Integrated education of gross anatomy and CT radiology for current advances in medicine

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Running Title

Anatomy-CT Integrated Education

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Abstract

It is essential to learn human anatomy in 3D for advanced medicine. We designed such an education system by integrating anatomy dissection with diagnostic CT radiology. Cadavers were scanned by CT, and students consulted the postmortem CT images while dissecting the cadaver to gain a better understanding of 3D human anatomy and diagnostic radiology. Students used handheld DICOM viewers at the bench-side (OsiriX on iPod touch). Students had lectures and workshops on diagnostic radiology, and study assignments where they discussed findings in anatomy labs in comparison with CT radiology. This teaching method for gross anatomy was used from 2009, and yielded positive students' perspectives, and significant improvements in radiology skills at clinical courses.

Keywords

CT, DICOM, anatomy, dissection, iOS, iPod touch, iPad, OsiriX

Abbreviations

- 3D = three Dimension(al)
- CT = (X-ray) Computer Tomography
- DICOM = Digital Imaging and Communications in Medicine
- MPR = Multiplannar Reconstruction
- MRI = Magnetic Resonance Imaging
- PACS = Picture Archiving and Communication System
- PET = Positron Emission Tomography

Introduction

In-depth knowledge regarding the 3D anatomy of human structures is crucial in advanced medicine with the rapid development of high-definition CT (Mayo Clinic, 2009), vascular catheterization (Tang et al., 2010), endoscopic or robot surgeries (Kaouk et al., 2009; Sugimoto et al., 2009; Irwin et al., 2010; Auyang et al., 2011; Kroh et al., 2011; Sodergren et al., 2011; Sugimoto et al., 2011; Volonté et al., 2012), fine-focused radiation oncology (Wowra et al., 2009; Alberti, 2011; Wowra et al., 2012), pre-operational 3D simulations (Fabian et al., 2008; Tang et al., 2008; Fang et al., 2010; Sugimoto et al., 2010a; Chen et al., 2012; Osawa, 2013), and 3D image-guided surgical operations (Sugimoto et al., 2010b; Volonté et al., 2011; Mazeron et al., 2013). Human gross anatomy courses with dissection labs provide the best possible opportunity for learning 3D anatomy, although this may not always be the case — traditionally, dissection progresses from the superficial to deep structures, viewed from a few planar views, such as frontal, dorsal, or lateral. Students often fail to appreciate arbitrary planes and structural relations in the course of such lab work. Dozens of trials have been described previously, where 3D models were incorporated into traditional dissections (Hisley et al., 2007; Petersson et al., 2009; Hopkins et al., 2011; Vuchkova et al., 2011; Brown et al., 2012), or radiology was integrated into anatomy education to various extents (McNiesh et al., 1983; Erkonen et al., 1990; Erkonen et al., 1992; Lanier and Kaude, 1993; Hisley et al., 2007; Petersson et al., 2009; Rengier et al., 2009; de Notaris et al., 2010; Lufler et al., 2010; Bohl et al., 2011; Cabrera et al., 2011; Griksaitis et al., 2012; Knobe et al., 2012; Kotzé et al., 2012; Machado et al., 2013). These studies indicated moderate to positive effects on student's perspectives or academic performance, although none provided methods to directly relate 3D CT to the cadavers.

Here, we report an education method for integration of CT radiology with cadaver dissections, which is referred to as “Anatomy-CT.” This was made possible fur to the use of a handheld device, iPod touch, with the inexpensive DICOM viewer software OsiriX (Rosset et al., 2004; Trelease and Rosset, 2008; Melissano et al., 2009; Choudhri and Radvany, 2010; Tam, 2010; Yamauchi et al., 2010). All cadavers were scanned with a CT scanner, and students used the device at the bench next to the cadaver to directly compare the postmortem CT and the cadaveric anatomy. This project was implemented and evaluated from 2009 to 2011.

Materials and Methods

Postmortem CT scanning

All cadavers were obtained by donation. Gunma University contracts with the prospective donors for use of their postmortem CT data for education. Cadavers with such contracts were scanned using Toshiba Asterion single-slice (Anatomy Classes of 2009 and 2010) or 4-slice (2010 and 2011) CT scanners (Toshiba, Tokyo, Japan) at the Postmortem Imaging Facility of Gunma University (Awata and Endo, 2009; Sano et al., 2011). Most cadavers were scanned within 1 day after death, but some were stored for up to 3 days at 4°C when the facility was not available.

