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## RADIOLOGICAL EDUCATION

# Cadaver-specific CT scans visualized at the dissection table combined with virtual dissection tables improve learning performance in general gross anatomy

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**Abstract**

*Objectives* The purpose of this study was to quantify the benefit of the incorporation of radiologic anatomy (RA), in terms of student training in RA seminars, cadaver CT scans and life-size virtual dissection tables on the learning success in general anatomy.

*Methods* Three groups of a total of 238 students were compared in a multiple choice general anatomy exam during first-year gross anatomy: (1) a group (year 2015, $n_1 = 50$) that received training in radiologic image interpretation (RA seminar) and additional access to cadaver CT scans (CT + seminar group); (2) a group (2011, $n_2 = 90$) that was trained in the RA seminar only (RA seminar group); (3) a group (2011, $n_3 = 98$) without any radiologic image interpretation training (conventional anatomy group). Furthermore, the students' perception of the new curriculum was assessed qualitatively through a survey.

*Results* The average test score of the CT + seminar group ($21.8 \pm 5.0$) was significantly higher when compared to both the RA seminar group ($18.3 \pm 5.0$) and the conventional anatomy group ($17.1 \pm 4.7$) ($p < 0.001$).

*Conclusions* The incorporation of cadaver CT scans and life-size virtual dissection tables significantly improved the performance of medical students in general gross anatomy. Medical imaging and virtual dissection should therefore be considered to be part of the standard curriculum of gross anatomy.

*Key Points*
- *Students provided with cadaver CT scans achieved 27 % higher scores in anatomy.*
- *Radiological education integrated into gross anatomy is highly appreciated by medical students.*
- *Simultaneous physical and virtual dissection provide unique conditions to study anatomy.*

## Introduction

Over the course of the last 30 years imaging technologies such as computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound have become an essential part in teaching human gross anatomy at many medical schools [1–6]. There is general agreement that students' interest in gross anatomy is stimulated by the incorporation of radiologic imaging modalities and that cross-sectional and three-dimensional (3-D) visualization improves the understanding of the spatial arrangement of anatomical structures and their sometimes complex neighbourhood relationships [1, 7–11]. Furthermore, radiology highlights the immediate relevance of anatomy with respect to clinical problems and stimulates greater interaction between the students and the faculty [12, 13].

The systematic implementation of cadaver CT scans and workstations in teaching human gross anatomy has

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been introduced in medical curricula at several universities [4, 6, 7, 12–17]. Performing cadaver CT scans allows students to correlate anatomical or pathological findings during the course of dissection with the corresponding appearance in the radiologic image. Furthermore, the computer visualization can be used to plan subsequent dissection steps or to recapitulate previously performed dissections. Although there is general consensus that radiologic imaging data derived from cadaver CT scans is useful for teaching anatomy, quantitative evaluations of its contribution to the learning success are rare and contradictory. Lufler et al. showed that students who were provided with cadaver CT scans achieved significantly better results in the final course grade and on spatial anatomy examination questions [13]. In contrast, Murakami et al. reported no improvement but an insignificant worsening in academic performance (gross anatomy and radiology) after the introduction of an integrated teaching method with cadaver CT scans [14]. Furthermore, Hisley et al. found no significant differences between the test scores of two student cohorts, one that was trained through physical dissection and another that was trained through virtual dissection [16].

The purpose of this study was to quantitatively investigate the contribution of a curriculum extended by cadaver CT scans and virtual dissection to the success of learning general human gross anatomy. In addition to the visualization of cadaver CT scans on computers installed next to the dissection tables, we established three life-size virtual dissection tables at the Institute of Anatomy and Cell Biology that provided a unique environment for studying anatomy by physical and virtual dissection.

We hypothesized that the incorporation of radiologic imaging modalities in terms of cadaver-specific CT scans and life-size virtual dissection tables into the anatomical curriculum improves the learning performance of first-year medical students in general anatomy.

