Chronicle of Anatomical Education in Thailand: Experiences at Siriraj Medical School

Adisorn Ratanayotha, M.D., Ph.D.*,, Eve Mon Oo, MBBS, MMedSc, Ph.D.*,*****

**Department of Anatomy, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkoknoi, Bangkok, 10700, Thailand, **Laboratory of Integrative Physiology, Department of Physiology, Graduate School of Medicine, Osaka University, Suita, Osaka, 565-0871, Japan, ***Department of Anatomy, University of Medicine Taunggyi, Taunggyi, Shan State, 06017, Myanmar.*

ABSTRACT

Anatomical education in Thailand has advanced significantly since the first class at Siriraj Medical School in 1890. Gross anatomy was formerly taught by traditional lectures and demonstrations using human anatomical models until cadaveric dissection was officially integrated into the medical curriculum in 1906. Educational standard at the medical school was then raised to an international level during the reform of the medical curriculum with the cooperation of the Rockefeller Foundation in 1923-1935, with the main anatomical disciplines organized into correlated courses, and it has since been continuously improved to the present day. This review summarizes a brief history of anatomical education in Thailand based on experiences at Siriraj Medical School, together with detailing the most significant developments that have occurred over time. Advancements in cadaver preservation and modern educational materials for anatomy teaching are also covered. The primary goal of all advances in anatomical education is to provide students with positive learning experiences that will also improve their learning outcomes.

Keywords: Anatomical education; cadaveric dissection; cadaver preservation; anatomical specimens; educational multimedia; medical school (Siriraj Med J 2022; 74: 463-471)

Anatomical Education at Siriraj Medical School

1. First introduction of modern anatomical teaching in the medical school.

Modern anatomical teaching was introduced to Thailand after the establishment of Siriraj Hospital in 1888. Prince Damrong Rajanubhab was granted royal permission from King Chulalongkorn to establish the first medical school in Thailand at Siriraj Hospital, conducting a three-year diploma course in medicine beginning from 1890.[1] Gross anatomy was first taught by Dr. Thomas H. Hays from 1890, and then by Dr. George B. McFarland from 1892, mainly through traditional lectures and demonstrations with human anatomical models. Dissection was occasionally performed on non-preserved cadavers to provide students with the opportunity to become familiar with real human structures.[1-3]

In 1901, Siriraj Medical School was renamed the "Royal Medical College" by King Chulalongkorn, and the diploma course in medicine was expanded to five years. Cadaveric dissection remained optional until 1906 when it was formally incorporated into the medical curriculum. During that time, Dr. McFarland, Dr. Michel St. Ann Fernandes, and Dr. Walter B. Toy were in charge of teaching gross anatomy and cadaveric dissection.[2-4] To facilitate students' learning, Dr. McFarland also wrote *Human Anatomy with Plates and Diagrams Vols I, II, and III*, which included Thai translations of anatomical terms.[5,6] Students generally studied musculoskeletal

Corresponding author: Adisorn Ratanayotha
E-mail: adisorn.rat@mahidol.edu
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ORCID ID: https://orcid.org/0000-0003-3278-8587
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anatomy without cadaveric dissection in the first year, and then dissected in the second and third years when studying blood vessels, the nervous system, and visceral organs. Non-preserved cadavers used for dissection were obtained from unclaimed human bodies and could only be dissected in a short period before the bodies decomposed.[2,3] Notably, cadaver preservation was most likely attempted before 1912, with a phenol-based solution infused into the femoral arteries of cadavers. However, the preservation efficiency was still inadequate.[7,8]

In 1917, King Vajiravudh founded Chulalongkorn University and merged the Royal Medical College to form the Faculty of Medicine. In 1919, the anatomical class was moved from Siriraj Hospital to the Faculty of Arts and Science in Pathum Wan District.[9,10] Dr. Toy, Luang Kayavibhag Banyai, and Lecturer Lim Chullabhandh were in charge of teaching gross anatomy and cadaveric dissection during that time. The course was revised to two years: students studied and dissected upper and lower extremities in the first year, followed by head and trunk in the second year, using cadavers preserved with a phenol-based solution and stored in large refrigerators.[8,9,11]

2. Anatomical education during the reform of the medical curriculum with the cooperation of the Rockefeller Foundation (1923-1935)

Anatomical education at the Faculty of Medicine was substantially improved when the Rockefeller Foundation, in cooperation with the Siamese Government, helped modernize medical education in Thailand. In 1923, a new six-year curriculum for a Bachelor of Medicine (M.B.) degree was implemented, and the anatomical class was returned to Siriraj Hospital.[10,11] In the same year, Prof. Claude W. Stump from the University of Edinburgh was appointed Professor of Anatomy at Siriraj Hospital. He introduced a new preservation method for cadavers using a formalin-based solution and conducted a one-year dissection class based on *Cunningham's Manual of Practical Anatomy*. He was also the first to teach embryology in the medical school. However, his embryology class appeared to have been limited to lectures and figure drawings due to a lack of microscopic slides.[2,8,12]