Cadavers were scanned from the neck to the knee at a slice thickness of 5 mm (single-slice scanner) or 2 mm (4-slice) first without fixation. After the initial scan, cadavers were injected with Gastrografin (Bayer, Leverkusen, Germany) radioopaque solution diluted 1:20 in unbuffered 3.7% formaldehyde through the left radial artery, and scanned at a thickness of 5 mm (single-slice) or 1 mm (4-slice). The postmortem CT data were interpreted by the radiologists at Gunma University Hospital, and the radiology reports were provided to the students for their reference (discussed later).

Curriculum and laboratory setup

The curriculum at Gunma University School of Medicine includes one and a half years of arts and sciences, one and a half years of basic medical sciences, and 3 years of clinical medicine and clerkship (**TABLE 1**). The gross anatomy course is taught for second-year students during the second semester (the academic year consists of two semesters).

The gross anatomy course spans over 14 weeks, and consists of 6 hours of systems lectures (neural, motor, and cardiovascular systems), 7 hours of regional anatomy lectures, 3 hours of radiology lectures (**FIGURE 1D**), 10 hours of embryology lectures, 11 hours of osteology labs, and 162 hours of dissection labs (these numbers are for Anatomy Class 2011). Students learn dissection using the textbook “Laboratory Manual of Dissection” (Terada and Fujita, 2004) in teams of 4 persons (3 for surplus) (**FIGURE 1C**). The teams were made up by students in their own way. Students were also required to take a 2-hour DICOM viewer workshop using DICOM software on their own computers (**FIGURE 1E**). In the radiology lectures and workshop, students learn the Hounsfield units, sectional anatomy of the thorax and abdomen, pulmonary and hepatic segmental anatomy, DICOM operations (queries and retrieval), and 3D reconstructions. Class guides, notes, and PDF copies of handouts were distributed and archived at a weblog site <http://anatomy.med.gunma-u.ac.jp/> [1].

DICOM systems

Students were rented an iPod touch (one par person for Class of 2010 and 2011) (**FIGURE 1A**). For the Class of 2009, students were advised to use their own laptops for viewing CT images in the lab because we could not purchase iPod touches for the class. Apps installed on the iPod touch include OsiriX for iOS devices (iPhone, iPod touch, and iPad), GoodReader (PDF viewer), some reference apps, and utility apps. OsiriX was pre-loaded with CT data of the cadaver assigned to the team, and those of representative healthy living individuals of different ages and genders.

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[1] **Note for editors and reviewers:** This address is valid since late May, 2013. The former address is <http://anatomy.dept.med.gunma-u.ac.jp/>.

Two iMac computers running the Mac version of OsiriX with 64-bit extension (Pixmeo, Bernex, Switzerland) were loaded with all the cadaver scans as well as sample datasets of different modalities (CT, MRI, PET, ultrasonography, and X-ray). The students voluntarily used the iMac at the lab for MPR and 3D renderings (OsiriX for iOS lacks these capabilities) (**FIGURE 1B**).

Students were advised to install OsiriX on their own Macs for assignments (discussed below). Those with Windows computers were directed to use another freeware DICOM viewer, INTAGE Realia (Cybernet, Tokyo, Japan; the product has been discontinued) as an alternative to OsiriX despite its limited 2D and networking features. Students were provided with DVDs containing CT images in DICOM format of all the cadavers for the class, and of healthy living individuals.

All the DICOM datasets were archived on a PACS server, Apple Xserve with dcm4chee (dcm4chee.org, 2013) (open-source PACS software), for local queries and retrieval. The anatomy lab was equipped with an IEEE802.11b/g/n WiFi network for DICOM transfers. The 3D reconstructions for the lectures and the exams were made with OsiriX and HDVR plug-in (Fovia, Palo Alto, CA) on a Mac Pro with 2 × 6-core processors.

Assignments designed for integration of anatomy and CT

To facilitate integration of CT radiology to anatomy dissection, we gave the students study assignments of two short papers, one each for the thorax and the abdomen. The students were provided with the certificate of death, where the cause of death is summarized, and a radiology report of the cadaver's postmortem CT. Prior to actual dissection, they were advised to learn interpretations of the respective regions in the report, and to possibly add their own findings by examining the CT images for themselves. The findings may include effusions, inflammation, tumors, injuries, postoperative changes, artifactual materials, postmortem changes, personal differences, and "no significant pathologies." The students were instructed to verify such radiological interpretations on the actual cadaver during dissection consulting the cadaver's CT images on the iPod touches, lab iMacs, or their own laptops.

For each of the thoracic and abdominal regions, each student should compile a two-page paper of anatomical verifications of the radiological findings comparing CT images and sketches of the corresponding structures of the cadaver (photography in the lab was prohibited for students to avoid possible privacy problems). The aim of the paper was provisionally set to provide the radiologists who wrote the radiology reports with materials to self-evaluate their interpretations. This way, the students focused on their own observations and not simply on reproducing the radiology reports.

