, from research to patient care (108). Medical students and physicians require a complete store of knowledge and competencies about digital systems and technologies in order to actively engage in the continuing process of digital transformation and avoid taking a passive position. However, the vast majority of them today lack enough digital competency training. Medical mistakes can occur due to a lack of digital competence, and the adoption of new digital tools can suffer as a result (109). In addition, this may obstruct the development of the medical field.

The heart and brain areas are one of the most complex areas featured in the medical gross anatomy curriculum. When first-year medical students are confronted with cadaver dissection, they have difficulty understanding the heart's anatomical structure and positional relationships. Such heart dissection, first due to the complex 3D interrelations of its parts, is known to be challenging (110). The heart should be described as normally positioned within the thorax (111). However, it is difficult in the dissecting laboratory to study the interrelationships of the cardiac components while the organ itself remains embedded within the mediastinum and encased by the thorax to identify its individual components. For reasons that are not clear, cardiac structures are described as though the heart has been taken out of the thorax. In addition, neuroanatomy is one of the most challenging subjects in anatomy for many novice students (112, 113). It requires students to thoroughly understand numerous neuroanatomical structures, vessels, and nerves, as well as complex spatial relationships between them (114). A previous study also confirmed neuroanatomy as one of the most difficult subjects (115).

As a result, fundamental frameworks of digital competencies and frequent training are needed to equip doctors for a digitalized health system. Virtual reality technologies, for example, can enhance educational environments by visualizing intricate structures and providing assessment and timely feedback. Therefore, I focused on the application of HMDs for VR, life-sized touchscreen, tablets, and related software for heart and brain dissection, focusing on what is possible based on current technology and what barriers still exist to widespread adoption in medical education. This study aimed to investigate the effectiveness and satisfaction of the virtual dissection compared to the cadaver dissection. The chapter 3 graphical summary is described in Figure 11.

Study Goals and Questions

Graphical summary and specific research questions guided chapter 3 study:

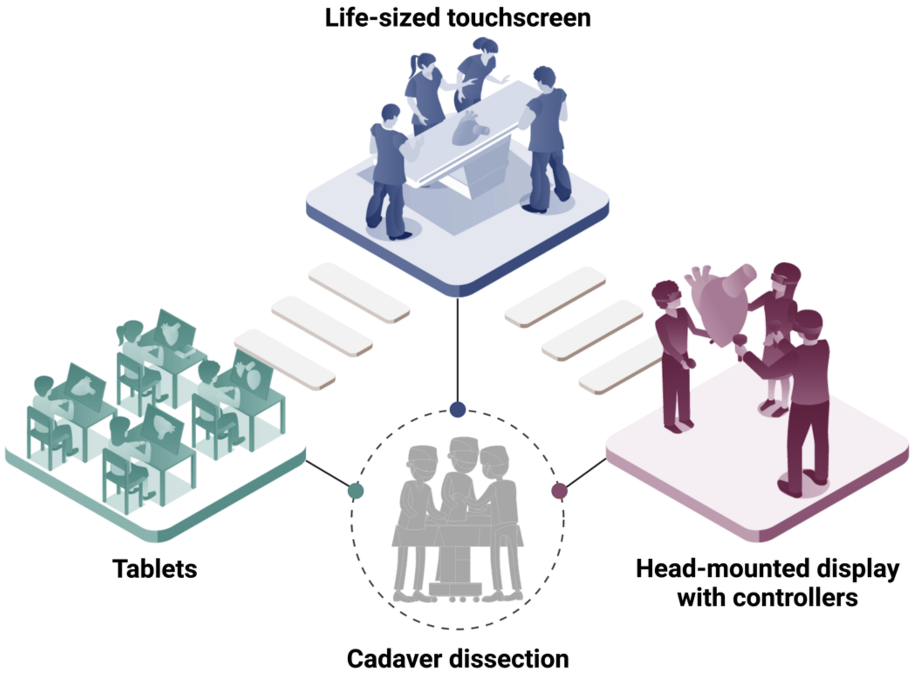

Figure 11. Graphical summary of chapter 3 study

- Are there differences in students' academic achievement between virtual dissection and traditional cadaver dissection?
- Are there differences in satisfaction between virtual dissection and traditional cadaver dissection?
- Which 3D simulations are helpful in studying anatomy while using tablets, HMDs for virtual reality, and a life-sized touchscreen?
- Can virtual dissection improve or replace traditional cadaver dissection?

Materials and Methods

ADDIE model

This study uses a development model, namely the ADDIE model (116). Based on the ADDIE model, this study developed and applied an anatomy education curriculum using digital technologies in five main stages: analysis, design, development, implementation, and evaluation, and evaluated its effectiveness. This educational curriculum development process is as follows (Figure 12):

ADDIE model	Development process of curriculum
1) Analysis	
Identify all course design variables, such as learner characteristics, learner's prior knowledge, and resources available.	Investigation of competencies for medical students and anatomical structures difficult for medical students to understand
↓	
2) Design	
Focuses on figuring out the course's learning goals and how materials will be made and designed.	Selecting and implementing digital-based technologies on anatomy teaching.
↓	
3) Development	
Content creation, including loading of content into a web site or LMS.	Making contents' scenarios, learning objectives and anatomical 3D images with labeling, and hide and fade functions.
↓	
4) Implementation	
Installing and using of instructional instruments and management of instructional materials	Curriculum application
↓	
5) Evaluation	
Summative evaluation	Analysis of curriculum results (students' academic performance and satisfaction to the curriculum)

Figure 12. The basic phase of the AADIE model for the design and development of virtual anatomy education at the SNUCM. Abbreviation: SNUCM = Seoul National University College of Medicine. LMS = learning management system

1) Analysis

In the analysis phase, previous studies were analyzed to select anatomical structures difficult for first-year medical students to understand in traditional cadaver dissection laboratories. Analysis of student characteristics was carried out to determine for sure the condition of students who experience digital technologies.

2) Design

In the design phase, curriculum topics, educational goals, and educational media were selected based on previous studies conducted in the analysis stage. In addition, equipment and software necessary for the selected educational medium were investigated.

3) Development

It is a phase in developing an educational curriculum based on digital technologies as an educational topic selected through the analysis and design stage. After the program was developed, a pilot test was conducted to correct program errors and improve and compensate for operational problems.

4) Implementation

The implementation phase is the stage of operating the developed digital-based anatomy curriculum. A crossover randomized controlled trial was applied to all first-year medical students at SNUCM.

5) Evaluation

The evaluation phase is to evaluate the developed educational curriculum. In this study, academic achievement was investigated between the cadaver and virtual groups, and satisfaction of the cadaver-based, HMD-based, life-sized touchscreen-based, and tablet-based education.

Participants

The subjects of this study were all first-year medical students who took Human Anatomy and Neuroanatomy courses at the SNUCM, Seoul, Republic of Korea. In the year 2021, there were 154 students in both courses.

Study Design

To ensure that all students had the same overall learning experience, I undertook a crossover randomized control trial with two intervention arms, cadaver and virtual dissection laboratories, and quizzes to examine students' learning performance. Students either had cadaver dissection followed by virtual dissection or virtual dissection followed by cadaver dissection. The Human Anatomy and Neuroanatomy laboratories were conducted for 2 hours. The cadaver and virtual dissection laboratories equally lasted for 50-54 minutes, and afterward, the students took quiz 1 (Q1). Students also took 3-6-minute quiz 2 (Q2) at the end of the cadaver and virtual laboratories and a 6-8-minute survey at the end of the laboratory.

The Study Design of "Human Anatomy" Laboratory

A flow chart of the study design of the Human Anatomy laboratory is displayed in Figure 13. One hundred fifty-four students were randomly divided into three classes: class A (n = 49), class B (n = 52), and class C (n = 53). In each class, the students were randomly assigned to two groups: the cadaver group (cadaver dissection → virtual dissection, n = 82) and the virtual group (virtual dissection → cadaver dissection, n = 72). In the cadaver dissection laboratory, three types of laboratory situations were presented that led to different natures of student experience: heart extraction (class A), dissection (class B), and observation (class C). Three devices were used in the virtual dissection laboratory for 54 minutes (Figure 14a). For every 18 minutes, nine students became a team and experienced HMDs, a life-sized touchscreen, and tablets. Since there were three HMDs, three students became a group again, experiencing an HMD for 6 minutes per student and observing it for 12 minutes (Figure 14b). In addition, three tutors taught three students each. In the life-sized touchscreen-based practice, nine students surrounded the screen, and a tutor taught the students (Figure 14c). Each student was given a tablet to engage in the tablet-based learning activity (Figure 14d). Three tutors helped the approximately nine students use the tablets.