In 1925, Prof. Edgar D. Congdon from Peking Union Medical College (PUMC) was appointed Professor of Anatomy at Siriraj Hospital to replace Prof. Stump, who had completed his contact with the Rockefeller Foundation and relocated to the University of Sydney, Australia. In 1927-1928, Prof. Congdon broadened anatomical teaching to cover gross anatomy, microscopic anatomy, embryology, neuroanatomy, and topographic anatomy, in line with international standards.[2,3,13] He developed a new method of anatomical teaching known as the "correlated course," in which students learned the developmental, gross, and microscopic anatomy of individual organs together in the course schedule.[14] He organized a dissection class in which four students would dissect one cadaver (4:1) by following his laboratory directions for an entire academic year[2,12] – a practice that is still implemented at Siriraj Hospital today. He also began preparing microscopic slides of tissue sections, laying the groundwork for the development of microtechniques in the department.[8] Furthermore, Prof. Congdon initiated collections of anatomical specimens for class demonstration, some of which were displayed at the 8th Congress of the Far Eastern Association of Tropical Medicine at Chulalongkorn University in 1930. His collections later became the centerpieces at an anatomical museum at Siriraj Hospital.[15-17]

In 1930, Dr. Sood Sangvichien became an instructor at the Department of Anatomy and received a scholarship from the Rockefeller Foundation to study anatomy and microtechniques at the University of Michigan and Case Western Reserve University in the United States. After returning in 1933, Dr. Sood Sangvichien further developed microtechniques in the department, with the assistance of Lect. Lim Chullabhandh, and succeeded in preparing microscopic slides of the total mounted and serial sections of chick and pig embryos, tissues and organs sections, and brainstem sections.[18,19] Microtechnique development since then has enabled the in-house preparation of microscopic slides that could sufficiently be used for anatomical teaching at the Faculty of Medicine and other health science schools. In 1942-1943, during the Pacific War in World War II, Dr. Sood Sangvichien began writing laboratory directions and distributing them to students to conduct cadaveric dissection despite the wartime shortage of standard textbooks. Prof. Sood Sangvichien's directions were later revised by Prof. Sanjai Sangvichien and his colleagues in 2009.[17,20]

3. Anatomical education under the supervision of Prof. Sood Sangvichien

In 1943, the Faculty of Medicine was transferred to the University of Medical Sciences. Dr. Sood Sangvichien was appointed Head of the Department of Anatomy in 1944 and served in this position until 1969.[21] He passionately dedicated himself to advancing anatomical knowledge and related disciplines, such as medical genetics, medical illustrations, and physical anthropology. In terms of education, the correlated course designed by Prof. Congdon remained the core of anatomical teaching, and Dr. Sood Sangvichien modified it further

to fit the medical curriculum at the time. He improved Prof. Congdon's formalin-based solutions for better cadaver preservation. He also encouraged Thai people to donate their bodies for anatomical education so that students would have sufficient cadavers for standard dissection class (4 students:1 cadaver). His development of in-house microtechniques since before World War II enabled him and his colleagues at the Department of Anatomy to prepare sufficient amounts of microscopic slides for students.[20] In 1947, the Faculty of Medicine Chulalongkorn Hospital was established, with a similar anatomical curriculum as at Siriraj Hospital.[3,22]

In 1948, Dr. Sood Sangvichien expanded Prof. Congdon's collections of anatomical specimens and officially founded Congdon's Anatomical Museum at Siriraj Hospital to honor Prof. Congdon for his crucial contribution to early anatomical education in Thailand.[16] Nowadays, over 2,000 organ specimens from donors who donated their bodies for anatomical education are on display, including world masterpieces, such as the whole-body peripheral nervous system, the heart and whole-body arterial system, and the whole-body muscles and subcutaneous veins.[17] The museum continues to benefit medical personnel and the general public interested in learning human anatomy.

In 1952, Dr. Sood Sangvichien was appointed Professor of Anatomy and continued to make significant contributions to anatomical education in Thailand. In 1962, he founded the Prehistoric Museum at Siriraj Hospital: for which he continued to work even after his retirement in 1970.[23] Physical anthropology has long been one of the department's research interests and staff members are still working on this today.

In 1960, the Faculty of Medicine Nakorn Chiangmai Hospital was founded, with the assistance of staff from Siriraj Hospital in organizing the anatomical curriculum. In the same year, Prof. Sood Sangvichien invited anatomy staff from Siriraj Hospital, Chulalongkorn Hospital, and Nakorn Chiangmai Hospital to organize the first academic meeting for anatomists at Siriraj Hospital.[18,21] This initiative later became the Anatomy Club of Thailand in 1978, and officially the Anatomy Association of Thailand in 2002.