Exams

The anatomy course was divided into three periods, and an exam was given at the end of each period. The exam featured written tests (short essays and multiple-choice questions) and practical tests. The students were divided into two groups at random. Each group took either written or practical test in the first 90 minutes, and took the other test in a subsequent 90 minutes. For the practical tests, students were to move from one question station to another (50 stations per exam) at timed intervals (90 s) and write answers using anatomical terms on an answer sheet (**FIGURE 1F**). The questions were made from dissected cadavers, photographs of dissected cadavers, and images of different modalities (~10 of 50 stations), i.e., X-ray, ultrasonography, CT, and MRI (slices and 3D) (**FIGURE 2**).

Surveys and analyses

The exam scores of Anatomy Classes 2008 – 2011 were analyzed according to the types of questions (written tests, radiological questions in practical tests, and non-radiological questions in practical tests). Class 2008 was included as a pre-project control. In the second year, students take neuroanatomy, histology, general physiology, and neurophysiology as well as gross anatomy. The scores of these basic sciences were also analyzed to standardize yearly differences in students' academic abilities. Questionnaires of semantic differential scales were taken at the end of the anatomy course of Classes 2009 – 2011 to survey the students' perspectives on the Anatomy-CT project (**TABLE 2**).

In the fourth year, students take small-team (5 – 6 students), case-based learning of clinical medicine (Clinical Tutorials). To evaluate the effects of our Anatomy-CT project on the clinical classes, we surveyed the fourth (Anatomy Class 2009), fifth (2008, pre-project), and sixth (2007, pre-project) year students at the end of academic year 2011, asking self-evaluation of their abilities in diagnostic radiology at Clinical Tutorials (**TABLE 2**). Thus, for the fifth and sixth year students, the survey was retrospective back to 2010 and 2009, respectively. We also surveyed the tutors of the Clinical Tutorials for radiological abilities of Anatomy Class 2009 compared to those of 2008 (**TABLE 2**).

Statistical data were analyzed with Microsoft Excel and the Statcel3 add-in (Yanai, 2011).

The project was assessed at the end of each academic year by a committee consisting of five professors of Gunma University of basic and clinical medicine, and four independent anatomy and radiology professionals.

Results and Discussions

Participants to the study

The numbers of students enrolled in the Anatomy Class were 102, 101, 117, and 122 in the academic years 2008, 2009, 2010, and 2011, respectively (the changes in numbers were due to changes in complements and a few holdovers). In the Japanese educational system, high school graduates and prospective graduates are eligible to apply for medical schools, and no previous degrees are required, although Gunma University School of Medicine takes 15 students with previous experience for each class.

Assignments

Students used CT images on iPod touches at the bench and for the dissections and the assignments (**FIGURE 1C**). When they found issues — pathologies, anomalies, distinct anatomy, etc. — on the cadaver, CT, or radiology report, they tried to identify and discuss these on both the cadaver and the CT images (examples shown in **FIGURE 3**). The papers of assignments were compiled into a book as a reference for the radiologists who examined the postmortem CT images.

Some pitfalls were indicated in the reports. There were different degrees of postmortem or near-death changes in most cadavers, such as pulmonary edema, pleural effusion, ascites, hypostasis, and ectopic gas in the vessels. Many of these might be insignificant but tend to attract students' attention. Also, artifacts occurred in the process of fixation after the CT scan. This produces significant discrepancies between the CT images and the cadaver anatomy, which might distract students' interpretations. Pulmonary infiltration of fixative, for example, often overlays preexistent edema and pneumonia and makes it difficult to match pathologies in the cadaver and CT images.

Academic performance

There have been significant yearly decreases in academic performance since Anatomy Class 2008 not only in gross anatomy but also in other basic sciences, including neuroanatomy, histology, general physiology, and neurophysiology (**FIGURE 4A**). This trend causes issues in other medical schools in Japan, and was discussed at the Association of Japanese Medical Colleges (Association of Japanese Medical Colleges, 2012). Thus, to evaluate the effects of our Anatomy-CT project on academic performances in anatomy and radiology, the scores of gross anatomy were standardized by the average score of all basic sciences except gross anatomy. With such standardization, there were no significant yearly alterations since 2008 in the total scores of gross anatomy, and the sum of written tests and non-radiological questions of practical tests (**FIGURE 4B**).