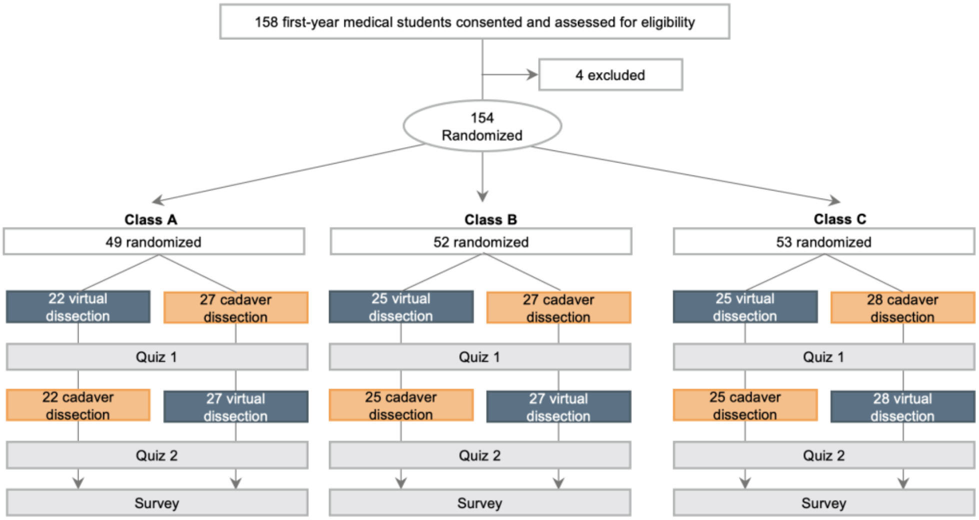

Figure 13. Study flow diagram of the Human Anatomy laboratory. Virtual dissection laboratory includes HMDs, a life-sized touchscreen, and tablets. Abbreviation: HMD = head-mounted display

A

Student No.	54 minutes								
	18 minutes			18 minutes			18 minutes		
	6 minute	6 minute	6 minute	6 minute	6 minute	6 minute	6 minute	6 minute	6 minute
3	HMD			Life-sized touchscreen			Tablet		
3									
3									
3	Tablet			HMD			Life-sized touchscreen		
3									
3									
3	Life-sized touchscreen			Tablet			HMD		
3									
3									

B

Student No.	Device No.	18 minutes		
		6 minute	6 minute	6 minute
3	1	HMD	1st Observation	2nd Observation
		1st Observation	HMD	2nd Observation
		1st Observation	2nd Observation	HMD
3	1	HMD	Observation	2nd Observation
		1st Observation	HMD	2nd Observation
		1st Observation	2nd Observation	HMD
3	1	HMD	1st Observation	2nd Observation
		1st Observation	HMD	2nd Observation
		1st Observation	2nd Observation	HMD

C

Student No.	Device No.	18 minutes
9	1	Life-sized touch screen

D

Student No.	Device No.	18 minutes
3	3	Tablet
3	3	
3	1	

Figure 14. The time schedule of virtual dissection in Human Anatomy laboratory using HMDs, a life-sized touchscreen, and tablets. Abbreviation: HMD = head-mounted display

The Study Design of "Neuroanatomy" Laboratory

Figure 15 shows the research design of the Neuroanatomy laboratory. One-hundred fifty-four students were randomly allocated to three classes: class A (n = 52), class B (n = 49), and class C (n = 53). Students in each class were randomly divided into two groups, as was the Human Anatomy laboratory: the cadaver group (cadaver dissection → virtual dissection, n = 71) and the virtual group (virtual dissection → cadaver dissection, n = 73). All classes conducted cadaver dissection under the same condition. In the virtual dissection laboratory, students were required to study neuroanatomical structures using a tablet.

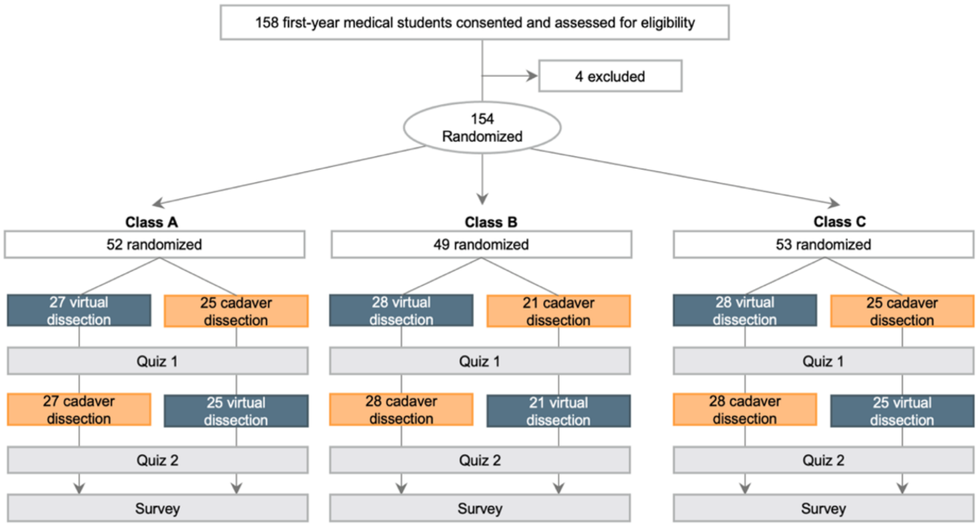

Figure 15. Study flow diagram of the Neuroanatomy laboratory. Virtual dissection laboratory includes HMDs, a life-sized touchscreen, and tablets. Abbreviation: HMD = head-mounted display

Instruments

Devices and Software

Four types of devices (i.e., Anatomage Table™, iPads®, MDBOX™, Oculus Quest 2™ HMDs and two touches), and three anatomy software (i.e., Anatomage™, Complete Anatomy®, and MDBOX™ software (version 1)), were used in this study. Anatomage Table™ combines specialized hardware and software. It is a life-sized touchscreen anatomy visualization table and includes a segmented real human 3D anatomy platform. The table comes pre-installed with 3D gross body male and female contents, 3D high resolution regional anatomy, and a digital anatomy library with over 120 pathological examples. The form factor resembles an operating table or hospital bed. iPad® is a touchscreen tablet that users can interact with directly through finger strokes. The most notable features of the iPad® are its vibrant display, long battery life, and massive number of applications for education. iPad® applications can be downloaded from the Apple App store. Complete Anatomy® is an educational 3D anatomy platform, and its content is available on iPad®, Mac, and Windows versions. Thousands of individually selectable structures, organized in layers across 12 body systems, make it easy to pinpoint the area of concern and highlight it in relatable 3D. MDBOX™ is a combination of unique hardware and software. It is a digital anatomy table with an all-in-one touch-interactive display compatible with HMDs, hand-tracking Microsoft HoloLens™, Oculus Quest 2™ controllers, and Leap motion™. Oculus Quest 2™ is an advanced all-in-one VR headset with advanced touch controllers and the highest resolution display ever. It delivers freedom in VR with a wireless headset, intuitive controls, a built-in battery, and an easy setup.

Quiz and Survey

Data was collected from the students' Q1 and Q2 results to determine which type of laboratory (i.e., cadaver dissection laboratory or virtual dissection laboratory) brings higher academic performance. In addition, the online Google Forms was a questionnaire that asked students for demographics (gender, age), and satisfaction with the cadaver and virtual dissection laboratories. In particular, the satisfaction survey used in this study was conducted after revising and supplementing according to the purpose of this study by referring to the questions used by Bae and Kwon (117). Students were asked to evaluate satisfaction with cadavers, HMDs, a life-sized touchscreen, and tablets on aesthetics, conceptual understanding, realism, spatial ability, immersion experience, and continuous use intention using 5-point Likert-type scale score (1 = very unsatisfied and 5 = very satisfied).

Statistical Analysis

All statistical analyses were performed in SPSS software, version 26 (IBM Crop, Armonk, NY). I used Student's t-test to assess the differences in quiz scores between virtual and cadaver groups and considered a 2-tailed $p < 0.05$ statistically significant. In addition, I used one-way ANOVA and Scheffe's *post hoc* tests to identify differences in satisfaction on cadavers, HMDs, a life-sized touchscreen, and tablets.

Ethical Approval

This study was approved by the Institutional Review of SNUH (IRB number: C-2103-066-1203). Only students who agreed to participate and submitted informed consent were surveyed. Students who did not participate in this study also provided equal opportunities for virtual and cadaver dissection laboratories.

Results

Subject Characteristics of "Human Anatomy" Laboratory

All 154 first-year medical students at SNUCM completed the Human Anatomy laboratory and responded to the survey. As shown in Table 2, the students' mean (SD) age was 20.8 (1.2) years. Of these students, most were male (69.5%), and 30.5% were female. Students reported that they have a personal tablet (54.5%) or a shared family tablet (6.5%), whereas 39.0% of students reported that they do not have a tablet. Of the 92 students with a tablet, the majority (76.1%) of students used a tablet for educational purposes, 4.3% for playing games, and 19.6% for watching videos or movies. More than half (59.7%) of students reported that they never used VR technology, and only 0.6% used VR technology 2-3 times a week, once a week, and once a day, respectively. Among the 62 students who have used VR technology, 87.1% experienced playing games, 1.6% experienced education, 9.7% experienced watching videos or movies, and only 1.6% experienced a research participant. Most students (65.6%) did not play VR games which are based on a first-person perspective, 40 (26.0%) once a year, 7 (4.5%) once a month, 1 (0.6%) 2-3 times a week, 4 (1.9%) once a week, and 1 (0.6%) once a day. A total of 97 (63%) students reported seeing the advantages of the virtual dissection laboratory compared with the cadaver dissection laboratory, whereas 37.0% of students preferred the virtual dissection laboratory to the cadaver dissection laboratory. 56.7% of students felt that he or she learns best on a tablet.

Table 2. Demographic characteristics of Human Anatomy survey respondents.

Characteristic	Student, No. (%) First year medical students (n = 154)[a]
Age, mean (SD), y	20.8 (1.2)
Gender	
Male	107 (69.5)
Female	47 (30.5)
Do you have a tablet?	
Personal tablet	84 (54.5)
Shared family tablet	10 (6.5)
Purpose of tablet usage (n=92)*	
Education	70 (76.1)
Game	4 (4.3)
Video or movie	18 (19.6)
No	60 (39.0)
Frequency of VR usage	
Once a day	1 (0.6)
Once a week	1 (0.6)
2-3 times a week	1 (0.6)
Once a month	4 (2.6)
Once a year	55 (35.7)
What was your experience with VR? (n=62)*	
Game	54 (87.1)
Education	1 (1.6)
Video or movie	6 (9.7)
Other[b]	1 (1.6)
Never	92 (59.7)
Frequency of VR games which are based on a first-person perspective	
Once a day	1 (0.6)
Once a week	4 (1.9)
2-3 times a week	1 (0.6)
Once a month	7 (4.5)
Once a year	40 (26.0)
Never	101 (65.6)
Frequency of graphic design software usage	
Once a day	3 (1.9)
Once a week	3 (1.9)
2-3 times a week	3 (1.9)
Once a month	18 (11.7)
Once a year	23 (14.9)

Never	104 (67.5)
Please select a laboratory that helped you better understand the heart's anatomical structure and positional relationship	
Cadaver dissection laboratory	57 (37.0)
Please select from the below why you prefer the cadaver dissection laboratory (n=57)*	
Sense of realism	9 (15.8)
Tangibleness	48 (84.2)
Virtual dissection laboratory	97 (63.0)
Which type of virtual laboratory was good for learning?	
Tablet-based learning	55 (56.7)
Head mounted display-based learning	29 (29.9)
Life-size touchscreen-based learning	13 (13.4)

Abbreviation: VR, virtual reality.