4. Anatomical education from the 1970s

The University of Medical Sciences became Mahidol University in 1969.[24] The Faculty of Medicine Siriraj Hospital and the Faculty of Medicine Ramathibodi Hospital (established in 1965) remain with Mahidol University, while the Faculty of Medicine Chulalongkorn Hospital and the Faculty of Medicine Nakorn Chiangmai Hospital were transferred to Chulalongkorn University and Chiangmai University, respectively. The anatomical curriculum at Siriraj Hospital was gradually changed over the years, with the correlated course remaining the core concept.[3]

The Faculty of Medicine Siriraj Hospital revised the medical curriculum in the early 1970s and later on a regular basis. Lecture and laboratory time were significantly reduced in all anatomical disciplines: from a total of 875 hours in 1956 to 726 hours in 1971, and 616 hours in 1982, and this trend has continued today. Topographic anatomy as a separate subject was discontinued in 1974, but it has since been incorporated into regional gross anatomy.[3,24,25] In 2014, gross anatomy, microscopic anatomy, and embryology were reorganized into functional systems (system-based curriculum) along with physiology, biochemistry, and related subjects. Furthermore, clinical applications have become increasingly integrated into anatomical teaching to ensure that students are well prepared for clinical practices.

5. Anatomical education in global trends and future perspective.

Thailand and many other countries appear to have comparable anatomical curriculums. In ASEAN countries, such as Myanmar, the curriculum prior to 2019 was quite similar to the previous one of Siriraj Hospital, as the main anatomical disciplines were organized into correlated courses based on regional anatomy. Case-based learning (CBL) was also used to help students gain more experience with clinical applications. However, since 2020, all medical universities in Myanmar have reorganized their anatomical curriculums into functional systems with a more holistic and integrated approach to medical education.

In other Asian countries, such as Japan, we learned that anatomical curriculums in certain universities are still based on regional anatomy but are condensed into half an academic year. Due to time constraints, student-centered and self-directed learning becomes increasingly important in laboratory practices. Meanwhile, many Japanese universities have implemented an integrated medical curriculum that combines basic and clinical medicine courses based on body organ systems.[26] This system-based approach is similar to the current preclinical curriculum at Siriraj Hospital, except that it also applies to clinical years. It should be noted that the preference for a system-based approach has increased in medical schools in various countries, including the United Kingdom and Ireland[27], the United States[28], and Australia and New Zealand.[29]

The coronavirus disease 2019 (COVID-19) pandemic

has disrupted current practices in anatomical education. Gross anatomy, in particular, has traditionally required cadaveric dissection, but the physical distancing regulation has limited such hands-on laboratory practice, posing enormous challenge to Siriraj Hospital and medical schools worldwide. Rapid adaptation has thus been made to overcome this challenge through the development of new online resources, digital technologies, and virtual reality workspaces.[30-34] This trend is likely to continue and will have a global impact on the future direction of anatomical education beyond the pandemic era.

Modern anatomical science at the Faculty of Medicine Siriraj Hospital

1. Gross anatomy

Gross anatomy is the study of visible structures in the human body, involving cadaveric dissection and medical imaging. It was the first anatomical discipline taught at Siriraj Medical School, dating back to 1890, before being integrated into the correlated course with microscopic anatomy and embryology by Prof. Congdon in the late 1920s.[14] The teaching of gross anatomy is organized into eight body regions: 1) body wall and axilla; 2) upper extremity; 3) head and neck; 4) thorax; 5) abdomen; 6) lower extremity; 7) perineum and pelvis; and 8) cranial nerves and organs of special senses.

Students attend lectures and conduct cadaveric dissection in parallel by following the laboratory directions. Generally, four students are assigned to dissect one cadaver (4:1) for an entire academic year. Studying gross anatomy by body regions allows students to appreciate human structures and their relations, thus conceptualizing anatomical knowledge more effectively. Regional anatomy at Siriraj Hospital has been reorganized to comply with the functional systems in the current medical curriculum while retaining the eight regions in the postgraduate curriculum. Clinical applications are integrated into the learning topics of all the regions to prepare students for advanced clinical knowledge.

2. Microscopic anatomy

Microscopic anatomy is the study of anatomical structures at the microscopic level, typically through a microscope to examine cells or tissues. Prof. Congdon first introduced and then incorporated microscopic anatomy into the correlated course in the late 1920s.[14]

Teaching microscopic anatomy at Siriraj Hospital begins with the fundamental concepts, such as the cellular components and basic cell types, and then proceeds to the detailed tissue structures correlated with organ systems learned in gross anatomy. Each student receives one optical microscope and one complete set of tissue-sectioned microscopic slides of all the essential organs (~250 slides) for individual use in laboratory classes during an academic year. Recently, high-resolution digital slides have also been implemented for teaching and demonstration. As with gross anatomy, teaching microscopic anatomy in the medical curriculum has been reorganized into functional systems while remaining a full-scale subject in our department's postgraduate curriculum.

