

RESEARCH ARTICLE

Alarming decline in recognition of anatomical structures amongst medical students and physicians[☆]

Mateusz K. Hołda^{a,*}, Tomasz Stefura^b, Mateusz Koziej^a, Oksana Skomarovska^b, Katarzyna A. Jasińska^b, Wojciech Sałabun^c, Wiesława Klimek-Piotrowska^a

^a Department of Anatomy, Jagiellonian University Medical College, Kraków, Poland

^b Faculty of Medicine, Jagiellonian University Medical College, Kraków, Poland

^c Department of Artificial Intelligence Method and Applied Mathematics in the Faculty of Computer Science and Information Technology, West Pomeranian University of Technology, Szczecin, Poland

ARTICLE INFO

Article history:

Received 21 May 2018

Received in revised form

10 September 2018

Accepted 12 September 2018

Keywords:

Gross anatomy education

Medical education

Undergraduate education

Surgical anatomy

Clinical anatomy

Cadaver dissection

ABSTRACT

Background: Insufficient anatomical training can put patients' safety at risk. The aim of this study was to assess the proficiency of medical students and physicians in identifying labeled anatomical structures. The second aim of the study was to evaluate factors that can affect this recognition.

Methods: An internet-based survey where participants had to correctly identify labeled anatomical structures on cadaveric specimens was designed.

Results: The study group included 1186 participants (58.7% females): 931 medical students and 255 medical graduates from all twelve Polish medical schools. The mean total survey score for the entire study group was 65.6%. Students gained significantly higher results than graduates (total: 67.3% vs. 59.5%, $P < 0.001$); 331 (27.9%) participants did not pass the test (< 60). There was a correlation observed between points gained in this survey and grade obtained in the gross anatomy course ($P < 0.001$). Multivariable logistic regression found that participation in cadaver laboratory classes most strongly increases anatomical competencies (OR = 5.30, 95%CI = 1.20–23.40, $P = 0.03$). Other significant factors boosting anatomical proficiency were membership in students' scientific clubs, being male, and having a high grade ($\geq 80\%$) in initial gross anatomy course. The time since anatomy course completion was negatively correlated with the total survey score (OR = 0.86, 95%CI = 0.81–0.92, $P < 0.001$).

Conclusions: Anatomical knowledge of Polish medical students is moderate ($< 70\%$) and it significantly decreases with time. Anatomical structure recognition can be up to 25% lower in highly trained physicians when compared to pre-clinical medical students. This trend may be reversed by replacing subject-based anatomy courses with system-based (integrated) curricula at the undergraduate level or introducing short refresher anatomical courses during postgraduate training.

© 2018 Elsevier GmbH. All rights reserved.

1. Introduction

Medical students and practitioners consider gross anatomy as one of the most important courses during medical school (Orsbon et al., 2014; Turney, 2007; Vorstenbosch et al., 2016). Despite such declarations, their knowledge and ability to recognize major anatomical structures is far from impressive (Dickson et al., 2009; Savran et al., 2015). This is quite alarming, since detailed knowledge of human anatomy is not only a prerequisite for surgical,

interventional (e.g. interventional cardiologists and neurologists), and radiological specialists, but it is also essential for most internal medicine practitioners (Orsbon et al., 2014). An inadequate knowledge of the particular anatomical structure can affect future understanding of its function or dysfunction (Yammine, 2014). The inability to properly identify anatomical structures is a serious handicap, and insufficient anatomical training may put patients safety at risk (Ates et al., 2016; Dickson et al., 2009; Dixon et al., 2018; Harrison and Hilmi, 2014).

Currently, there is debate amongst anatomists and academics about whether medical students and physicians possess an adequate working repertoire of anatomical structures (Bergman et al., 2011). Some evidence suggests anatomical knowledge among medical professionals has declined in recent years and may in fact be

[☆] This paper belongs to the special issue Medical Education 2018.

* Corresponding author at: Department of Anatomy, Jagiellonian University Medical College, ul. Kopernika 12, 31-034 Kraków, Poland.
E-mail address: mkh@onet.eu (M.K. Hołda).

insufficient, which could lead to an increased amount of medical errors. A very exhaustive gross anatomy curriculum, reductions in teaching hours and a proven loss of basic anatomical knowledge as a function of time may all be responsible for this phenomenon (Bergman et al., 2011; Doornik et al., 2017; Yammine, 2014). Moreover, other factors such as nonmedically qualified anatomy instructors, absence of a core anatomy curriculum, decreased use of dissection as a teaching tool, lack of clinical relevance and the use of inadequate assessment tools also seem to negatively influence anatomical acquisition and retention (Bergman et al., 2014).