## Materials and methods

### Heidelberg Curriculum Medicinale (HeiCuMed) of gross anatomy

The curriculum established at Heidelberg Medical School requires students to pass the anatomy course during the first semester. The course consists of 191.5 contact hours, with 94.5 h allocated to lecture time (63 days, 90 min each lecture), 78 h allocated to physical dissection (26 days, 180 min each appointment including continuous access to visualization of cadaver-specific CT data on computer workstations mounted next to the dissection tables), 9 h allocated to the RA seminar (six appointments, 90 min each) and 10 h allocated to special training at the life-size virtual dissection table (10

appointments, 1 h each). The new elements of the curriculum are described in more detail below.

### Radiologic anatomy (RA) seminar

In 2007, the Institute of Anatomy and Cell Biology and the Clinic of Radiology established an elective seminar called "Virtuelle Anatomie" (Engl. virtual anatomy). The principal motivation behind this course was to introduce clinically related work with x-ray images, CT data sets and plastinated anatomical cross-sections in parallel with the gross anatomy course. The main learning objective of the RA seminar is to enable students to identify anatomical structures on standard radiologic imaging modalities and plastinated anatomical cross-sections. Moreover, CT and x-ray images of illustrative common pathologies are demonstrated, yielding a distinction of normal anatomy from pathologic processes by the students. The seminar can accommodate 120 out of the approximately 400 students in parallel to the gross anatomy course. The participants receive assistance in six 90-min teaching modules by tutors and teachers of the Anatomy and Radiology Departments. Students can navigate by themselves through the data sets using the 3-D image post-processing software AnatomyMap, specifically designed for classroom work with an emphasis on user-friendly operation and powerful 3-D rendering capabilities (developed by Dr.-Ing. R. Unterhinninghofen, Institute of Anthropomatics, Karlsruhe Institute of Technology, Karlsruhe, Germany). AnatomyMap was also reported by Rengier et al. in a previous publication describing its use [18].

### Life-size virtual dissection tables

In 2013 the virtual anatomy teaching was extended by three life-size virtual dissection tables, fitted with an interactive touch display (Anatomage Table, Anatomage Inc., San Jose, Ca, USA). The overall dimensions of the tables are 86" × 28" × 33" (2.2 m × 0.7 m × 0.8 m) with a display surface measuring 82" × 23.8" (2.1 m × 0.6 m). The system offers preinstalled CT data sets of normal anatomy and about 120 illustrative pathology cases. Furthermore, a high-resolution atlas of regional CT anatomy, MRI scans of the head, and whole body cross-sections of fresh frozen cadaver specimens are provided. These data sets can be visualized as cross-sections in all planes, as well as 3-D reconstructions at any possible angle. According to the structure of the gross anatomy course, the Anatomage teaching units were subdivided into the categories extremities, thorax, abdomen and head & neck. The selected cases are focused on subjects that especially benefit from the 3-D-visualiziation and the possibility to illustrate perspectives that are not feasible in the course of manual dissection.