[a]Data are presented as the number (percentage) of survey respondents unless otherwise indicated. [b] Other included only a research participant. *Only the subgroup of the students

Academic Achievements of "Human Anatomy" Laboratory

In order to assess whether there was a statistically significant difference in academic performance between cadaver and virtual groups, Q1 and Q2 scores obtained by each group were compared. In the Human Anatomy laboratory, the laboratory situation of the virtual group was the same for all classes, but the cadaver group for each class was different; extraction (class A), dissection (class B), and observation (class C). As shown in Figure 16a, comparing the means of the Q1 scores between cadaver and virtual groups revealed no significant differences in classes A and B. However, the difference between the means of Q1 scores in class C was significantly ($p < 0.05$) higher in the virtual group than in the cadaver group. Overall, the mean score of Q1 in the virtual group was slightly higher than that in the cadaver group, but it was not statistically significant (Figure 16b). In Q2, our results revealed no significant difference between groups in all classes (Figure 16c). In addition, insignificant differences were observed in Q2 among the groups (Figure 16d).

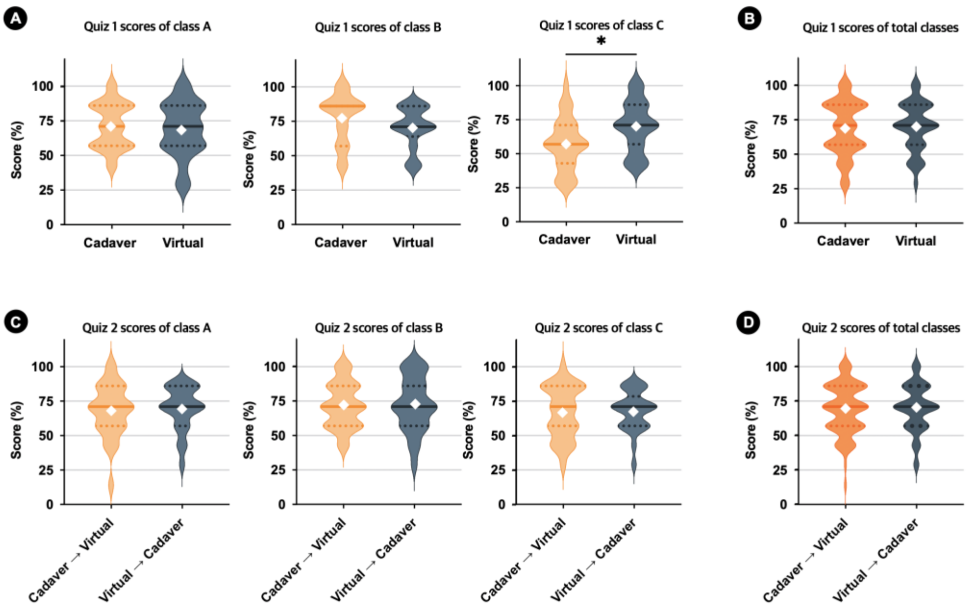

Figure 16. Violin plots showing the distribution of quiz 1 and 2 scores of class A, B, C, and all: in the Human Anatomy laboratory. Students' academic performance on quiz 1 and 2 was assessed using t-test. Violin plots showing the distribution of quiz 1 score of classes A, B, and C **(A)**. Violin plots of quiz 1 score of total classes **(B)**. Violin plots showing the distribution of quiz 2 scores of class A, B, and C **(C)**. Violin plots of Quiz 2 score of total classes **(D)**. The dotted line ranges from the lower to the upper quartile. The solid line represents the median value. The white diamond represents the mean. $*p < 0.05$

Survey Results of "Human Anatomy" Laboratory

The first-year medical students' satisfaction in responding to the cadavers for dissection and devices for virtual dissection were investigated on a 5-point Likert scale and are shown in Figure 17-22. In terms of user-friendliness, the impact of esthetics, concept understanding, reality, spatial ability, immersion, and continuous use intention on the cadavers, HMDs, a life-sized touchscreen, and tablets were investigated. The red pairwise comparison on the bar indicates a significant difference between cadaver and virtual dissection laboratories. On the other hand, the blue pairwise comparison on the bar indicates a significant difference between virtual dissection laboratories (e.g., head-mounted display-based, life-sized touchscreen-based, and tablet-based laboratories).

Esthetics

In terms of easy-to-see anatomical structures, the satisfaction level of the tablet-based laboratory was significantly higher than the cadaver dissection laboratory and other virtual dissection laboratories (Figure 17). Overall, the well-designed laboratory was tablet-based, and the satisfaction level was significantly higher than the cadaver dissection laboratory and other virtual dissection laboratories. The liveliest laboratory was the cadaver dissection laboratory, and the satisfaction level was significantly higher than the three types of virtual dissection practice. In the virtual dissection laboratory, the satisfaction level of the tablet-based laboratory was higher than the life-sized touchscreen-based laboratory.

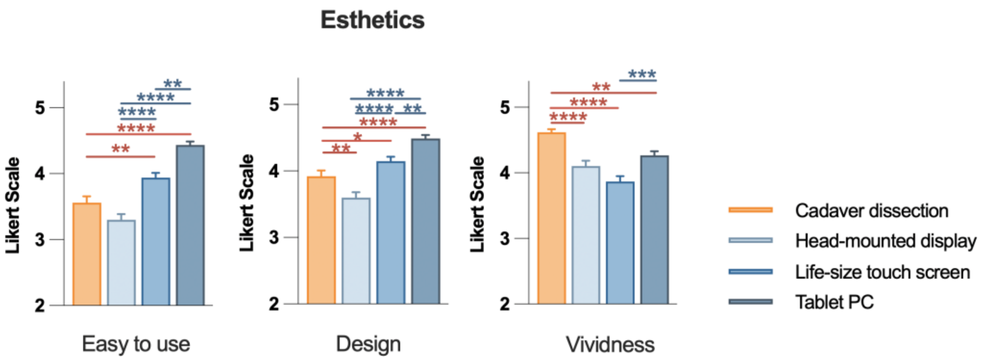

Figure 17. Comparison of the impact of esthetics on cadaver dissection, head-mounted displays, a life-sized touchscreen, and tablets. Students' satisfaction on cadaver and virtual dissection laboratories was ranked on 5-point Likert-type scale (1 = very unsatisfied and 5 = very satisfied). The red pairwise comparison on the bar indicates a significant difference between cadaver and virtual dissection laboratories. The blue pairwise comparison on the bar represents a statistically significant difference between virtual dissection laboratories. $*p < 0.05$; $**p < 0.01$; $***p < 0.001$; $****p < 0.0001$

Understanding of Concept

The cadaver dissection laboratory had the lowest satisfaction because the structure could not be labeled (Figure 18). In contrast, the satisfaction level of the tablet-based laboratory was much higher than those of the head-mounted display-based and the cadaver dissection laboratories, except for the life-size touchscreen-based laboratory. The satisfaction of the cadaver dissection and head-mounted display-based laboratories was the lowest in viewing the anatomical structures from the desired angle, and there was no significant difference between the two laboratories. On the other hand, the tablet-based laboratory had significantly higher satisfaction than all types of laboratories. To understand the anatomical structures easily, the cadaver dissection laboratory was more satisfactory than the head-mounted display-based laboratory. Among virtual dissection laboratories, the tablet-based laboratory was significantly higher than the other two (e.g., life-sized touchscreen-based and head-mounted display-based laboratories). As a result, the tablet-based laboratory had the highest satisfaction in understanding the concept.

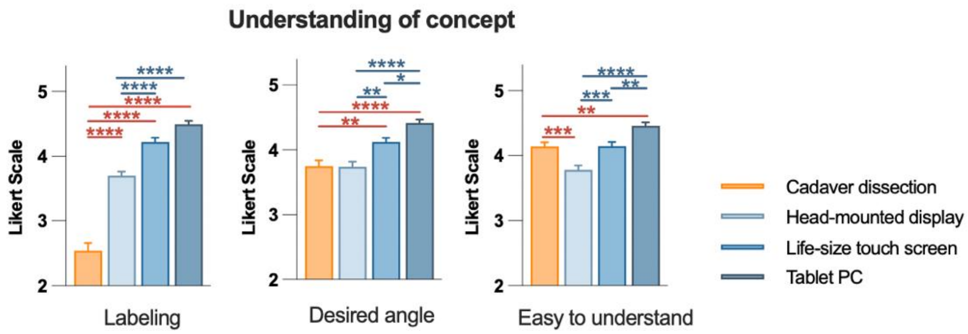

Figure 18. Comparison of the impact of understanding of the concept on cadaver dissection, head-mounted displays, a life-sized touchscreen, and tablets. Students' satisfaction on cadaver and virtual dissection laboratories was ranked on 5-point Likert-type scale (1 = very unsatisfied and 5 = very satisfied). The red pairwise comparison on the bar indicates a significant difference between cadaver and virtual dissection laboratories. The blue pairwise comparison on the bar represents a statistically significant difference between virtual dissection laboratories. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.0001$

Reality

Satisfaction with realistic anatomical structures was significantly higher in the cadaver dissection laboratory than in all virtual anatomy laboratories, and there was no significant difference in the three types of digital anatomy practice (Figure 19). The satisfaction with the laboratory that made it feel like entering the anatomy was the highest in the head-mounted display-based laboratory and significantly higher than the other two types of virtual dissection laboratories. However, there was no significant difference from the cadaver dissection laboratory. The laboratory that felt real was the cadaver dissection laboratory, and it was significantly higher than the other three forms of digital education. Among the virtual dissection laboratories, students reported that the head-mounted display-based laboratory was the most similar to the real world.