In order to become familiar with human anatomy, medical students need to be exposed to several teaching techniques. To help reinforce the studied material, a healthy mix of theory, pictorial representations and cadaveric dissections is required. Conveying this course via a multiple representation approach is supported by the Cognitive Theory of Multimedia Learning, which postulates that learners process information through separate auditory-verbal and visual-pictorial channels (Holland et al., 2015). Moreover, the use of images, text, and cadaveric classes has been shown to enhance the development of spatial abilities, further helping students visualize and understand the human body (Nguyen et al., 2012). Team-based learning methods, adequate learning resources, small groups of students, qualified instructors, use of multiple good-quality cadavers and dissection images along with frequent formative and summative assessments have also been shown to boost anatomical knowledge acquisition (Burgess et al., 2012).

Research shows that students prefer their anatomical knowledge tested via practical assessments (identifying tagged structures) (Rowland et al., 2011). Up until now, no large study evaluating the proficiency in recognizing anatomical structures between medical students and physicians at different stages of their careers has been conducted. Previous studies assessing anatomical knowledge focused on small groups of participants (no more than 150) and compared subjects with similar levels of medical education or medical practice (Ikah et al., 2015; Meyer et al., 2016).

Polish medical undergraduate studies last six years with the required entry level being an attainment of a high-school diploma. The medical education is divided into two phases: pre-clinical (first to third year of study) which covers basic science courses, and clinical (from the fourth year) which includes bedside teaching and in-hospital training. There is no national standardized anatomy curriculum in Poland, but anatomical education is similar between all Polish medical schools. At the time of this work, all anatomical curricula in Polish medical faculties were subject-based, and taught during the first year of studies (Janczukowicz, 2013). Generally, anatomy classes are comprised of 2 major course components; there is a lecture component (20–90 h), and a lab component (65–160 h) which includes cadaveric dissections. In Poland, anatomy is generally taught via this traditional instructional mode (lectures and cadaveric dissections), although other resources including 3D anatomical models, 3D printed organs, ultrasonography, computed tomographic/magnetic resonance imaging scans, and “virtual cadavers” are also available. At the end of the entire anatomy course, both theory-based (written) and practical (pin/tag test) examinations are conducted, and results from these evaluations reflect the final grade for this subject (Zurada et al., 2011).

In Europe, there is a lot of variation in anatomical curricula and course formats. Over the past few years, there has been a trend to replace the traditional, subject-based approach by integrated curricula with multimodal teaching tools, (Estai and Bunt, 2016) but some universities continue to promote the former instructional mode. Central and eastern European schools are part of this belief and include famous schools such as the University of La Sapienza in Italy, which offers a three-semester subject-based course. The diversity of approaches is not limited by this distinction. The length, emphasis, content, and presentation are also unique to each uni-

versity. It suffices to look at a few renowned schools to illustrate the impressive assortment of anatomy curricula. For instance, The French L'Université Paris Descartes offers a subject-based clinical and numerical anatomy program, but what makes it one-of-a-kind is its anatomical drawing classes. At the University of Cambridge in the United Kingdom, students have a much longer anatomy course. There, students undergo a two-year long, subject-based topographical anatomy course (first year covers thorax, abdomen, pelvis, upper and lower limbs; second year covers head and neck anatomy) and are taught primarily through cadaveric dissection (although their course is also supplemented by lectures, applied anatomy sessions and clinical demonstrations). On the other hand, the School of Medicine Charité in Berlin, Germany offers anatomical education by integrating it with other courses, and this up to the ninth semester of medical school. From the third semester students may also participate in a dissection course, which runs in the third and fourth semester as a parallel course to other modules, but to which it is adapted thematically.

As mentioned earlier, Polish anatomical education is subject-based and taught exclusively during the first year of medical school. Since all physicians undergo relatively similar training in this domain, Poland constitutes a great environment to test anatomical knowledge on a larger sample size. This study aimed to assess and compare the anatomical proficiency among medical students and medical physicians at all stages of their careers. The second aim of the study was to evaluate factors which affect recognition of anatomical structures. We hypothesized that anatomical knowledge declined during later stages of medical education and practice.