## Virtual and practical dissection combined at the dissection table and CT workstation
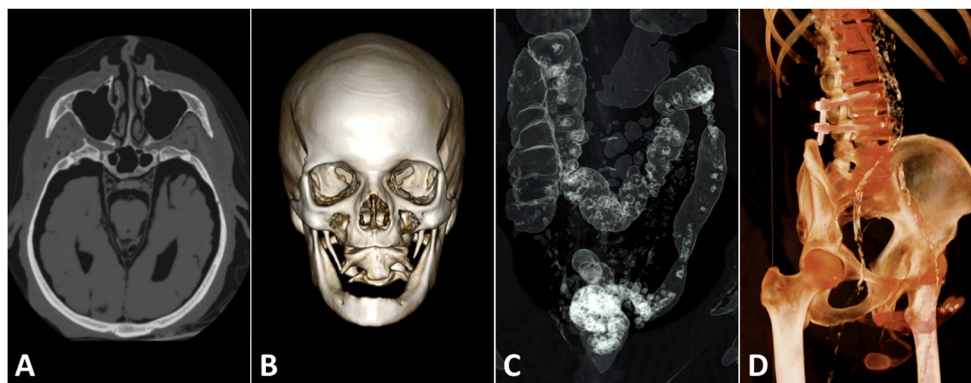
Whole body cadaver CT scans were performed on an institution-owned Toshiba 16 line CT scanner. The scans were acquired in the axial projection at 1-mm slice thickness with coronal and sagittal reconstructions. During the winter semester 2014/2015, we provided CT data sets of all 21 cadavers dissected in the gross anatomy laboratory. Hence, for every cadaver the specific CT data set was available on a CT workstation next to the dissection tables running AnatomyMap (Fig. 1a, b) and on the life-size virtual dissection tables (Fig. 1c, d). In total 21 Intel i/-4770 3.4–3.9 GHz computers equipped with a 27" Samsung flat screen (resolution 1920 × 1080 pixels) were installed in the preparation hall, one workstation per dissection table. The leading idea for this interactive approach is that students will haptically explore the anatomical regions while visualizing the corresponding spatial planes or 3-D reconstructions. The main learning objective of the introduction of cadaver-specific CT scans is to link anatomical knowledge, acquired in the course of physical dissection, with corresponding conventional radiologic 2-D and 3-D visualizations. Hence, this approach should prepare students for transferring their knowledge as future physicians to radiologic images as encountered in daily clinical practice. Furthermore, the additional imaging modality should improve the quality of physical dissection since students are enabled to perform targeted preparation with extended prior knowledge. The morphology of a new dissection area is virtually inspected in advance of the preparation, thereby allowing students to develop an idea of what kind of findings to expect, analogously to a surgeon who prepares an operation by studying imaging data of the patient. This approach enables the identification of conditions and pathological changes, such as diseases of the skeletal system (e.g. old fractures, prosthesis or osteophytes), status of the teeth, arteriosclerosis, stroke, pacemakers, stents, cancer, enlarged ventricles and atrophy or hyperplasia of organs.

## Quantitative analysis

### Design of the anatomy exam used to test performance in general anatomy

The HeiCuMed course of gross anatomy was evaluated quantitatively through a multiple choice general anatomy exam. All participants took a test of 40 highly discriminating questions, comprising of 10 questions each on head & neck, abdomen, thorax and extremities. The test was designed by S. Doll in the course of her bachelor thesis to assess possible learning benefits on general gross anatomy of students participating in the RA seminar [19]. The questions were derived from the 10 % most difficult questions of the National Medical Board Examinations between 2005 and 2010. Since the most difficult questions were selected, the average score of the students in this study appears low. The questions were intentionally selected to test general anatomical knowledge, avoiding image-based queries that could be answered just by visual graphic memory. The test duration was 30 min. The test was conducted in the course of quality assurance and quality improvement (QA/QI) measures performed to assess possible learning improvement effects of the described curriculum changes in the first-year of gross anatomy. The intention of this investigation was to quantitatively assess the effects associated with cadaver-specific CT imaging used in teaching general anatomy.



**Fig. 1** Non-enhanced cadaver-specific CT scans visualized on AnatomyMap and the virtual dissection table. All cadaver CT scans were performed on an institution-owned CT scanner and visualized using AnatomyMap (**a**, **b**) or the virtual dissection Anatomage Table (**c**, **d**) (Anatomage Inc., San Jose, Ca, USA). **a** Axial CT scan on bone window through the level of the maxillary sinuses. Trapped air displays as hypodense spots in soft tissue as typically seen on post-mortem CTs. **b** 3-D volume reconstruction of the skull in hard tissue volume rendering. **c** Transparent soft tissue rendering of the whole colon. Post-mortem rotting processes with consecutive gas formation in the gastrointestinal tract allow its visualization and reveal diverticulosis of the colon. **d** Transparent hard tissue rendering of a non-enhanced cadaver showing a lumbar spinal osteosynthesis, significant arteriosclerosis and a penis prosthesis

*Student cohorts*

The group of the course year 2014/2015 had access to CT workstations, virtual dissection tables and additional training in the RA seminar, taught by clinical radiologists (CT + seminar group, $n_1 = 50$). These students were provided with the specific CT scan of the cadaver they were assigned to. The results from this group were compared to two groups of students of the course year 2010/2011: one group with additional training in the RA seminar during the course of gross anatomy (RA seminar group, $n_2 = 90$) and a group without any radiologic image interpretation training (conventional anatomy group, $n_3 = 98$).