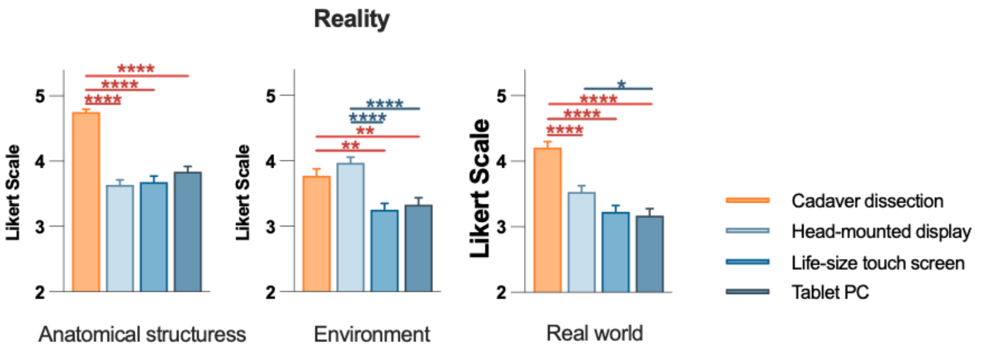

Figure 19. Comparison of the impact of reality on cadaver dissection, head-mounted displays, a life-sized touchscreen, and tablets. Students' satisfaction on cadaver and virtual dissection laboratories was ranked on 5-point Likert-type scale (1 = very unsatisfied and 5 = very satisfied). The red pairwise comparison on the bar indicates a significant difference between cadaver and virtual dissection laboratories. The blue pairwise comparison on the bar represents a statistically significant difference between virtual dissection laboratories. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.0001$

Spatial Ability

The laboratory that facilitated the observation of deeper layers of anatomical structures was the tablet-based laboratory (Figure 20). It was followed by the life-sized touchscreen-based laboratory, head-mounted-display-based laboratory, and cadaver dissection laboratory. However, it was not statistically significant with the life-sized touchscreen-based laboratory. The tablet-based laboratory was the one that made anatomical structures and locations clear and intuitive. Furthermore, satisfaction was higher in the order of life-sized touchscreen-based and head-mounted-display-based laboratories. However, the cadaver dissection laboratory was higher than the head-mounted-display-based laboratory. The laboratory that developed spatial perception was the tablet-based laboratory, and there was a significant difference between the life-sized touchscreen-based and the head-mounted display-based laboratories. However, there was no significant difference from the cadaver practice.

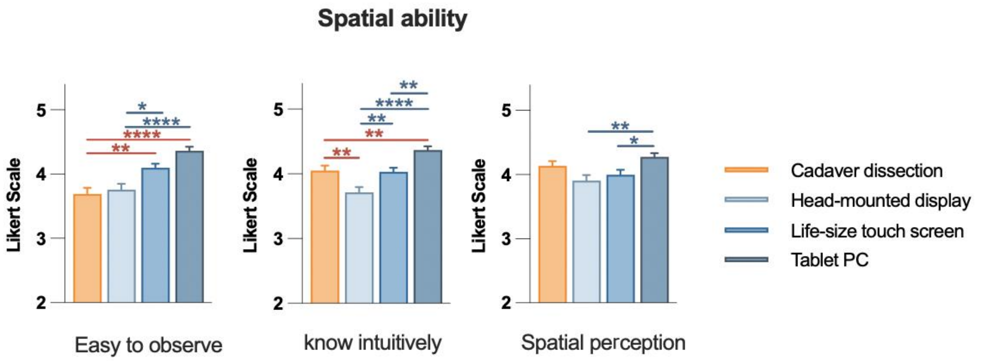

Figure 20. Comparison of the impact of spatial ability on cadaver dissection, head-mounted displays, a life-sized touchscreen, and tablets. Students' satisfaction on cadaver and virtual dissection laboratories was ranked on 5-point Likert-type scale (1 = very unsatisfied and 5 = very satisfied). The red pairwise comparison on the bar indicates a significant difference between cadaver and virtual dissection laboratories. The blue pairwise comparison on the bar represents a statistically significant difference between virtual dissection laboratories. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; $^{****}p < 0.0001$

Immersion

The laboratory that students did not want to go back to their daily life the most was the cadaver dissection laboratory (Figure 21). Among the virtual dissection laboratories, it was higher in the order of tablet-based laboratory, life-sized touchscreen-based laboratory, and head-mounted display-based display laboratory. When students conducted the head-mounted display-based laboratory, they thought it was most out of reality and in a different space. It was significantly higher than the cadaver dissection and other virtual dissection laboratories. The cadaver dissection laboratory was the easiest laboratory to forget daily life for a while, and it was significantly higher than the life-sized touchscreen-based laboratory.

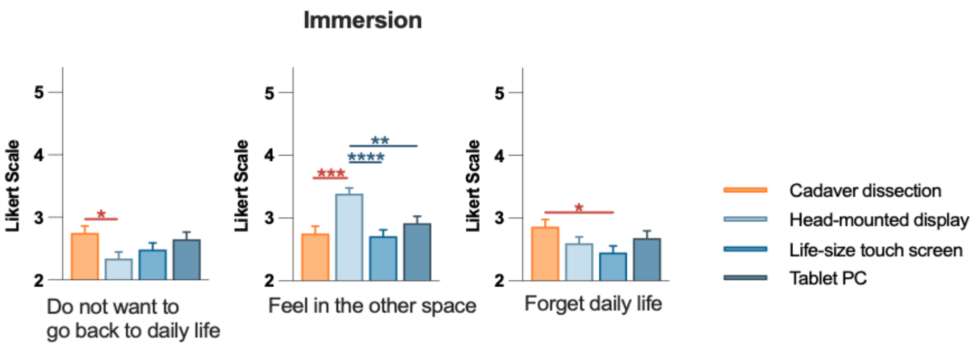

Figure 21. Comparison of the impact of immersion on cadaver dissection, head-mounted displays, a life-sized touchscreen, and tablets. Students' satisfaction on cadaver and virtual dissection laboratories was ranked on 5-point Likert-type scale (1 = very unsatisfied and 5 = very satisfied). The red pairwise comparison on the bar indicates a significant difference between cadaver and virtual dissection laboratories. The blue pairwise comparison on the bar represents a statistically significant difference between virtual dissection laboratories. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.0001$

Continuous Use Intention

Students wanted to experience the tablet-based laboratory the most in the future, followed by the life-sized touchscreen-based laboratory and a head-mounted display-based laboratory (Figure 22). The satisfaction level of the cadaver dissection laboratory was significantly higher than the head-mounted display-based laboratory. The laboratory students would like to repeat in the future was the tablet-based laboratory, and the satisfaction level was higher than the other two types of virtual dissection and cadaver dissection laboratories. On the other hand, compared to the cadaver dissection laboratory and other types of virtual dissection laboratories, the satisfaction level of the cadaver dissection laboratory was significantly higher than the head-mounted display-based laboratory. In the future, the tablet-based laboratory was the laboratory that students most wanted to conduct other anatomical structures. However, there was no significant difference from the cadaver dissection laboratory. On the other hand, the cadaver dissection laboratory was significantly higher than the head-mounted display-based practice.

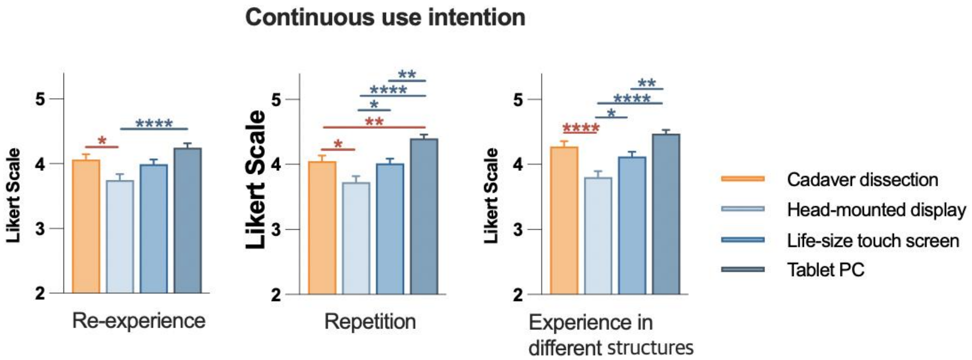

Figure 22. Comparison of the impact of continuous use intention on cadaver dissection, head-mounted displays, a life-sized touchscreen, and tablets. Students' satisfaction on cadaver and virtual dissection laboratories was ranked on 5-point Likert-type scale (1 = very unsatisfied and 5 = very satisfied). The red pairwise comparison on the bar indicates a significant difference between cadaver and virtual dissection laboratories. The blue pairwise comparison on the bar represents a statistically significant difference between virtual dissection laboratories. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.0001$

Contents' Scenario of "Human Anatomy" Laboratory

The contents were composed in the order of the coronary artery, chamber, valve, and conducting system. Tutors produced contents' scenarios in advance using a head-mounted display, life-sized touchscreen, and tablets and organized the contents to be explained to students. All heart content was stored in the library and preset tabs during tablet-based and life-sized touchscreen-based laboratories (Figure S1 and S2). Similarly, when students looked at the heart with a head-mounted display, there was a contents tab in the upper right corner (Figure S3). The contents to be explained by the tutor in each content are as follows in S1 Appendix.