In contrast to our expectations, there were no significant increases in the performances of the radiological questions on the practical tests (**FIGURE 4B**). This may be partly attributed to the exams themselves. The questions were mostly different every year, and radiological questions in Anatomy Class 2008 were rather simpler than those in Class 2009 – 2011. The questions in 2008 were basically identification of structures in CT slices and 3D reconstructions, while those in 2009 – 2011 required more advanced knowledge and skills in radiology, such as window level/width settings, segmental anatomy of the lung and the liver, and different radiology modalities (X-ray, ultrasonography, MRI, and CT).

To evaluate the state of integration of radiology to anatomy education, correlations were analyzed between scores of radiological and non-radiological questions of practical tests, and written tests (**TABLE 3**). Anatomy Class 2008 showed high correlations (R2 = 0.61) between written exams and non-radiological questions, but low to moderate correlations (0.24 and 0.41) between radiological and other types of questions. In contrast, Class 2009 showed high correlations (0.62 – 0.63) between radiological questions and other types of questions, suggesting that radiology was successfully integrated into traditional anatomical studies. Classes 2010 and 2011 also showed moderate to high correlations between radiological questions and other types of questions, although the values (0.38 – 0.67) were somewhat lower than those of Class 2009. This might be because of qualitative variations of students' abilities as mentioned above (**FIGURE 4A**).

Students' perspectives about the project

The surveys performed at the end of the anatomy classes showed very positive student perspectives regarding our project (**TABLE 2** and **FIGURE 5**). Anatomy Classes of 2010 and 2011 were combined for the summary here, although Class 2009 was omitted because iPod touches were not available for the class. About 70% of students thought that CT radiology was useful for better understanding of anatomy (**FIGURE 5A**), ~46% thought the iPod touch with OsiriX was useful for dissection (5B), and ~48% thought Anatomy-CT achieved its goal (**5C**). Although ~56% of students thought the CT software workshops were useful (**5D**), only ~14% gave positive self-evaluations about their proficiency in CT radiology (**5E**), suggesting some room for improvement in the workshops. There seemed to be some discrepancy between students' perspective and their actual usage of the iPod touch (**5B** and **F**). This might be because a team often shared the iPod touch of a spontaneous leader of discussions, and we had anatomy labs 2 – 4 days a week, which fit the choice of “weekly” in the questionnaire.

In summary, the concept of the Anatomy-CT project was well understood and appreciated by the students, although there is some room for further development to improve students’ radiological accomplishments, consistent with the academic performances discussed above.

The positive comments to the question for appreciations in Anatomy-CT in Classes 2009–2011 included:

- Good understanding of 3D structures of the human body.
- Early learning CT radiology.
- Early exposure to clinical medicine through radiology.
- Practical usage of CT data using DICOM viewers.
- Experience of problem-based learning through the assignments.

The negative responses included:

- The iPod touch screen is too small for CT viewing.
- Too few lectures and labs.
- Too few CT software workshops.
- Too little guidance regarding iPod touch usage.

By adjusting schedules and contents for lectures, workshops, and labs, negative comments on lectures and workshops disappeared by Class 2011. To address the screen issue, we introduced 10-inch iPads for Class 2012 for future evaluations.

Effects on clinical classes

In the academic year 2011, we conducted another survey to the fourth to sixth year students for effects of Anatomy-CT to clinical classes in the fourth year (**TABLE 2** and **FIGURE 6A**). The questionnaire asked the students' skills in CT radiology at their "Clinical Tutorials". The Clinical Tutorials are small-team, case-based learning of clinical medicine, where students are provided clinical cases often with radiological data. The fourth year students in 2011 were the first to take Anatomy-CT as Anatomy Class 2009.

The fourth year students gave significantly better self-estimation than the fifth or sixth year students (Anatomy Classes 2008 and 2007, respectively). Although the survey was retrospective for the fifth and the sixth year students, this suggested that Anatomy-CT improved radiology skills in clinical classes.

We also surveyed teachers ("tutors") of Clinical Tutorials in 2011, asking if there were any improvements in students' radiological skills compared to the previous year (**TABLE 2** and **FIGURE 6B**). Although three quarters of the responses were neutral or inconclusive, one quarter were positive and only a few were negative, again suggesting improvement of radiological skills of students who took Anatomy-CT.

Future Plans

The Anatomy-CT project concluded with very positive student perspectives. Although there were no immediate effects in academic performance in the gross anatomy classes, prospective improvements of radiology skills were indicated in clinical classes. As we had requests from the students for larger screens, we introduced the iPad, one per team, for Anatomy Class 2012 as the successor to the iPod touch. Preliminarily, we observed positive perspectives on the use of iPad (with requests for more iPads), increased discussions within teams using CT images on the iPad screen with decreased demands for the lab iMacs. We will continue the project with the iPad and assess the effects of the Anatomy-CT project. We hope our trials will contribute to fulfillment of anatomical and radiological education.