*Statistics*

An analysis of variance (ANOVA) was performed with post hoc Holm–Bonferroni multiple comparisons among the three groups for the total test result and for all subcategories (head & neck, abdomen, thorax and extremities). The statistical evaluations were carried out with SigmaPlot version 12.5 (SystatSoftware, Inc., San Jose California USA). For all statistical analyses the level of significance was set at $p < 0.05$.

**Qualitative analysis**

To assess the students' perspective on the new curriculum, a 12-item questionnaire was answered by the CT + seminar group. Each question had to be answered on a Likert scale with five items: 1 = full disagreement, 2 = partial disagreement, 3 = neutral/indifference, 4 = partial agreement, 5 = full agreement. Overall agreement (OA) was calculated for each question, defined as the sum of full and partial agreements divided by the number of students who answered the questionnaire. Furthermore, the median response was calculated for each question.

**Results**

**Quantitative analysis**

In the general anatomy exam the CT + seminar group achieved an average test score of $21.8 \pm 5.0$ compared to $17.1 \pm 4.7$ by the conventional anatomy group and $18.3 \pm 5.0$ by the RA seminar group (Fig. 2a). The differences between the CT + seminar group and the two other groups were statistically highly significant ($p < 0.001$). In total, the CT + seminar group achieved a relative improvement of 27.3 % and an absolute improvement of 11.7 % compared to the conventional anatomy group. In comparison to the RA seminar group a relative improvement of 19.2 % and an absolute improvement of 8.8 % was determined. The differences between the RA

seminar group and the conventional anatomy group were small (relative test result improvement of 6.8 % and absolute improvement of 2.9 %) but statistically significant ($p = 0.045$).

The CT + seminar group showed highly significant improvements compared to the other two groups in the topics head & neck ($p < 0.001$) and extremities ($p < 0.001$, $p = 0.002$) (Fig. 2b, e). In the category of thorax small but significant differences were detectable between the students of the CT + seminar and the conventional anatomy group ($p = 0.022$) and no significant differences were observed between the CT + seminar and the RA seminar group (Fig. 2d). Furthermore, insignificant differences were observed in the category of abdomen among all groups (Fig. 2c). Significant differences between the RA seminar and the conventional anatomy group were only found in the category of thorax ($p = 0.025$) (Fig. 2d).

**Qualitative analysis**

According to the evaluation of the questionnaire (Fig. 3), 87.8 % of the students agreed that teaching with radiologic imaging modalities was a good supplement to first-year gross anatomy. A high proportion (89.8 %) of the responders were able to recognize anatomical structures on the imaging data. A large majority of 85.4 % stated that it was sensible to learn how to read CT scans at the beginning of their medical studies. Even though 67.4 % of the students agreed that the new course design contributed to a better understanding of anatomical facts, only 26.5 % stated that the course made a contribution to their success in the gross anatomy exams. Moreover, 79.6 % of all RA seminar participants would highly recommend additionally attending this seminar. Among the different imaging modalities students mostly benefited from studying CT scans. A large proportion of the students also benefited from learning with conventional x-ray images. Studying with anatomical cross-sectional photographs and 3-D CT reconstructions were evaluated as less beneficial.

**Discussion**

The study showed that the incorporation of cadaver CT scans and virtual dissection tables in the course of gross anatomy resulted in a significant improvement of first-year medical students' learning success as probed by a general gross anatomy exam.

In 2007, the RA seminar was introduced as an elective radiologic imaging module to accompany the gross anatomy course during the first semester. Rengier et al. reported that the RA seminar is well liked by participating students and that they feel more confident regarding their anatomical and radiologic knowledge [20]. This is in agreement with a small, but significantly increased, overall score of the RA seminar group