3. Embryology

Embryology is the study of the prenatal development of embryos and fetuses, as well as congenital abnormalities. It was first taught at the medical school by Prof. Stump in 1923[2,3,13] and was integrated into the correlated course by Prof. Congdon in the late 1920s.[14]

Teaching embryology begins with the basic knowledge of gametogenesis, fertilization, and early embryonic development, and then progresses to the detailed morphogenesis and organogenesis correlated with gross anatomy. The course also covers congenital abnormalities and clinical applications. During an academic year, each student receives a complete set of total mount and serial section slides of chick and pig embryos at various stages of development. Currently, 3D models, digital slides, and interactive multimedia are also available to help students conceptualize embryonic development. Embryology has been integrated into the functional system of the current medical curriculum and redesigned into developmental biology in our department's postgraduate curriculum.

4. Neuroanatomy

Neuroanatomy is the study of the structures and organization of the nervous system, including the neuronal pathways and clinical correlation. Prof. Congdon first taught neuroanatomy at Siriraj Hospital in 1928.[2,3,13]

Teaching neuroanatomy begins with the fundamental knowledge, such as the general organization of the nervous system, and then proceeds to the detailed structures from the spinal cord to the cerebral hemispheres and internal neural connections. The rationale for teaching neuroanatomy in an "ascending manner" is that students begin with the simple structures in the spinal cord and progress to the more complex structures in the brainstem, and finally to the cerebral hemispheres and their associated circuitries. Functional and clinical correlations are integrated into all learning topics. In laboratory class, every two students are provided with a complete set of nervous tissue slides, including all the spinal cord levels, brainstem, and diencephalon,

all of which are prepared in our department. To better understand the brain's structures, students can also study whole brains and dissected brains impregnated with polyethylene glycol (PEG) as well as serial brain sections preserved in formalin-filled plastic boxes (brain boxes). Neuroanatomy has been integrated with neurophysiology in the current medical curriculum, and is currently being redesigned as clinical neuroanatomy and neuroscience in the postgraduate curriculum in our department.

5. Topographic anatomy

Topographic anatomy is the study of the human body focusing on the relationships between various structures in body parts. This can be accomplished by examining human serial sections in the same way that sectional radiographic images are examined. Prof. Congdon first taught topographic anatomy at Siriraj Hospital in 1927, using illustrations and 1-inch serial sections of embalmed cadavers as teaching materials.[3,25] Some samples of complete human serial sections are currently displayed in Congdon's Anatomical Museum.

In 1974, the teaching of topographic anatomy as a separate discipline was discontinued, but was later incorporated into gross anatomy.[3,25] However, our department recently resumed the subject as an elective course for medical students in 2020. The course begins with the fundamental concepts in topographic anatomy and then proceeds to serial sections of various parts of the human body based on regional anatomy. Clinical imaging is incorporated into all learning topics to help students correlate their knowledge with clinical practice. The course has yet to be resumed in the postgraduate curriculum at our department.

6. Applied anatomy

Applied anatomy at Siriraj Hospital initially focused on clinical applications based on topographic anatomy, and it involved teaching staff from various clinical departments, such as radiology, surgery, and internal medicine.[25,35] However, the teaching concept shifted with the discontinuation of topographic anatomy in 1974, and applied anatomy was subsequently integrated into all anatomical disciplines in the medical and postgraduate curriculums at Siriraj Hospital.

Beginning in 2019, our department has offered new elective courses in modern applied anatomy for medical students. The currently available courses are applied anatomy of the upper extremities, applied anatomy of the lower extremities, and evolutionary anatomy. We also offer refresher courses in clinical anatomy for residency training in collaboration with clinical departments, such as the Department of Otorhinolaryngology and the Department of Radiology. Additional courses in our plan include biomechanics and kinesiology, physical and forensic anthropology, modern media in anatomy, 3D anatomical reconstruction, and integrative clinical neuroscience.