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Maki Sugimoto, M.D., Ph.D. is a professor of medicine at Kobe University. He is involved in projects of advanced medicine as 3D printing of human organ models and OsiriX-based surgical technologies, and has contributed to Anatomy-CT project.

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Hiroshi Yorifuji, M.D., Ph.D. is a professor of anatomy at GU since 2002. He is responsible to the general management of Anatomy-CT project.

Figures and Tables

TABLE 1 Outline of the curriculum of Gunma University School of Medicine.

	1st	2nd	3rd	4th	5th	6th
Arts and Sciences	✓	✓				
Basic Medicine		✓	✓			
Clinical Medicine				✓		
Clinical Clerkship					✓	✓

TABLE 2 Summary of the surveys.

Survey	Object	Year conducted	Recovery
Students' perspective on Anatomy-CT	2nd year	2009	87/101
		2010	115/117
		2011	119/122
Self-evaluation of radiology skills at "Clinical Tutorials"	4th year (Anatomy Class 2009)	2011	67/98
	5th year (Anatomy Class 2008)		94/97
	6th year (Anatomy Class 2007)		97/106
Tutors' perspective on students' radiology skills	Tutors of "Clinical Tutorials"	2011	90/190

TABLE 3 Correlations between different types of exams

Coefficient of determinations (R^2) are shown. >0.8: very high, 0.5 – 0.8: high, 0.25 – 0.5: moderate, <0.25: low.

Year	written – radiology	radiology – non-radiology	non-radiology – written
2008	0.24	0.41	0.61
2009	0.63	0.68	0.76
2010	0.43	0.67	0.67
2011	0.38	0.52	0.42

FIGURE 1 Scenes in Anatomy-CT.

A, iPod touch with OsiriX. **B**, iMac with OsiriX for MPR and 3D. **C**, Dissection with CT on iPod touch. **D**, Radiology lecture with the students practicing a lung segmental anatomy mnemonics. **E**, CT viewer workshop with the students practicing 3D renderings. **F**, A thread of radiology problems in a practical test.

FIGURE 2 **Examples of radiology questions used for the practical exams.**

A and **B**, Sectional CT anatomy of the abdomen and the thigh, respectively. **C** and **D**, 3D CT anatomy of the vessels of the heart and the lower extremities, respectively. **E**, X-ray angiography of the celiac artery. **F**, 3D MRI anatomy of the sinuses of the head. **A–C** and **E–F**, Rendered with OsiriX. **D**, Rendered with Fovia HDVR Plug-in and OsiriX. The original problem texts were in Japanese.