Subject Characteristics of "Neuroanatomy" Laboratory

All 154 first-year medical students at SNUCM completed the Neuroanatomy laboratory and participated in the survey. According to Table 3, the mean (SD) age of students was 21.9 (9.4%) years. The majority of these students were male (70.8%), while only 29.2% were female. Students indicated they own a personal tablet (93.5%) or a family tablet (1.3%), whereas 8% reported not owning a tablet. Of the 146 students who have a tablet, more than half (59%) of students use a tablet once a month. In addition, students (70.1%) bought virtual anatomy applications, mainly using Complete Anatomy® (56.5%), followed by Atlas (9.1%), Anatomy Learning (3.9%), and 3D Anatomy (0.6%). Among the 108 students who bought virtual anatomy applications, 11.7% use them once a day, 12.3% use them once a week, 32.5% use them 2-6 times a week, 9.7% use them 2-3 times a month, and only 3.9% use them once a month. A total of 105 (68.2%) students reported that the tablet-based laboratory helped them understand the diencephalon's anatomical structures and positional relationships compared to the cadaver dissection laboratory. The remaining 31.8% preferred the cadaver dissection laboratory to the tablet-based laboratory.

Table 3. Demographic characteristics of Neuroanatomy survey respondents.

Characteristic	Student, No. (%) First year medical students (n = 154)[a]
Age, mean (SD), y	21.9 (9.4)
Gender	
Male	109 (70.8)
Female	45 (29.2)
Do you have a tablet?	
Personal tablet	144 (93.5)
Shared family tablet	2 (1.3)
Frequency of tablet usage (n=146)*	

Once a day	17 (11%)
Once a week	5 (3.2%)
2-6 times a week	35 (22.7%)
2-3 times a month	6 (3.9%)
Once a month	91(59%)
No	8 (5.2)
Did you buy virtual anatomy applications?	
Yes	108 (70.1%)
What is the name of virtual anatomy application? (n=108)*	
Complete Anatomy	87 (56.5%)
Atlas	14 (9.1%)
Anatomy Learning	6 (3.9%)
3D Anatomy	1 (0.6%)
Frequency of virtual anatomy applications usage (n=108)*	
Once a day	18 (11.7%)
Once a week	19 (12.3%)
2-6 times a week	50 (32.5%)
2-3 times a month	15 (9.7%)
Once a month	6 (3.9%)
No	46 (29.9%)
Please select a laboratory that helped you better understand the diencephalon's anatomical structure and positional relationship	
Cadaver dissection laboratory	49 (31.8%)
Please select from the below why you prefer the cadaver dissection laboratory (n=49)	
Sense of realism	8
Tangibleness	37
Tablet-based laboratory	105 (68.2%)

[a] Data are presented as the number (percentage) of survey respondents unless otherwise indicated. [b] Other included only a research participant. * Only the subgroup of the students

Academic Achievements of "Neuroanatomy" Laboratory

The virtual and cadaver groups in the Neuroanatomy laboratory had identical laboratory conditions for all classes. To determine whether there was a statistically significant difference in academic performance between the cadaver and virtual groups, the scores from the first and second quizzes were compared. The Q1 mean score was statistically significant (*p*

< 0.01) in class A, indicating that the virtual group performed at a significantly higher level than the cadaver group (Figure 23a). However, although the virtual groups in classes B and C had higher mean scores than the cadaver group, there was no significant difference between the two groups. As shown in Figure 23b, the Q1 mean score of all classes was significantly higher in the virtual group than in the cadaver group ($p < 0.05$). In Q2, I found no statistically significant difference between groups in all classes (Figure 23c). Moreover, there was no significant difference between the groups on Q2 (Figure 23d).

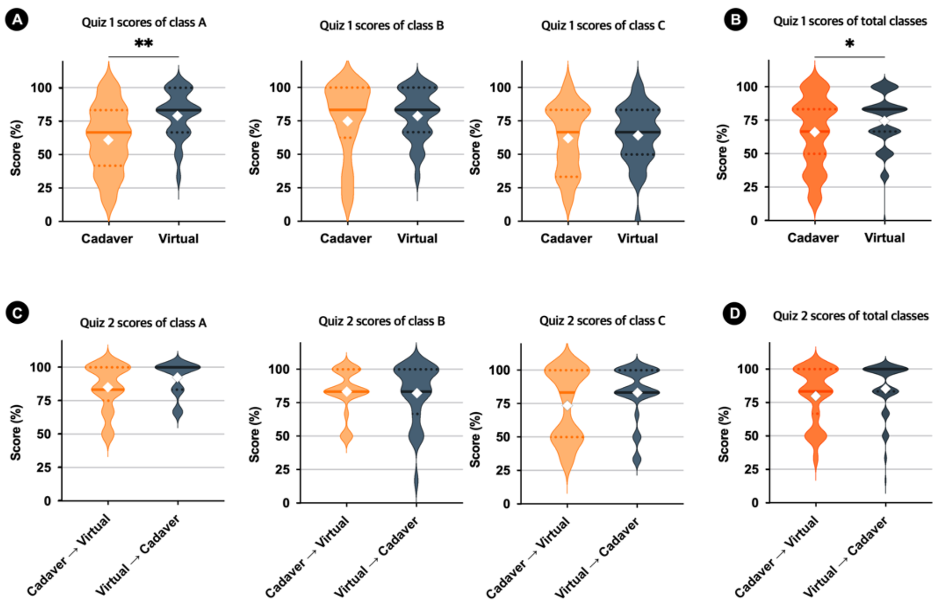

Figure 23. Violin plots showing the distribution of quiz 1 and 2 scores of class A, B, C, and all: in the Neuroanatomy laboratory. Students' academic performance on quiz 1 and 2 was assessed using t-test. Violin plots showing the distribution of quiz 1 score of class A, B, and C (A). Violin plots of Quiz 1 score of total classes (B). Violin plots showing the distribution of quiz 2 scores of classes A, B, and C (C). Violin plots of quiz 2 scores of total classes (D). The dotted line ranges from the lower to the upper quartile. The solid line represents the median value. The white diamond represents the mean. *$p < 0.05$; **$p < 0.01$

3.2.3 Survey Results of "Neuroanatomy" Laboratory

It has been confirmed that students prefer a tablet-based laboratory in the Human Anatomy laboratory. Therefore, a study was conducted in the Neuroanatomy laboratory to compare tablet-based and cadaver dissection laboratories. On a 5-point Likert scale, first-year medical students' satisfaction with the cadaver dissection and tablet-based laboratories was assessed, as depicted in Figure 27. The impact of esthetics, concept understanding, reality, spatial ability, immersion, and continuous use intention on cadaver dissection and tablets-based laboratories was studied.

Esthetics

The satisfaction of the tablet-based laboratory, designed for easier use and well-designed in harmony overall, was significantly higher than the cadaver dissection laboratory (Figure 24a). On the other hand, there was no significant difference between the cadaver and virtual anatomy laboratories.

Understanding of Concept

Since the cadaver dissection laboratory was not labeled on the anatomical structures, the satisfaction level was lower than that of the virtual dissection laboratories (Figure 24b). Furthermore, students stated that the laboratory that was good for observing anatomical structures from the desired perspective and the laboratory that was good for understanding anatomical structures was better for performing a virtual dissection laboratory.

Reality

Students reported that anatomical structures looked real and felt like they were in the anatomical structure space was the cadaver dissection laboratory

(Figure 24c). In addition, the laboratory in which the world of anatomical structure seemed to exist was also the cadaver dissection laboratory.

Spatial Ability

The laboratory that facilitated the observation of deeper layers of structures and made anatomical structures and locations clear and intuitive was the tablet-based laboratory (Figure 24d). A tablet-based laboratory was also good for developing spatial perception skills.

Immersion

There was no significant difference between virtual dissection laboratories and the cadaver dissection laboratory in the degree of laboratory that felt like continuing the conduct, not wanting to go back to daily life, or being in a different space outside of reality (Figure 24e). In addition, there was no significant difference between virtual dissection laboratories and the cadaver dissection laboratory in the degree to which daily life was forgotten for a while during practice.

Continuous Use Intention

Students reported that they wanted to re-experience, repeat, or experience tablet-based laboratory in other anatomical structures (Figure 24f). Still, there was no statistically significant difference compared to the Cadaver dissection laboratory.

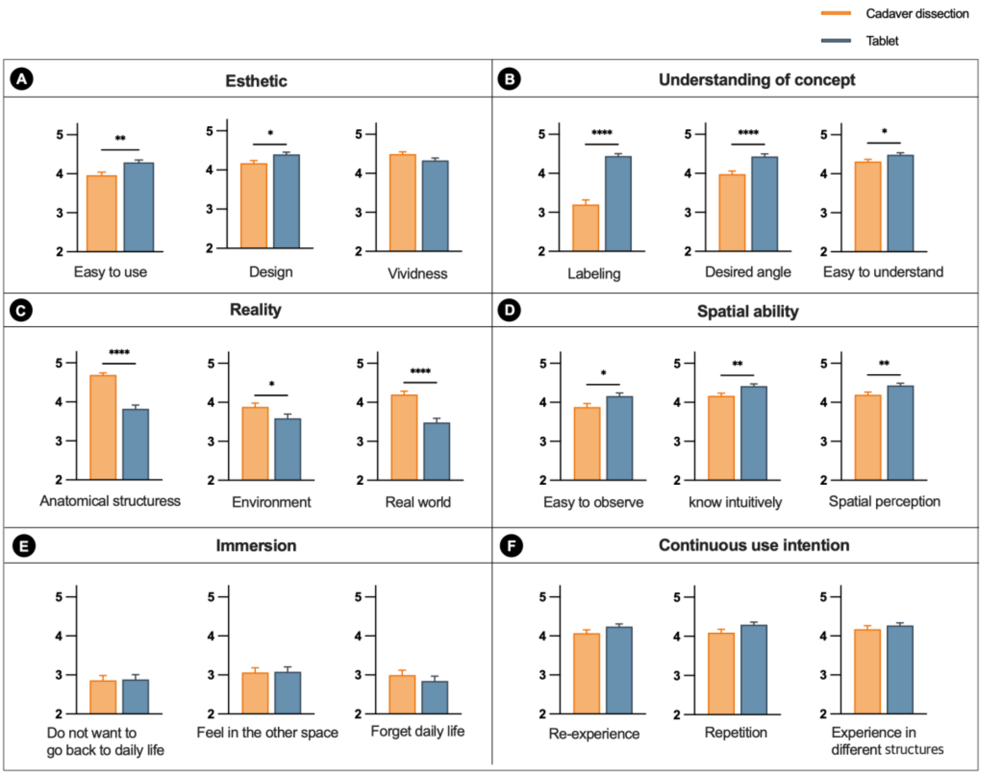

Figure 24. Comparison of the impact of esthetics, understanding of the concept, reality, spatial ability, immersion, and continuous use intention on cadaver dissection and tablet. (A) esthetics, (B) understanding of the concept, (C) reality, (D) spatial ability, (E) immersion, and (F) continuous use intention. Students' satisfaction on cadaver and virtual dissection laboratories was ranked on 5-point Likert-type scale (1 = very unsatisfied and 5 = very satisfied). *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.0001$

Contents' Scenario of "Neuroanatomy" Laboratory

The contents included several structures of the diencephalon and telencephalon and structures related to the third ventricle and the lateral ventricle. Tutors produced contents' scenarios in advance using tablets and organized the contents to be explained to students. All diencephalon contents were stored in the library during tablet-based laboratories (Figure S4). The contents to be explained by the tutor in each content are as follows in S2 Appendix.