Advancement in human cadaver preservation

Human cadavers have been used for anatomical education since the beginning of Siriraj Medical School. Medical students at the time typically used non-preserved cadavers in their dissection classes because the preservation methods were still underdeveloped. This situation created an inconvenient learning experience because non-preserved cadavers would decompose rapidly, especially under the tropical weather environment in Thailand. Notably, non-preserved cadavers were most likely used for dissection classes until around 1912 when a phenol-based solution was used to preserve human bodies at Siriraj Hospital. Nonetheless, the preservation efficiency was still inadequate and an intensely unpleasant odor remained the primary concern.[7,8]

Prof. Stump was the first to use formalin-based solution to preserve cadavers at Siriraj Hospital in 1923.[2,12,13] Several cadaver preservation methods have since been developed, including the conventional formalin/arsenic-based solution, the most commonly used in medical schools in Thailand. Currently, three types of preserved cadavers are available in the Department of Anatomy, the Faculty of Medicine Siriraj Hospital: 1) conventional embalmed human cadavers; 2) soft cadavers; and 3) fresh cadavers.[36] Each type has advantages and disadvantages, making them appropriate for different dissection purposes.

1. Conventional embalmed human cadavers

Human cadavers were preserved by infusing the femoral arteries with a mixture of formalin, potassium nitrate, arsenic, glycerin, ethanol, and phenol; the cadavers were then submerged in a phenol-glycerin immersion solution for at least three months before being used for cadaveric dissection. The method was first used by Prof. Congdon, likely around 1925, and then modified by Prof. Sood Sangvichien in 1927 to make the cadavers more suitable for use in Thailand. The detailed formula is available from our department upon request. Conventional embalming has since been used as the primary preservation method in our department because it is inexpensive, suitable for use in the long-term preservation of cadavers at room temperature, and ideal for general cadaveric dissection. However, it has significant drawbacks as it causes joint stiffness and tissue rigidity in cadavers.

2. Soft cadavers

Soft cadaver preservation was first implemented in our department in 2011, using a protocol adapted from Thiel's cadaver preservation.[36] The method was developed by Prof. Walter Thiel at Graz Institute of Anatomy.[37] Human cadavers were infused in the femoral arteries with Thiel's infusion solution – a mixture of various chemicals, including boric acid, ethylene glycol, ammonium nitrate, potassium nitrate, sodium sulfate, and formalin. The cadavers were then submerged in the immersion solution with similar components but different concentrations to the infusion solution for at least three months before being used for cadaveric dissection.[36-38] Unlike conventional embalming, Thiel's method preserves the tissue texture, plasticity, and joint flexibility similar to a fresh specimen; thus providing cadavers suitable for surgical skill practices. The disadvantages of this method, however, include its complicated formula, high cost, and lengthy preparation time.

3. Fresh cadavers

Our department began developing fresh cadaver preservation for surgical training in 2006.[36] Human cadavers were immediately preserved in a deep freezer at -20°C without a preservative solution; they were then defrosted just before being used. This method preserves the tissue consistency and joint motion as close to living humans as possible; thus, the cadavers are appropriate for surgical skill practices that require near-living cadavers, such as facial skin injection and laparoscopic surgery. However, because no preservative solution is used, the cadavers preserved with this method should be dissected in a low-temperature environment and are only available for a limited time.

4. Future direction of human cadaver preservation

The Department of Anatomy at Siriraj Hospital has long been dedicated to the advancement of cadaver preservation. Cadavers preserved in our department are widely used in anatomical teaching and research at Siriraj Hospital and are also distributed among medical and dental institutes throughout Thailand. We have collaborated with the Siriraj Training and Education Center for Clinical Skills (SiTEC) to host national and international surgical workshops using soft and fresh cadavers since 2014. Furthermore, we are currently developing "brain-preservative soft cadavers" – a method that combines traditional embalming with soft cadaver preservation[39] – for future anatomical education and research, particularly in the fields of neuroanatomy and neurosurgery.

Modern materials and multimedia in current anatomical education

Although cadaveric dissection has long been and will continue to be the primary method of anatomical education, a wide range of materials and multimedia are now available to help students better understand human anatomy. Summarized below are some examples of supplemental educational materials that have been successfully used in the Department of Anatomy at Siriraj Hospital.

1. Plastination

Dr. Gunther von Hagens of Heidelberg University first developed cadaveric plastination in 1979[40], and it has since been used for preparing specimens in medical schools and anatomical museums. In this technique, water and lipids in biological tissues are replaced with curable polymers, which are subsequently hardened, resulting in dry, odorless, and long-lasting specimens. Our department has used the Silicone S-10 standard plastination technique to preserve organ specimens for demonstrations in dissection classes and exhibitions in the anatomical museum.[41] The Plastination Unit of our department is dedicated to producing high-quality plastinated specimens, and we are currently developing thin-sheet plastination.