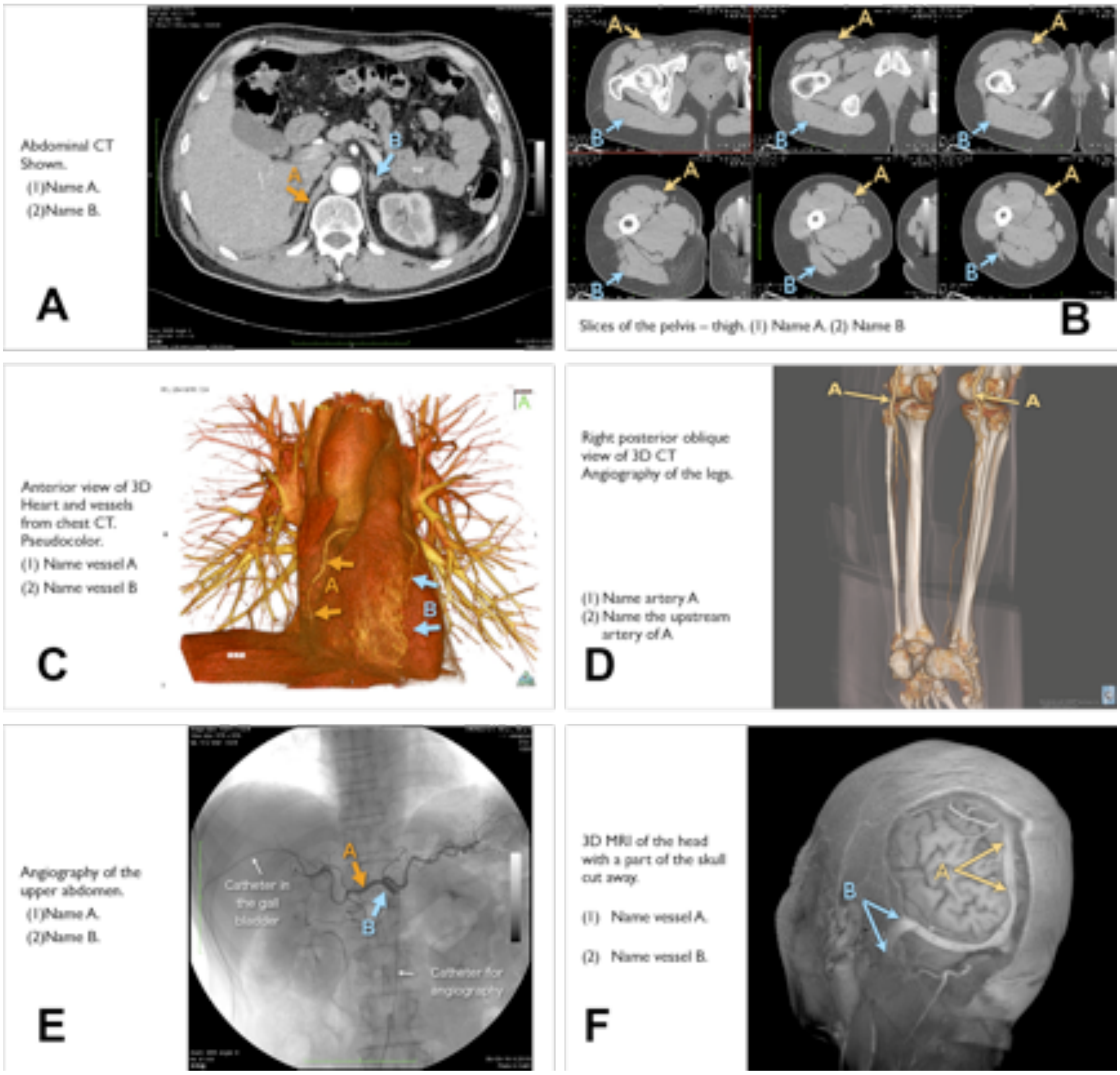


FIGURE 3 Figures from representative assignment papers of Anatomy-CT.

A, Coronal sections of the right lung. This particular individual had an anomaly lacking the oblique fissure of the right lung, so the student intended to show the bronchial tree homologous to those of normal individuals. **B**, Identification of renal pathologies on the cadaver (left) and the abdominal CT (right). The student intended to show renal cysts in his sketch of the dissected kidneys and the corresponding abdominal CT slices.

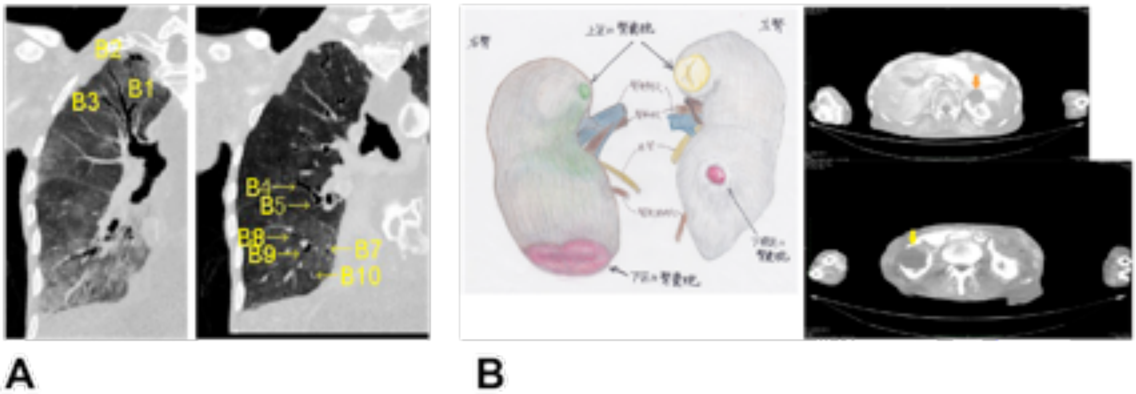


FIGURE 4 Trends of academic performance.

A, Average academic performances of basic medicine. 2008, pre-project year. 2009 – 2011, Anatomy-CT project years. Note the generalized decline of the performances. **B**, Average academic performances of the gross anatomy by types of tests. Adjusted by average scores of basic medicine excluding gross anatomy. There were no significant yearly changes of averages of total scores, written tests plus non-radiological questions, and radiological questions.