**Fig. 2 a** Quantitative results from written anatomy exams in 2011 and 2015. The CT + seminar group (course year 2015) achieved significantly higher scores than the conventional anatomy group (course year 2011, no training with radiologic imaging modalities) and the seminar group (course year 2011, training in six 90-min sessions with conventional CT scans and x-rays). The total teaching contact times were equivalent for all groups. Significant differences between the groups are indicated as *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$. The general anatomy exam included 40 multiple choice questions. The results for every subtopic (**b** head and neck, **c** abdomen, **d** thorax and **e** extremities) are additionally illustrated
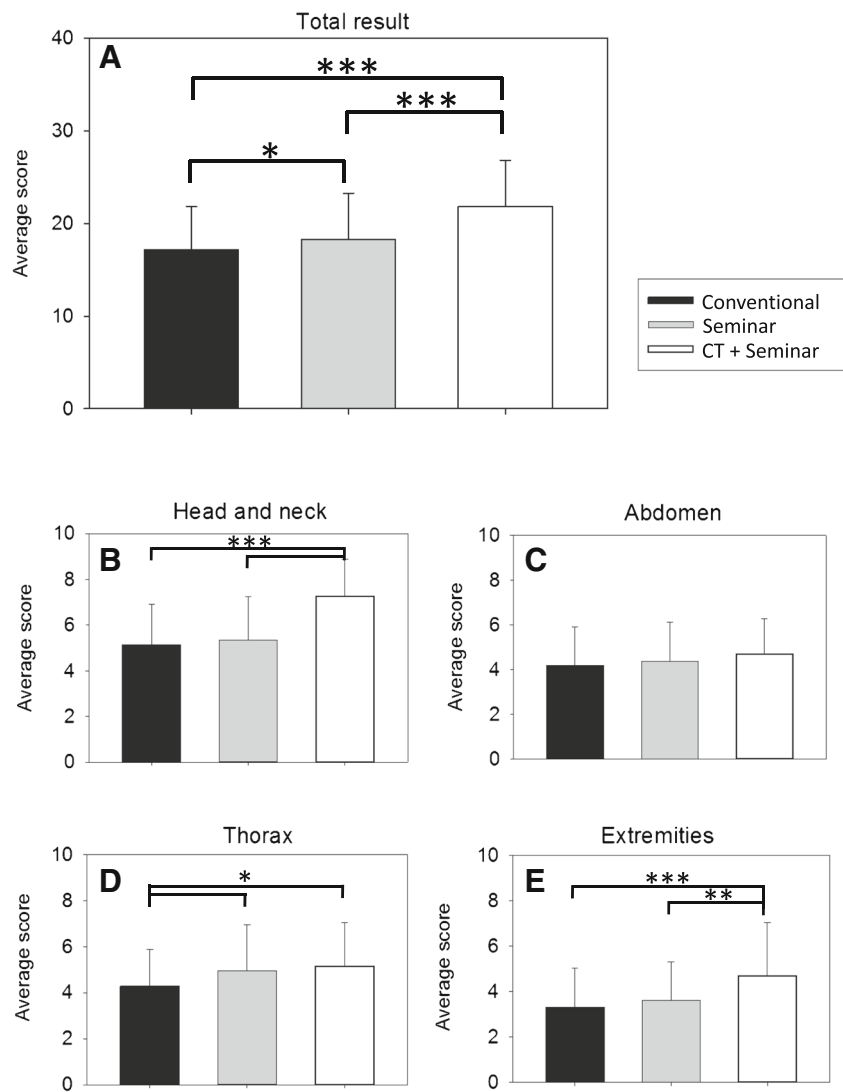


(2011) compared to the conventional anatomy group (2011) in the general anatomy exam [19]. However, the improvement of the CT + seminar group (2015) undergoing the new curriculum is statistically highly significant compared to both the conventional anatomy and the RA seminar group from 2011. The most relevant increases were observed for the subcategories head & neck and extremities. An explanation for the pronounced improvement in the subcategory head & neck might be that intra- and extracranial anatomical structures are complex and small and therefore profit from the virtual dissection. During the extremities teaching units, students were trained to identify muscles in CT cross-sections and to trace arteries from proximal down to distal parts which is only possible to a limited extend in the dissected cadaver.

Interestingly, Rizzolo et al. found that students who participated in a Clinically Engaged Anatomy course (C-EA) (including teaching in radiologic cases centred on specific surgical operations and clinical procedures) performed significantly better in a 49-question anatomy exam in the subcategories head & neck and abdomen [21, 22].