2. Cadaveric angiography

An angiographic approach has been used to infuse colorized polymers into the blood and lymphatic vessels of cadavers.[42,43] This technique can be used to colorize the vessels and preserve the vascular framework; therefore, it is useful for preparing vascular specimens for anatomical teaching, research, and exhibition. Masterpieces from our Cadaveric Angiography Unit include the colorized coronary arterial system, vasculatures of the adult liver and intestines, external facial vasculatures, arteries of the upper and lower extremities, and the entire arterial system of a newborn baby. This method is also utilized to investigate the vascular distribution and surgical anatomy of various organs.[44,45]

3. PEG-impregnated brains and serial brain sections (brain boxes)

Polyethylene glycol (PEG) has been used in our department to preserve brain specimens as an alternative to conventional formalin-embalming and plastination. PEG impregnation produces durable specimens with soft texture, high flexibility, and no skin irritation.[46,47] We have used PEG-impregnated brains for teaching neuroanatomy, enabling students to study and dissect

brain structures with greater appreciation. The specimens can be stored in closed plastic bags at room temperature and thus are suitable for long-term use as educational materials.

We have also prepared serial brain sections (brain boxes) for students. Conventional embalmed brains were serially cut in the horizontal, coronal, or sagittal planes with the appropriate thickness to display the internal structures. The specimens were then preserved in clear plastic boxes filled with formalin-based solution and arranged in series so that students could use them for reviewing the topographic anatomy of the brains in correlation with clinical imaging. Our serial brain sections have been used at Siriraj Hospital and distributed among medical schools throughout Thailand.

4. Three-dimensional printed models.

Three-dimensional (3D) printing technology has recently attracted considerable interest from those working in medicine and healthcare. 3D-printed anatomical models, the bio-printing of tissues and organs, and customized implants and prostheses are among the beneficial applications of this technology.[48-50] Our department at Siriraj Hospital has used 3D printing technology to create anatomical models of various organ structures, including those difficult to access in conventional cadaveric dissection, such as the ear ossicles and vestibular organs. These models help students conceptualize anatomical knowledge more effectively. We also plan to apply 3D printing technology in biomedical research in the near future.

5. Digital microscopic slides, interactive multimedia, and virtual dissection tables

Digital transformation is the leading future direction for anatomical education, particularly in the post-pandemic era. We have applied immersive technology[51] in teaching to help students understand basic anatomical concepts and clinical applications. Currently, histological and embryological slides produced in our department have been digitized to high-resolution images and stored in cloud libraries that are accessible by staff and students. Gross anatomical specimens and serial embryological sections have been reconstructed to create 3D interactive multimedia. Furthermore, virtual dissection tables, known as Anatomage tables, have recently been integrated into our anatomical courses, enabling students to simulate virtual cadaver-based dissections and surgical operations, complementing the conventional cadaveric dissection. These digital technologies, when combined, provide students with positive learning experiences and therefore improve their learning outcomes.

Conclusion and future perspective

Anatomical education in Thailand has advanced significantly since the first class at Siriraj Medical School in 1890. Teaching and research in anatomical disciplines have been expanded to all medical schools that have since been established. As Thailand's oldest anatomical department, the Department of Anatomy at the Faculty of Medicine Siriraj Hospital is constantly working to improve anatomical education by following our great professors' footsteps and incorporating new technologies to enhance students' understanding and learning experiences.

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Competing interests

The authors declares that no competing interests exist.

REFERENCES

1. Sangvichien S. Siriraj Hospital: the first hospital. In: Sirinavin C, Thongcharoen P, Ratanamaneechat S, editors. Siriraj Hospital's Centennial: history and development. Bangkok, Thailand: Victory Powerpoint Co. Ltd; 1988.p.1-26.
2. Sangvichien S. Anatomy in Thailand, Part I before 1928. Cremation volume for Luang Kayavibhag Banyai: Chuan Pim Press; 1964.p.84-100.
3. Diloksambandh V. The development of anatomy at Siriraj Medical School. Siriraj Hosp Gaz. 1982;34(10):823-7.
4. Sangvichien S. Royal Medical College. In: Sirinavin C, Thongcharoen P, Ratanamaneechat S, editors. Siriraj Hospital's Centennial:

history and development. Bangkok, Thailand: Victory Powerpoint Co., Ltd; 1988.p.35-84.
5. McFarland GB. Anatomy Vol. I and II. 2nd ed. Bangkok, Thailand; 1916.
6. McFarland GB. McFarland Family History. In: Borirakwetchakan, editor. Cremation volume for Prah Arj Vidyagom (George B McFarland). Bangkok, Thailand: Sereewanich Press; 1950. p. 1-23.
7. Khun Chamni Vejasarn. Siriraj Medical School 50 years ago (Part I). Siriraj Hosp Gaz. 1967;19(11):601-7.
8. Sangvichien S. Professor Crosby and the teaching of neuroanatomy in Thailand. Siriraj Hosp Gaz. 1984;36(5):327-40.
9. Sangvichien S. The development of the Faculty of Arts, Chulalongkorn University, as well as the Faculty of Medicine Siriraj Hospital, between 1923 and 1935. Siriraj Hosp Gaz. 1984; 36(1):35-53.
10. Sangvichien S. Faculty of Medicine and Siriraj Hospital, Chulalongkorn University. In: Sirinavin C, Thongcharoen P, Ratanamaneechat S, editors. Siriraj Hospital's Centennial: history and development. Bangkok, Thailand: Victory Powerpoint Co. Ltd; 1988.p.85-180.
11. Sangvichien S. Reform of the medical education in Thailand during the cooperation with the Rockefeller Foundation, between 1923-1935. Siriraj Hosp Gaz. 1983;35(7):661-70.
12. Sangvichien S. Anatomical knowledge in our country. In: Sangvichien S, editor. Professor Edgar Davidson Congdon and the History of Anatomy in Thailand until 1967. Bangkok, Thailand: Aksorn Sampan Press; 1967. p. 78-122.
13. Sangvichien S. Medical curriculum during the cooperation with the Rockefeller Foundation (1923-1935). Siriraj Hosp Gaz. 1983;35(6):569-83.
14. Congdon ED. An attempt to improve the methods of anatomical teaching, including the organization of the dissection to an unusual degree by systems and the bringing of the developmental, gross, and microscopic anatomy of individual organs together in the schedule. The Anatomical Record. 1930;45(4):323-37.
15. Sangvichien S. Professor E.D. Congdon. Siriraj Hosp Gaz. 1967;19(3):169-81.
16. Sangvichien S. History of Congdon's Anatomical Museum. In: Sangvichien S, editor. Memorial note: cerebration of Anatomy and Physiology Building with the official opening of Congdon's Anatomical Museum. Bangkok, Thailand: Thai Kosana; 1948.
17. Editorial Team of 120 Memorabilia of Siriraj. Medical education: how the medical school began and developed. In: Sangvichien S, Sukpanichnant S, Sangruji T, Mekanant P, Namatra C, Em-yam S, et al., editors. 120 Memorabilia of Siriraj. Bangkok, Thailand: Plan Printing Co., Ltd.; 2008.p.230-311.
18. Sangvichien S. Anatomy in Thailand, Part II. In: Sangvichien S, editor. Professor Edgar Davidson Congdon and the History of Anatomy in Thailand until 1967. Bangkok, Thailand: Aksorn Sampan Press; 1967.p.47-77.
19. Sangvichien S. In remembrance of Lim. In: Sangvichien S, editor. Cremation volume for Lim Chullabhandh. Bangkok, Thailand: Aksorn Sampan Press; 1970.p. 9-14.
20. Sangvichien S. Sood Sangvichien's Textbook of Anatomy: dissection directions. 2nd ed. Bangkok, Thailand; 2009.
21. Sangvichien S. Faculty of Medicine and Siriraj Hospital, the University of Medical Sciences. In: Sirinavin C, Thongcharoen P, Ratanamaneechat S, editors. Siriraj Hospital's Centennial: history and development. Bangkok, Thailand: Victory Powerpoint Co. Ltd; 1988. p. 181-264.
22. Diloksambandh V. The curriculum of anatomy at Siriraj. Siriraj Hosp Gaz. 1972;24(8):1319-32.
23. Subhavan V, Pramankij S, Solheim WG. Sood Sangvichien, 1907-1995. Asian Perspectives. 1997;36(2):260-4.
24. Sangvichien S. Faculty of Medicine Siriraj Hospital, Mahidol University. In: Sirinavin C, Thongcharoen P, Ratanamaneechat S, editors. Siriraj Hospital's Centennial: history and development. B angkok, Thailand: Victory Powerpoint Co. Ltd; 1988. p. 265-324.
25. Diloksambandh V. The teaching of topographic anatomy. Siriraj Hosp Gaz. 1984;36(4):251-4.
26. Shimura T, Aramaki T, Shimizu K, Miyashita T, Adachi K, Teramoto A. Implementation of integrated medical curriculum in Japanese medical schools. J Nippon Med Sch. 2004;71(1):11-6.
27. Smith CF, Freeman SK, Heylings D, Finn GM, Davies DC. Anatomy education for medical students in the United Kingdom and Republic of Ireland in 2019: A 20-year follow-up. Anat Sci Educ. 2021.
28. McBride JM, Drake RL. National survey on anatomical sciences in medical education. Anat Sci Educ. 2018;11(1):7-14.
29. Bouwer HE, Valter K, Webb AL. Current integration of dissection in medical education in Australia and New Zealand: Challenges and successes. Anat Sci Educ. 2016;9(2):161-70.
30. Pather N, Blyth P, Chapman JA, Dayal MR, Flack N, Fogg QA, et al. Forced Disruption of Anatomy Education in Australia and New Zealand: An Acute Response to the Covid-19 Pandemic. Anat Sci Educ. 2020;13(3):284-300.
31. Longhurst GJ, Stone DM, Dulohery K, Scully D, Campbell T, Smith CF. Strength, Weakness, Opportunity, Threat (SWOT) Analysis of the Adaptations to Anatomical Education in the United Kingdom and Republic of Ireland in Response to the Covid-19 Pandemic. Anat Sci Educ. 2020;13(3):301-11.
32. Harmon DJ, Attardi SM, Barremkala M, Bentley DC, Brown KM, Dennis JF, et al. An Analysis of Anatomy Education Before and During Covid-19: May-August 2020. Anat Sci Educ. 2021;14(2):132-47.
33. Shin M, Prasad A, Sabo G, Macnow ASR, Sheth NP, Cross MB, et al. Anatomy education in US Medical Schools: before, during, and beyond COVID-19. BMC Med Educ. 2022;22(1):103.
34. Nakai K, Terada S, Takahara A, Hage D, Tubbs RS, Iwanaga J. Anatomy education for medical students in a virtual reality workspace: A pilot study. Clin Anat. 2022;35(1):40-4.
35. Sangvichien S. Anatomical studies and research projects. In: Sangvichien S, editor. Professor Edgar Devidson Congdon and the History of Anatomy in Thailand until 1967. Bangkok, Thailand: Aksorn Sampan Press; 1967.p.123-42.
36. Sangchay N. The soft cadaver (Thiel's Method) : the new type of cadaver of Department of Anatomy, Siriraj Hospital. Siriraj Med J. 2014;66(6 Suppl):S228-S31.
37. Thiel W. Supplement to the conservation of an entire cadaver according to W. Thiel. Ann Anat. 2002;184(3):267-9.
38. Ottone NE, Vargas CA, Fuentes R, Del Sol M. Walter thiel's embalming method. Review of solutions and applications in different fields of biomedical research. International Journal of Morphology. 2016;34(4):1442-54.
39. Miyake S, Suenaga J, Miyazaki R, Sasame J, Akimoto T, Tanaka T, et al. Thiel's embalming method with additional intra-cerebral ventricular formalin injection (TEIF) for cadaver training of head and brain surgery. Anat Sci Int. 2020;95(4):564-70.