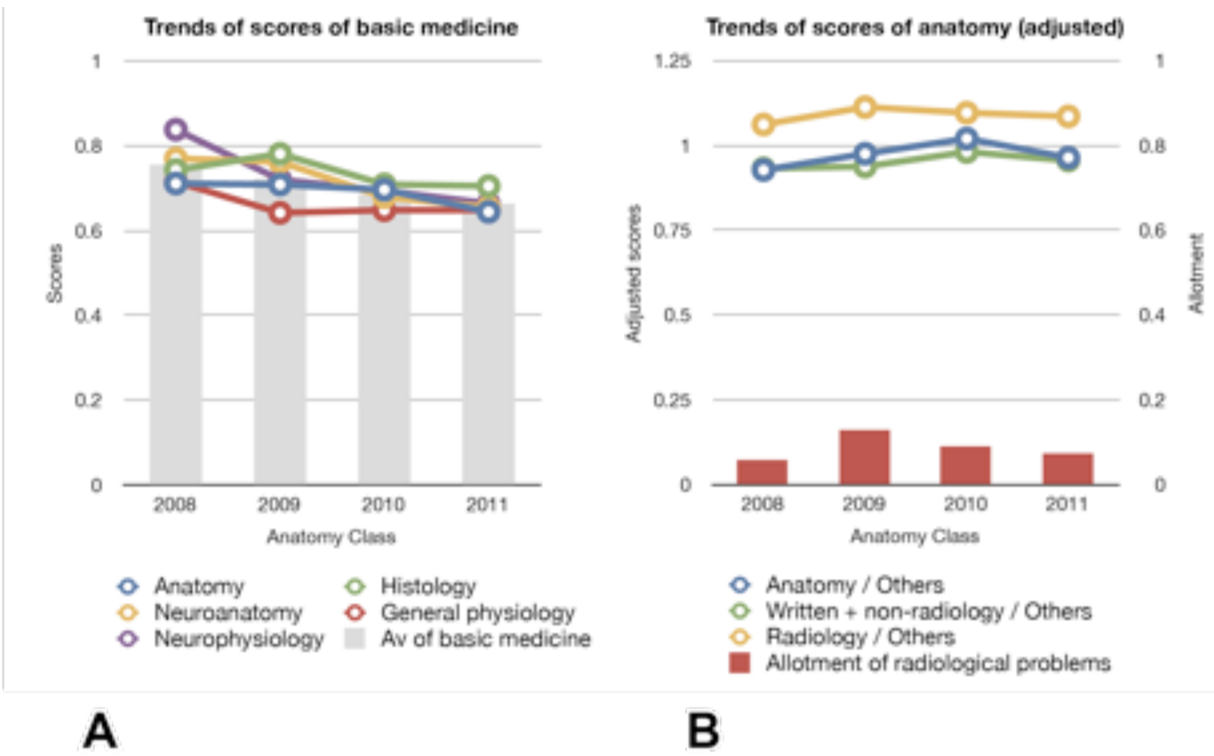


FIGURE 5 Students' perspectives to Anatomy-CT project.

Students were surveyed for their perspectives to Anatomy-CT. Anatomy Classes 2010 and 2011 combined. "th/abd", the dissection of the thorax and the abdomen.