2. Materials and methods

2.1. Study design

The study protocol for this research conformed to the ethical guidelines of the 1975 declaration of Helsinki. An anonymous cross-sectional survey was designed to evaluate the recognition of anatomical structures among undergraduate medical students and medical physicians. This internet-based survey was distributed exclusively via social media, mailing lists, and discussion websites; it was available from February 21st to April 17th, 2017. Before beginning the study, participants were informed about its aim and informed consent was obtained electronically. Detailed instructions on how to complete the survey were provided. The survey also secured against multiple responses from one person by limiting the access to the questionnaire via a verification system based on the Internet Protocol address.

2.2. Exclusion and inclusion criteria

Polish undergraduate medical students (regardless of year of study) and physicians (regardless of the stage of their carrier) could partake in this study. Other medical and health professionals (both students and graduates) were excluded. No other exclusion criteria were applied. The survey reached 2107 participants, and 372 did not meet the inclusion criteria. Of the 1735 participants, 1186 persons (68.4%) fully completed the survey and were included in the study.

2.3. Internet-based survey

The participants were asked about nine demographic details: sex, age, year of study (or time since graduation), medical school name (both students and graduates), clinical interests or chosen residency program (surgical or non-surgical), length of anatomy course (in semesters), final grade in their anatomy course, attendance in cadaver laboratory classes during their anatomy course,

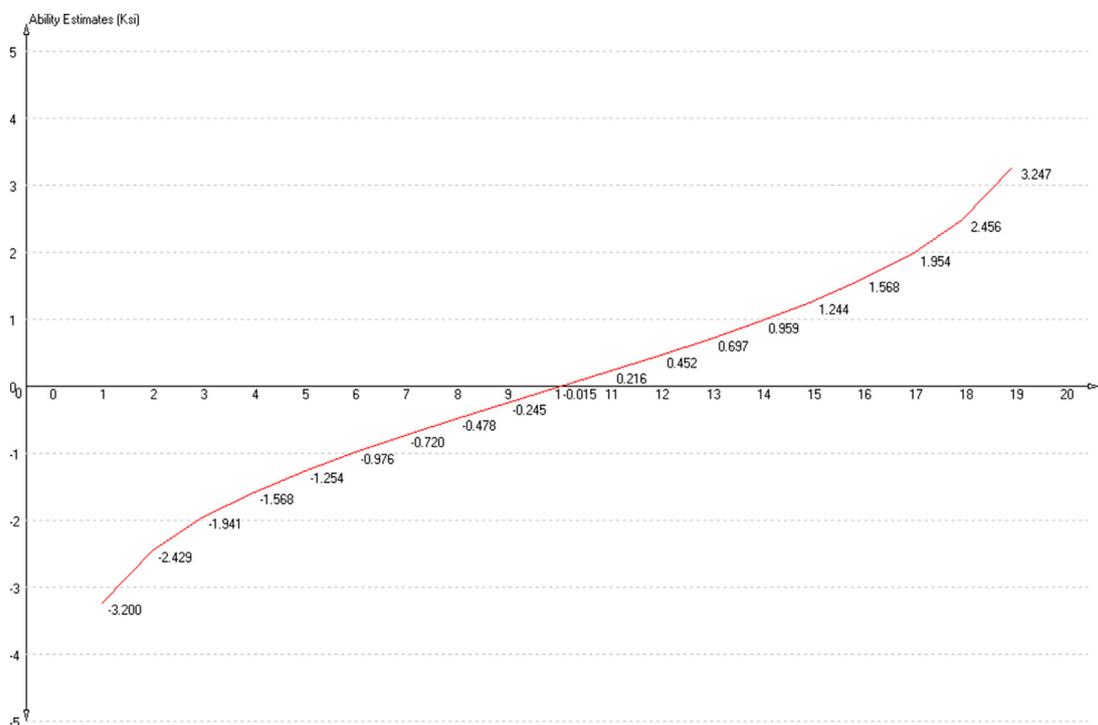


Fig. 1. Test characteristic curve showing the relationship between total score on a test and person location estimate.

and whether they belonged to student scientific circles (anatomy, surgical, other basic science or other non-surgical circles). Participants were also asked to subjectively evaluate their anatomical knowledge before starting the pin/tag test; their self-assessment score was ranked out of a four-grade scale (excellent (5), good (4), satisfactory (3) or poor (2)).

The questionnaire was designed to simulate the laboratory part of the final examination conducted among Polish undergraduate medical students during the human anatomy courses (pin/tag test). Competency in recognition of anatomical structures was assessed by 20 questions divided into two blocks based on recognizing 20 anatomical structures in various human body regions. Each question concerning the interpretation of a single anatomical structure had a response time limit of 45 s and was displayed independently without the possibility of returning to the previous question. If the time limit was exceeded, then the next question was automatically displayed.