40. von Hagens G, Tiedemann K, Kriz W. The current potential of plastination. Anat Embryol. 1987;175(4):411-21.
41. Amonmettajit N, Waema M, Wiwatwongsakul A. Improvement S10 method for higher quality of plastinated gross specimens. Siriraj Med J. 2019;71(Suppl 1):S90-S2.
42. Ratanalekha R, Oonjitti T, Piyaman P, Ongsiriporn M, Ittawittayawat P. Colored contrast agent for three-dimensional CT angiography and anatomical dissection: a cadaveric study. Siriraj Med J. 2019;71(Suppl 1):S9-S13.
43. Ratanalekha R, Sangkamard K, Chongkolwatana W, Piyaman P, Predapramote P. Comparing orthodontic methylmethacrylate and polyurethane-based media in corrosion casting: for medical education. Siriraj Med J. 2019;71(Suppl 1):S14-S8.
44. Piyaman P, Patchanee K, Oonjitti T, Ratanalekha R, Yodrabum N. Surgical anatomy of vascularized submental lymph node flap: Sharing arterial supply of lymph nodes with the skin and topographic relationship with anterior belly of digastric muscle. J Surg Oncol. 2020;121(1):144-52.
45. Yodrabum N, Patchanee K, Oonjitti T, Piyaman P. Technical Challenges in "Micro" Lymph Node Identification during Vascularized Submental Lymph Node Flap Harvesting. Plast Reconstr Surg Glob Open. 2020;8(12):e3330-e.
46. Steinmann WF. Makroskopische Präparationsmethoden in der Medizin. Stuttgart, Germany: Thieme; 1982.
47. König HE, Probst A, Sora C, Dier H. Production of anatomical specimens for teaching practice in veterinary anatomy by means of polyethylene glycol (PEG) impregnation. a comparison with the method of plastination. Chilean J Agric Anim Sci. 2013;29: 59-64.
48. Ventola CL. Medical applications for 3D printing: current and projected uses. P T. 2014;39(10):704-11.
49. AbouHashem Y, Dayal M, Savanah S, Štrkalj G. The application of 3D printing in anatomy education. Med Educ Online. 2015; 20:29847.
50. Ye Z, Dun A, Jiang H, Nie C, Zhao S, Wang T, et al. The role of 3D printed models in the teaching of human anatomy: a systematic review and meta-analysis. BMC Med Educ. 2020; 20(1):335.
51. Srikong M, Wannapiroon P. Immersive technology for medical education: Technology enhance immersive learning experiences. Siriraj Med J. 2020;72(3):265-71.