Discussion

Numerous disciplines, including medicine, benefit from having access to human cadavers to study anatomy at its actual size. However, cadaver dissection is time-consuming, and some body parts are so difficult to access that they may be damaged. Once a structure has been damaged or cut during cadaver dissection, it is irreparable. This is the most significant disadvantage of cadaver dissection. Cadavers are frequently cumbersome and difficult to move, making it difficult for students to visualize specific structures. Additionally, the dissection sequence is relatively consistent when performed on a cadaver. For instance, the abdominal organs cannot be dissected without first dissecting the front abdominal wall. This makes it difficult to revisit completed dissections on a cadaver. The lack of cadavers and high costs have also substantially impacted the development of alternative teaching methods. The method of anatomy instruction must be continuously revised and updated to determine the approaches that best accommodate the changes in these circumstances. As a result of these numerous changes in circumstance, I have conducted multiple digital anatomy educations using a virtual dissection table, a life-sized touch screen, and tablets. Although surgical VR simulators, 3D anatomical models, and virtual worlds are relatively well represented in the literature, there is limited evidence on the use of virtual dissection tables and mobile VR (118). As highlighted in this study, the majority of students were positive about virtual anatomy education, and the 3D atlas was more helpful in studying anatomical structures than cadaver dissection.

Digital Competence

In a recent report on essential competences for lifelong learning, the European Parliament lists digital competence as one of eight fundamental abilities that are equally important to thriving in a knowledge society (119). In particular, the widespread use of digital technologies and the subsequent rise in the need for digital competence have significantly affected the medical field. In addition, digital competence is also important not only for learners but also for educators. According to the findings of one study, educators' motivation to use technology in the curriculum was influenced by their perceptions to digital competence (120). As a result, the key questions of this study were researched using a design-based approach which is called ADDIE model. I employed many digital resources to ensure that my digital-based anatomy curriculum is user-friendly, easy to follow, and, most importantly, compatible with the medical students' learning process. Therefore, this study presents more structured digital-based anatomy curriculum aimed at covering the core Human anatomy and Neuroanatomy laboratories curriculum for first-year medical students.

Academic Achievements of "Human Anatomy" Laboratory

The Q1 and Q2 mean scores were compared for each group to evaluate whether there was a statistically significant difference in academic achievement between the cadaver and virtual groups (see Figure 16). This is the first study to investigate students' academic achievement in three laboratories with different situations of cadaver dissection. In the Human Anatomy laboratory, the cadaver group for each class had different situations, with extraction (class A), dissection (class B), and observation (class C). The Q1 mean score was significantly higher in the virtual group than in the cadaver group (see Figure 16a). This study suggests that observing a damaged heart during dissection was more challenging to study anatomical structures than when the heart was extracted directly, taken out of the body, and dissected. This finding is also consistent with existing studies (8, 121, 122). Once any structures are damaged or cut during dissection, they cannot be reconstructed. This makes it students difficult to re-visit completed dissection on a cadaver. In addition, I found no significant difference in Q2 mean score between the cadaver and virtual groups after finishing the Human Anatomy laboratory. I may interpret that if the anatomical structure was incomplete, such as Class C, virtual anatomy education could be helpful for study.

Survey Results of "Human Anatomy" Laboratory

I found that from an aesthetic point of view, the cadaver laboratory was harder to practice and less well-designed than the life-sized touchscreen-based and tablet-based laboratories except for vividness. In order to understand the concept, the labeling of the tablet-based laboratory was the best, and it was possible to turn it to the desired angle and the easiest to understand. Cadavers had the highest sense of reality than virtual dissection laboratories because they existed in reality and could be touched. In this study, the tablet-based laboratory was easy to observe from the perspective of spatial perception, and the structure seemed intuitive. It was confirmed that the practice that made students not want to return to their daily life and forget their daily life was the cadaver practice, and the practice that seemed to be in the most different space was the head-mounted display-based practice.

Academic Achievements of "Neuroanatomy" Laboratory

In the Neuroanatomy laboratory conducted under the same conditions, each class had a higher academic achievement of Q1 than the virtual group compared to the cadaver group (see Figure 23). In particular, the virtual group of all classes had significantly higher academic achievement in Q1 than the cadaver group (see Figure 23b). This outcome demonstrates a high potential for the effectiveness of virtual anatomy education in supplementing traditional teaching methods. This result is consistent with the advantages of virtual anatomy education in a laboratory (123-126) In addition, there was no significant difference in the mean score of Q2 between the virtual and cadaver groups. This result suggests that virtual and cadaver groups made the same progress in retaining major anatomical concepts.

Survey Results of "Neuroanatomy" Laboratory

Students stated that a tablet-based laboratory was a more satisfactory cadaver dissection laboratory from the perspective of aesthetics, concept understanding, and spatial ability. In addition, from an aesthetic point of view, students reported that the tablet-based laboratory was easier to understand the anatomical structure than the cadaver laboratory, and the design was better. This finding is also consistent with previous studies (126). It has been demonstrated that 3D visualization is superior to conventional approaches to learning anatomy. On the other hand, the anatomical structure was more realistic in the cadaver. If the contents of a tablet-based laboratory were more realistic than a cadaver, there is a possibility that the satisfaction level of a tablet-based laboratory was higher. Many studies have reported the development and validation of a 3D atlas (72, 127). Finally, there is no difference in students' immersion in tablet-based and cadaver laboratories. In addition, I found that students wanted to experience and repeat the tablet-based laboratory rather than the cadaver laboratory, but there was no significant difference. According to a previous study, surgical theater platform such as head-mounted display provides an immersive experience.

Limitations

The following limitations are present. One type of virtual dissection device could not accommodate all students experiencing the virtual anatomy laboratory. Since there are only three head-mounted displays, approximately three students in a group used one head-mounted display in 18 minutes. Further study needed to be conducted in an environment with sufficient resources. Second, only two anatomical regions were investigated in this study. The experiment's expansion to other anatomical regions might be interesting and merit consideration in follow-up studies to assess the extent of generalizability referred to the anatomical topic. Finally, the study participants were restricted to first-year medical students. Whether these findings could be generalized to different grades needs to be determined.

Conclusion

Various qualities are essential for medical students in all medical disciplines. For students to succeed in clinical practice, medical schools should focus on equipping them with the necessary competencies. As technology becomes more affordable, available, and versatile, the nature of anatomy education is shifting. Many digital resources are available for students of medicine or related subjects for anatomy learning. In addition, the present coronavirus pandemic, the lack of cadaver donors, and health issues highlight the growing importance of digital technologies in medicine. Therefore, students must take a proactive role and participate in the digital revolution of anatomy education to stay up with the rapid evolution of medicine.

However, concerted digital-based training curriculums are needed because of the lack of digital competencies in undergraduate education. This study describes the need for the incorporation of digital competencies in medical education and presents a digital-based anatomy curriculum on how the implementation of these competencies in undergraduate anatomy curriculums can be achieved. In the chapter 2 study, in the era of infectious diseases, the quality of education is critically dependent on the planning and preparation of on-off lectures, cadaver dissection, and digital educational software. Also, the first-year medical students found digital anatomy resources valuable for learning and understanding anatomical structures. These findings provide important insights regarding digital educational software and detailed examples of anatomy education schedules during the pandemic era. In the chapter 3 study, using a design-based methodology referred to as the ADDIE model, I propose a more structured digital anatomy curriculum designed to cover the fundamental Human anatomy and Neuroanatomy laboratories curriculum for first-year medical students.

Based on my experience with the above studies and review of the available literature, I believe novel medical technologies can address several challenges, such as high costs, time intensity, shortage of cadavers, and the era of infectious disease. In conclusion, this study demonstrates that there is potential usefulness for virtual dissection to augment cadaver dissection in medical education.

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Supporting Information

S1 Appendix

Coronary Arteries

• Let us look at the coronary arteries of the heart.

1) Coronary arteries supply blood to the heart muscle and wrap around the outside of the heart.
2) The main coronary arteries are the right and left main coronary arteries (LMCA). However, usually the LMCA divides into two branches. The left anterior descending artery is a branch of the left coronary artery that supplies blood to the left side of the heart's anterior surface. The circumflex artery originates from the left coronary artery and surrounds the heart muscle. This artery supplies blood to the heart’s exterior and posterior regions.
3) The right coronary artery (RCA), on the other hand, the separates into smaller branches, including the right posterior descending artery. And the acute marginal artery. The RCA provides blood to the right ventricle, right atrium, and sinoatrial (SA) and atrioventricular (AV) nodes, which regulate cardiac rhythm.
4) The right coronary artery, along with the left anterior descending artery, contributes to blood supply to the heart's middle or septum.