Our results indicated only small or insignificant improvements in the subcategories thorax and abdomen. This might be because intrathoracic and intra-abdominal organs display very differently on cadaver CT scans compared to clinical CT scans as a result of the process of decomposition. This effect is clearly less pronounced in the extremities and the head. Slon et al. collected CT scans from local clinics and hospitals taken while the body donors were still alive [7]. This is a clever approach to avoid the problems associated with cadaver CT scans but imposes organizational challenges.

Regarding the conception of an integrated course design, Lufler et al. found no difference in performance between students who dissected the scanned cadavers and those who dissected a different cadaver [13]. Consequently, it would not be necessary to scan every cadaver but to use only one representative data set, implying a high potential for cost and time

**Fig. 3** Qualitative analysis of the incorporation of radiologic anatomy into preclinical gross anatomy 2015. Questions 1–12 were answered by $n = 49/50$ students from the CT + seminar group who received training both in the RA seminar and on CT workstations. The overall agreement (OA) was defined as fraction of all full (5) and partial (4) agreements divided by the number of all participating students. The median is additionally shown. The *bar graph* displays the mean value for each question over all students. The *error bars* indicate the positive and negative standard deviation
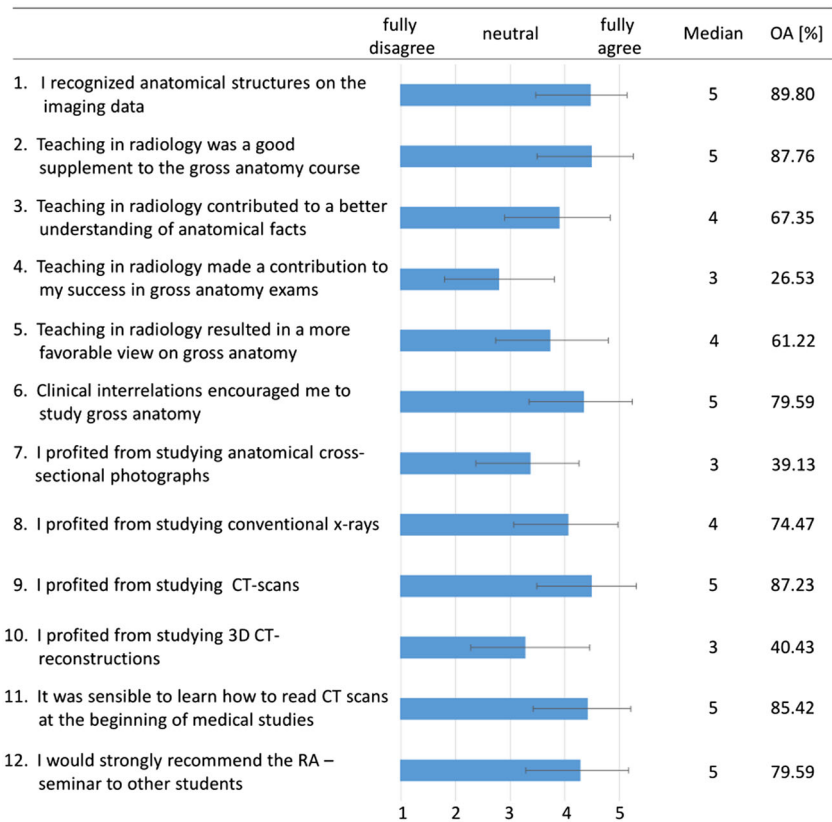


savings. Bohl et al. showed that the learning process is enhanced if students can navigate by themselves through CT data sets [12] which emphasizes the importance of the implementation of (CT) workstations with radiologic imaging software.

The introduction of radiologic imaging modalities was evaluated as a good supplement to gross anatomy lectures and physical dissection by the students. Furthermore, students affirmed that it was sensible to introduce radiologic imaging techniques at the beginning of medical studies. This is supported by subjective accounts such as "The medical student perspective" on cadaver CT scans by Nwachukwu [23].

Even though most students agreed that teaching in radiology resulted in a more favourable view on gross anatomy and contributed to a better understanding of anatomical facts, only a minority group stated that the course made a contribution to their success in the gross anatomy exams. This perception might be due to the specific nature of the anatomy exams during the first semester at our faculty: the students have to pass oral exams taken by docents at the dissection table. Regarding this point the outcome might be different if the exams in gross anatomy also included multiple choice, image-related questions. However, besides the real learning effect resulting from additional imaging modalities, increased motivation to study anatomy using radiologic data sets and

visualization systems might be an important contributor to the improved performance.