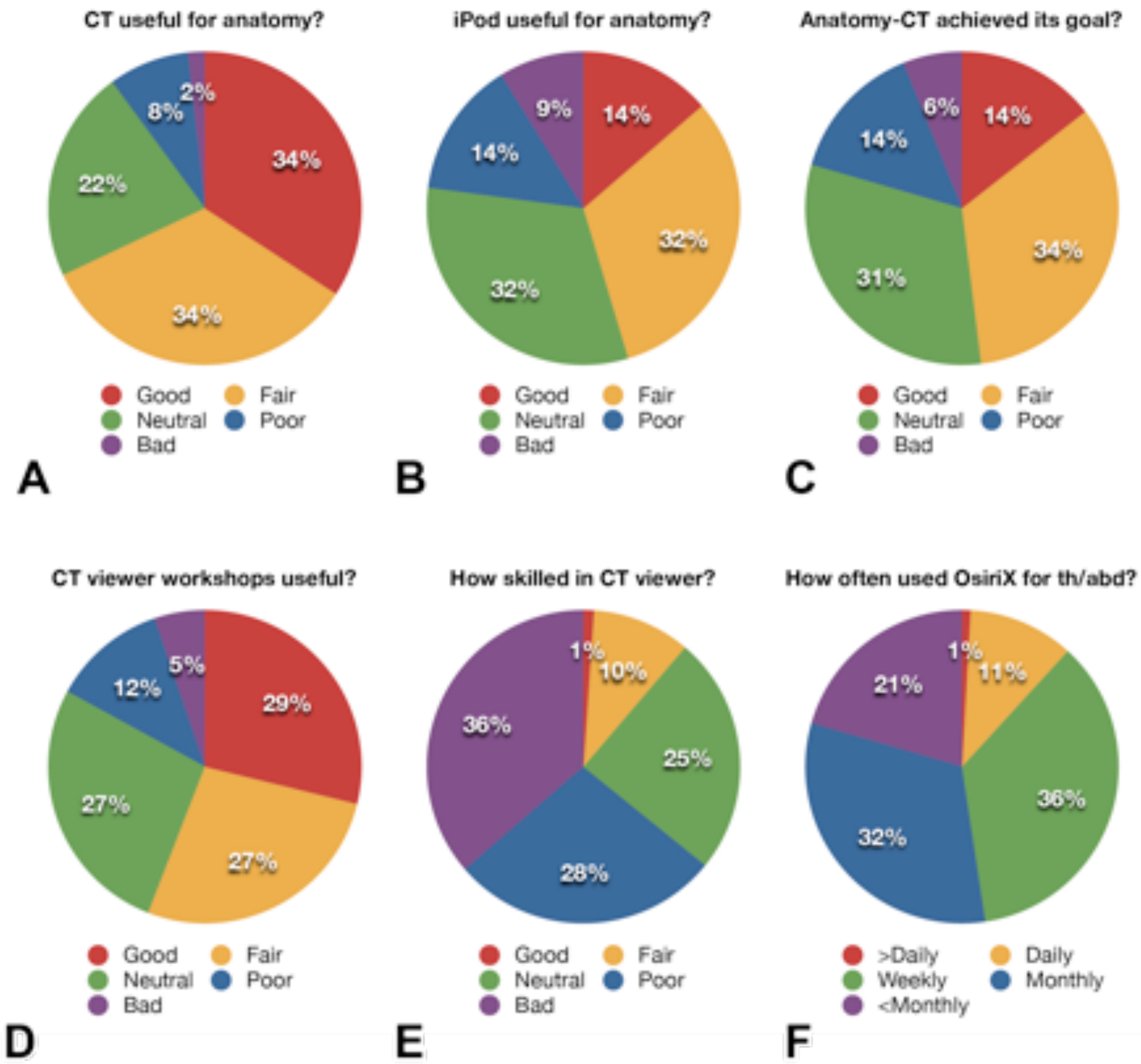
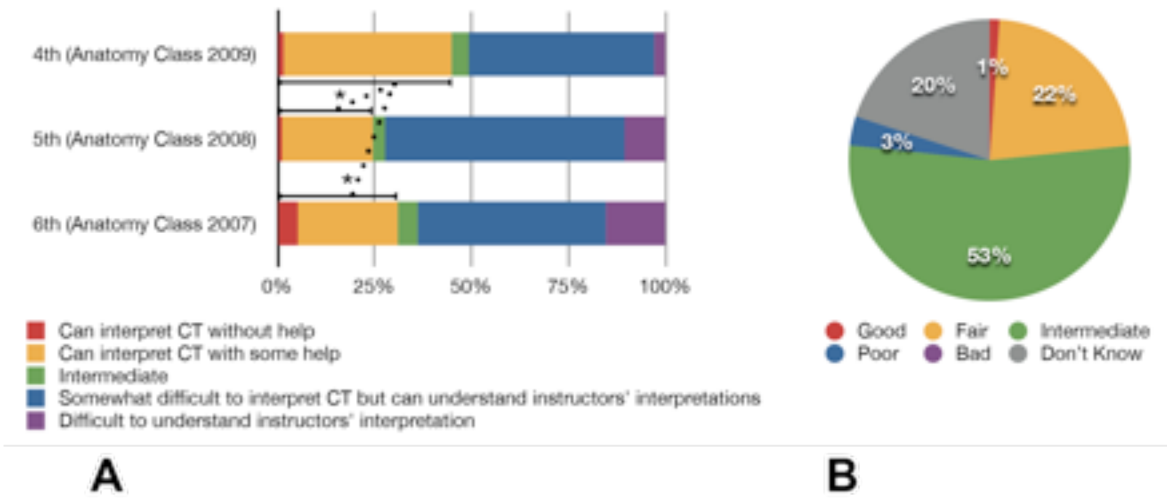


FIGURE 6 Effects on radiology skills at Clinical Tutorials.

A, The students' self-evaluations on their skills of radiological diagnosis at Clinical Tutorials. *, differences of combined numbers of "Good" and "Fair" were significant at p<0.05. **B**, The tutors' perspectives on improvements of the students' radiological skills at Clinical Tutorials compared to the previous year.



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