Chambers of the Heart

• Let us understand the overall shape of the heart when you look at it from the front.

1) The higher chambers, the right and left atria, receive incoming blood. The lower chambers — the right and left ventricles — are responsible for pumping blood out of your heart.
2) It is trapezoidal and has a slightly pointed shape towards the apex. This sharpness is because both ventricles are pointed, forming the apex.
3) There are both atriums towards the base.
4) Let us observe the atrium and ventricle of the right and left. The top 2 chambers are called the right atrium and left atrium. The bottom 2 chambers are called the right and left ventricles.

Valves and Cusps of the Heart

• Let us look at the valves and cusps of the heart.

1) Look at the aortic valve that comprises the posterior, right, and left cusps. These three valves open to let blood flow from your heart's left ventricle to the aorta.
2) Next, look at the pulmonary valve. This valve also has anterior, right, and left cusps. They allow blood to pump from the right ventricle to the pulmonary artery.
3) Look at the tricuspid valve. This valve has the septal, anterior, and posterior cusps. They allow blood to flow from the right atrium to the right ventricle.
4) Lastly, look at the mitral valve, which has the anterior and posterior cusps. This valve allows blood to pass from the lungs into the left atrium. They also restrict backflow from the left ventricle to the left atrium.

• Let us look at the papillary muscles that open and close the cusps of the heart.

1) The papillary muscles of the heart are pillar-like muscles found within cavity of the ventricles and linked to their walls.
2) Look at the presence of septal, anterior, and posterior papillary muscles in the right ventricle.
3) Next, observe the anterior and posterior papillary muscles in the left ventricle.

<u>Conducting System of the Heart</u>

• Let us look at the conducting system of the heart.

1) The heart must be synchronized with the atrium and contracted together at once, and then the ventricles must be synchronized again and contracted together at once.
2) The electrical signal is generated by the sinoatrial (SA) node and then travels from SA node to the atrioventricular (AV) node. Impulses are delayed for a brief moment before continuing along the conduction pathway into the ventricles through the bundle of His. The bundle of His separates into right and left routes, known as bundle branches, to stimulate the right and left ventricles.

S2 Appendix

The Structure inside the Cerebrum

1) The diencephalon is a complex of neural structures located between the cerebrum and the midbrain. Most are composed of the thalamus and hypothalamus. If you look at the first content, the skull is transparent so that you can see the structure inside well. Rotate the structure to see the positional relationship of the different structures.
2) The upcoming practice ranges from the ventricle inside to the structure outside. Let us look at each layer and study the lobes of the brain.

The Structure of the Ventricle

1) Let us learn about the third ventricle, which is located in the innermost part of the brain, and the different ventricles that connect this space.
2) The interventricular foramen connects the space of the third ventricle. Through this, it passes through the lateral ventricle in the telencephalon and through the aqueduct of the midbrain to the fourth ventricle.
3) Press the label on the structures of the lateral ventricle from the front horn of the lateral ventricle to the occipital horn of the lateral ventricle one by one to observe the location.
4) Let us observe the remaining lateral aperture of fourth ventricle and central canal of spin code.

The Structure of the Thalamus

1) Next, let us observe the nuclear structure of the thalamus located on both sides of the third ventricle.
2) The thalamus is the main mass of the brain, an egg-shaped structure about 4 cm long, which acts as an intermediary for sensory and motor signals and consists of several nuclei.

3) If you look at the content, the right part of the award is opaque, and the left part of the award is transparent, so you can observe the external structure of the award and the structure of the sagittal nucleus.
4) Click down from the medial nuclei of the thalamus label located on the inner side of the table. Learn the location and name. In particular, the pulvinar is enlarged at the back end of the award, and the sagittal pillows on both awards are open.
5) Let us observe the pineal body and gland are on the median plane above the superior colliculus.

Anatomical Relationship between Ventricle, Global Pallidus, and Striatum

1) If we look at the structure of the thalamus, now let us look at the relationship between the lateral globus pallidus, the medial globus pallidus, and the striatum, which is further outside.
2) Here, the striatum is divided into a caudate nucleus and putamen.

Anatomical Relationship between Thalamus, Ventricle, Global Pallidus, and Striatum

1) Let us review the thalamus, ventricle, global pallidus, and striatum structures.
2) We will take a closer look at fornix in the following observation.

Hypothalamus

1) Look at the structure of the fornix before the hypothalamus observation.
2) The fornix starts with the hippocampus and, around it, becomes a cru of the fornix, goes upward, and then connects to the front of the cerebrum.

3) Observe that the crus of fornix merge into each other in the median plane and become the body of fornix, then become the column of fornix again in the front, and then are buried in the sagittal plane and headed toward the mamillary body.
4) It consists of a mamillary body behind the boundary of hypothalamus on the brain's surface, an optic chiasm in the front, and an optic tract in the side.
5) The mamillary body is observed as a pair of structures that rise in a circle just above the midbrain.
6) Observe that the optic chiasm meets both optical nerves in the middle plane and verify that the optic tract drives behind the optic chiasm to connect to the lateral geniculate body.

The Front View of the Cerebral Hemisphere

1) The lamina terminalis forms the front wall of the middle part. It looks like a thin band and after checking it, observe the anterior commission on the dorsal side of this structure.
2) The septum pellucidum is a thinly illuminated structure under the corpus callosum that makes up the inner wall of the lateral ventricle. There is a space between the left and right transparent membranes called cavum septum pellucidum. Observe and view this.

Cerebral Lobes (Lateral Surface)

1) The cerebrum is divided into two hemispheres: the cortex (gray matter) on the outside and the nucleus on the inside (white matter). There are four lobes in the cortex: the frontal, parietal, temporal, and occipital lobes.
2) Let us observe the frontal, parietal, occipital, and temporal lobes.

The Top View of the Cerebrum

1) Let us look at the frontal, parietal, and occipital lobes,
2) Next, observe the gyrus inside the cerebrum. A gyrus is a ridge-like elevation found on the surface of the cerebral cortex.

Supplementary Figures

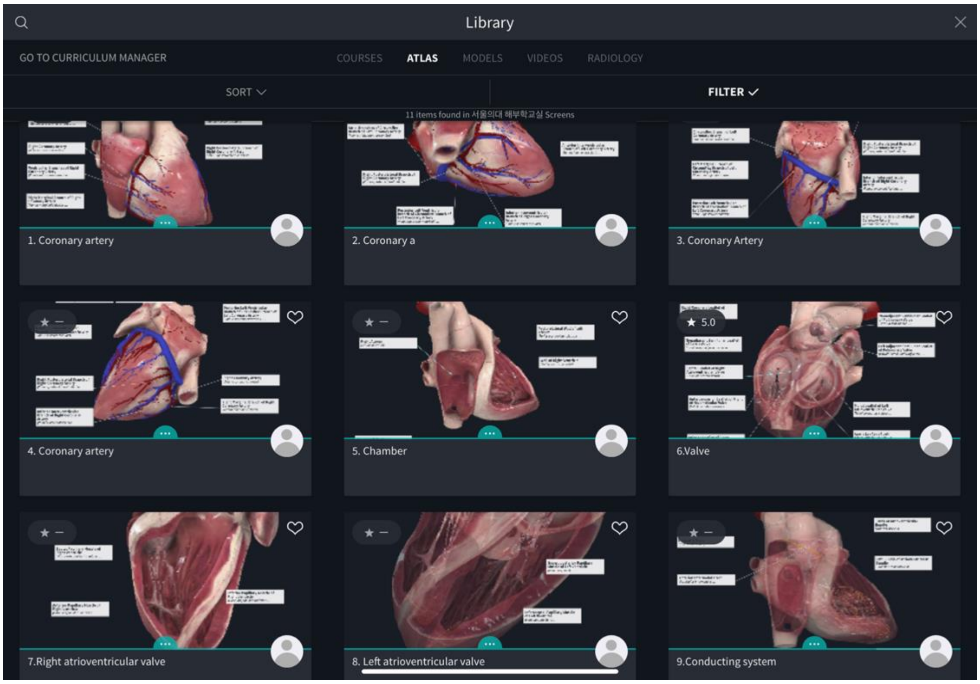

Figure S1. Screenshot of the heart models from tablet-based laboratory with labels from various angle

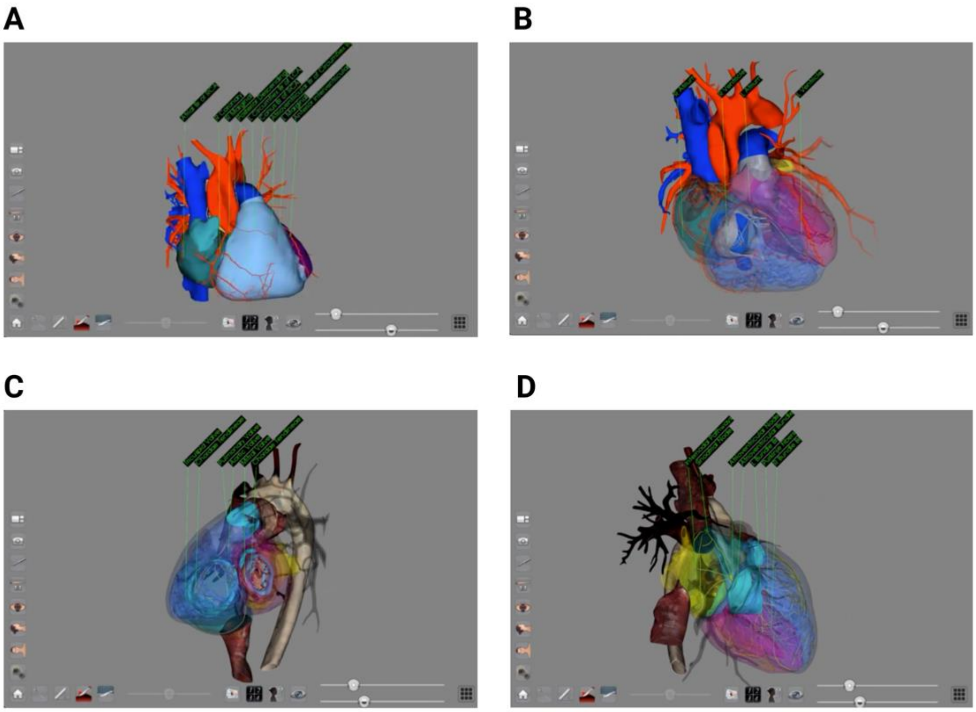

Figure S2. Screenshots of the heart model from life-sized touchscreen-based laboratory with labels from various angle