The majority of students considered CT the most valuable imaging technique for learning anatomy. Furthermore, students benefited more from conventional x-ray images, rather than from 3-D reconstructions and anatomical cross-sectional photographs. This result was not expected but could be explained by the fact that students primarily used conventional x-ray images to prepare the first exam "osteology" in the course of gross anatomy. Moreover, the CT scans acquired at our institution were performed without the administration of contrast media. Consequently, high-quality 3-D visualizations of the cardiovascular system were not possible for the cadaver-specific CT scans, therefore posing a significant limitation to the benefit of 3-D reconstructions in our study. Anatomical cross-sections were less popular, since structures are more difficult to identify because of displacements or deformations of different organs in the course of fixation. The clinical interrelations were highly appreciated. In this light, a more clinically focused anatomy curriculum, as presented by Rizzolo et al. [22], is to be discussed and investigated in further studies.

The dissection of cadavers has been a key point of teaching anatomy since the Renaissance [24]. However, especially among European schools, there is a general trend towards a reduction of hours devoted to cadaveric-based teaching, with

some schools removing it entirely [4, 8, 25–27]. There are divergent opinions on this development both among anatomists and clinicians. Some are concerned that this trend poses a significant risk of inadequate anatomical knowledge and subsequently to patients' health in all medical disciplines [28, 29]. Recently, Sheikh et al. asked surgeons to assess the value of different methods used for teaching anatomy. A majority of 65 % considered "cadaver/prosection demonstration" as the best method which should be increased in anatomy education [28]. However, in contrast, McLachlan et al. reported on teaching anatomy without the use of cadavers [8]. They stated that most clinicians encounter anatomy through radiologic images or surface anatomy and that students should therefore be trained in this context right from the beginning [30]. Even though the true impact of dissecting cadavers remains hard to quantify, a vast majority of publications on this subject strongly recommend the use of physical dissection.

There are some limitations to this study: (1) The CT + seminar group of the course year 2014/15 was compared to student cohorts from 2010/11. However, the non-radiology-related teaching elements were not changed in the new curriculum which is an important condition that is fulfilled. (2) The assignment of the students to the RA seminar was not randomized but based on a first come, first served principle (2010/11 and 2014/15). Since we compared the CT + seminar group both to students that participated in the RA seminar and to a conventional anatomy group without any radiologic image interpretation training, possible confounding effects are likely to be negligible. (3) The number of questions in the general anatomy exam is relatively low and may therefore limit the interpretation of the influence of anatomical subcategories. Nevertheless, statistically meaningful differences could be detected between the categories head & neck, thorax, abdomen and extremities. (4) The specific cadaver CT scans varied in quality due to different body constitutions and due to artefacts resulting from metal implants. In such situations the best CT data set acquired over the years could serve as a reference data set, supported by the results of Lufler et al. [13]. (5) The costs of a systematic implementation of cadaver-specific CT scans and CT visualization systems is a limitation to large-scale realizations at many universities. However, there are various opportunities to reduce operational costs, for instance through the acquisition of post-mortem CT scans in the radiology department in time slots with low patient frequency and data visualization on conventional computers using free software solutions.

## Conclusion

The traditional approach of gross anatomy teaching has been around for several centuries. We firmly believe that physical dissection of the cadaver cannot be fully substituted by virtual tools. In our opinion radiological imaging should be regarded as a perfect complement to the cadaver dissection rather than a substitute. The interactive approach is particularly powerful to reveal structures that cannot easily be seen in their topographical arrangement. Our results indicate that learning gross anatomy can be improved significantly by systematically implementing interactive virtual anatomy approaches. Moreover, these approaches anticipate clinical cases and facilitate a smooth transition into the clinical work. The early contact with clinically relevant challenges is exceptionally fascinating for all students. In summary, we are convinced that the newly introduced approach will strongly improve the ability of the students to develop their personal detailed 3-D representation of gross anatomy and to apply this towards the interpretation of radiological image data.

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