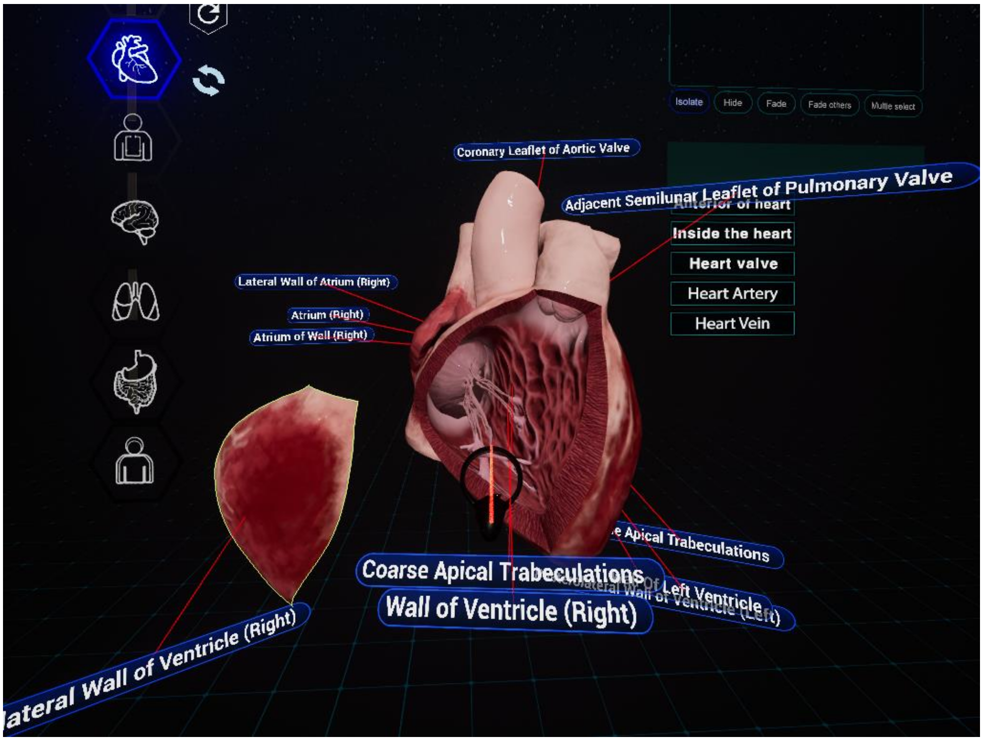

Figure S3. Screenshot of the heart model from head-mounted display-based laboratory with labels

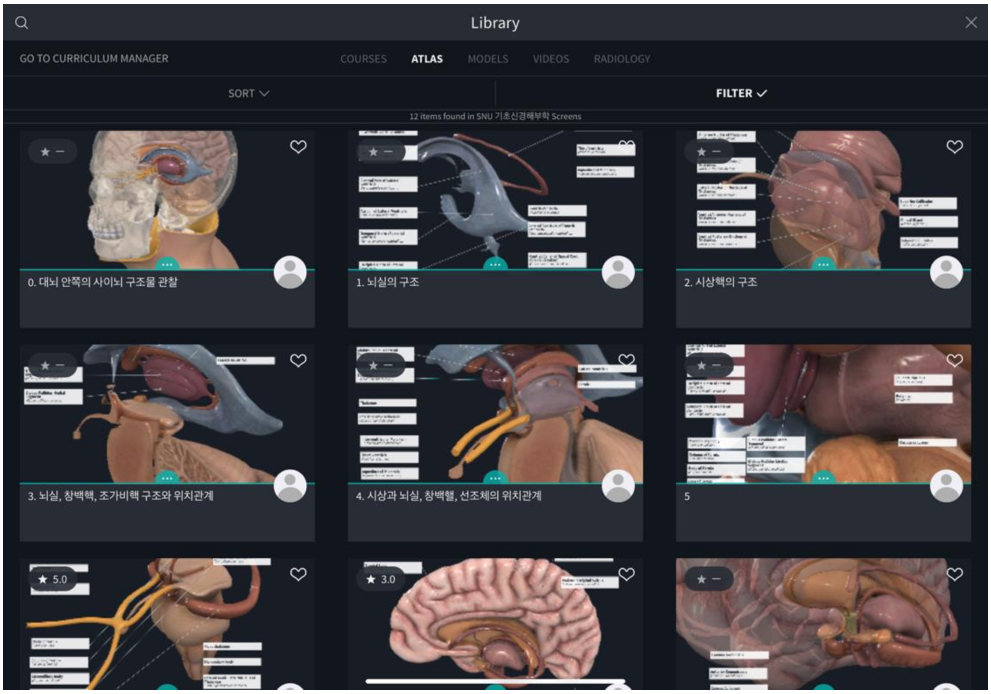

Figure S4. Screenshot of the diencephalon models from tablet-based laboratory with labels from various angle

국문 초록

의대생을 대상으로 한 디지털 기반 해부학 교육과정 개발과 교육효과에 관한 연구

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전통적인 카데바 해부는 다양한 이유로 인해 급격하게 감소하였고, 최근 몇 년 동안 기술 발전으로 의료 교육 분야에서는 다양한 디지털 기기와 소프트웨어가 생산되고 있다. 본 논문은 디지털 기술을 적용한 교육과정을 개발하고 디지털 기반 해부학 교육의 학습효과와 만족도를 알아보기 위해 두 가지 연구로 진행되었다.

첫번째 연구에서는 2019 년 코로나 바이러스 발생으로 의료 교육과 의료 시스템이 약화되었다. 따라서 본 연구는 온라인 수업의 도입과 3 차원 해부학 어플리케이션을 통한 수정된 일정이 학생들의 학업성취도와 만족도에 미치는 영향을 분석하였다. 해부학 교육은 코로나 19 범유행으로 인해 3 개의 하위단위(상하, 몸통, 머리와 목)로 나뉘었다. 온라인 강의를 제외한 카데바 해부와 필기 및 실기시험은 각각 50 여명씩 3 개의 반으로 나뉘어 진행됐다. 또한, 학생들의 학업성취도를 3 개의 하위 단위에서 필기시험과 실기시험을 통하여 평가하였고, 수정된 해부학 일정에 대한 설문지를 작성하였다. 필기시험과 실기시험 점수는 대부분 2019 년에 비해 2020 년에 크게 떨어졌다. 다만, 가상해부학 어플리케이션을 활용한 몸통 세션에서는 2020 년 실기시험 점수가 2019 년보다 월등히 높았다. 70% 이상(팔다리와 몸통 세션)과 53% (머리와 목 세션) 학생들이 대면

실습에서 해부학을 공부하는 데 큰 어려움이 없다고 보고했다. 또한, 50% 이상의 학생들이 모든 세션에서 어플리케이션의 상당한 도움을 받았다.

두번째 연구에서 오늘날의 모든 의학 분야는 디지털 전환의 영향을 크게 받는다. 본 연구는 의학교육에서 디지털 역량의 통합 필요성을 설명하고, 학부 교육에서 이러한 역량의 구현이 어떻게 이루어질 수 있는지 디지털 기반 해부학 교육 커리큘럼을 제시한다. 이 연구는 교차 무작위 대조 시험이었다. 인체해부학과 신경해부학 실습은 3 분반 (A 반, B 반, C 반)으로, 1 학년 의대생은 가상 해부 집단 (가상 해부 → 카데바 해부)과 카데바 해부 집단 (카데바 해부 → 가상 해부)으로 무작위 분류되었다. 가상 해부실습은 헤드마운티드 디스플레이, 태블릿, 실물 크기의 터치 스크린을 사용했다. 퀴즈 1 은 첫번째 가상 해부실습 또는 카데바 해부실습 후에 해부학 지식을 비교하기 위해 진행되었다. 퀴즈 2 와 설문조사는 모든 가상해부실습과 카데바 해부실습이 끝날 때 수행되었다. 인체해부학 실습의 경우, 퀴즈 1 의 평균 총점에서는 유의미한 차이가 없었다. 그러나, C 반에서는 가상 해부 교육이 카데바 교육보다 월등히 높은 학업성취도를 보였다. 디지털 기기들 중에서, 대부분의 학생들은 태블릿 기반 학습이 효과적인 학습 방법이라고 생각했다. 신경해부학 실습에서는 가상 해부 교육이 카데바 교육보다 통계적으로 유의하게 높은 학업 성취도를 보여주었다. 대부분의 학생들은 3 차원 디지털 기반 학습이 시체 해부학에 대한 이해를 향상시켰다고 보고하고, 디지털 실습 기기를 통한 가상 해부학 실습 경험에 가장 만족했다.

본 연구는 의학교육에서 디지털 기반 해부학 교육의 가능성을 보여주고 디지털 기반 해부학 교육은 전통적인 카데바 교육을 강화하는 혁신적인 학습 경험을 제공할 수 있을 것이다.

주 요 어: 해부학 교육, 디지털 기반 해부학 커리큘럼, 헤드마운티드 디스플레이, 가상해부 테이블, 태블릿, 카데바 해부

학 번: 2021-31502

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