- Block I – 10 multiple-choice closed-ended questions with a request to properly naming the following structures: (1) renal papilla, (2) corpus callosum, (3) left gastric artery, (4) horizontal fissure of the right lung, (5) anterior interventricular branch of left coronary artery, (6) inferior mesenteric artery, (7) common bile duct, (8) soft palate, (9) oval foramen of the skull, and (10) left common carotid artery (Supplementary Fig. 1). Five possible names were suggested for each structure, but only 1 was correct.
- Block II – 10 open-ended (fill-in the blank) questions with a request to properly name the following marked structures: (11) trachea, (12) right vertebral artery, (13) cauda equina, (14) cerebral falx, (15) right subclavian artery, (16) sternocleidomastoid muscle, (17) tendinous chords, (18) pulmonary trunk, (19) interventricular septum, and (20) ureter (Supplementary Fig. 2).

2.4. Material selection

All cadaver specimens were photographed in the anatomical position and structures to be identified were marked in a routine

way. The photographs used in this study were selected from a larger databank (100 structures) and included all anatomical regions and organs. This database was used previously, and the difficulty level of each marked structure was validated on a group of 50 second-year medical students – the difficulty level correlated inversely with the percentage of correct answers. The group of medical students used for validation was excluded from the study group. The validation process aimed to choose 20 structures with varying degrees of difficulty starting from 90% to 30%. Degree of difficulty was assigned based on percentage of correct answers during validation process. Due to the lack of precise guidelines and a wide range of potential clinical applications in various medical specialties of different anatomical structures, the clinical significance of the structure or anatomical region where the structure is located was not a criterion for selection.

2.5. Evaluation of answers

The possible maximal score in this survey was 20 points. For each properly identified structure, participants gained 1 point. For multiple-choice closed-ended questions (block I), the correct answers were compiled automatically. For open-ended questions, (block II) the answers were scored automatically using a key. Answers in Polish, English, or Latin were accepted; single spelling errors were tolerated and considered as good answers. The total score was calculated as a sum of points cumulated from block I and block II questions. The Item response theory paradigms were used to determine the passing score. The relation between true scores and ability scores was identified by using the Rasch model, which is simple and does not require complex estimation. The obtained model is easy to understand and apply (Chi-square test 139.128 and $P < 0.001$) (Fischer and Molenaar, 2012). Fig. 1 presents the identified relationship between abilities and the total score. Based on the Rasch model, students were graded according to their total score in the following way: 18–20 pts – excellent or 5.0; 16–17 pts – good or 4.0; 11–15 pts – satisfactory or 3.0; ≤ 10 pts – poor/failure or 2.0.

For this study, we distinguished between pre-clinical medical students (from 1st to 3rd year of study) and clinical medical students (from 4th to 6th year of study). Medical students which graduated less than a year ago were defined as medical interns. Graduates of medical schools enrolled in a medical residency program were classified as residents, whereas physicians with completed residency training were labeled as specialists.

2.6. Statistical analysis

All data was analyzed using Statistica version 13.1 PL (Stat-Soft Inc., Tulsa, OK). The percentage of correct answers within a single block was calculated by dividing the number of correct answers by the total number of questions in each block. The normal distribution was checked using a Shapiro–Wilk test. The Levene’s test was performed to verify the homogeneity of variance. The results are reported as a percentage, as a mean with standard deviation (SD), and as a median with interquartile range (Q₁–Q₃) based on the normal distribution. The study of categorical variables employed a Chi-square test of independence with a Bonferroni correction applied for multiple comparisons. The *t*-test and ANOVA test were used for normally distributed quantitative data. The Mann–Whitney U test and the Kruskal–Wallis test were used for non-normally distributed quantitative variables. Multiple comparisons were performed to assess differences in scores between participants from different universities. To check if the effects had a relevant magnitude, the effect sizes (Cohen’s D) were calculated to describe the strength of a phenomenon. The internal consistency was measured using Cronbach’s alpha (Cronbach, 1951). A correspondence analysis plot described the relationship between grades earned in the survey and grades earned in the anatomy course as well as self-evaluations. If certain row and column points deviated in the same direction, then there was an increased likelihood that there was an association between the two variables.

A multivariable logistic regression model was used to identify the factors that significantly influenced competency in recognizing anatomical structures. The outcome variable was a grade of good or higher (≥80%). Sex, time elapsed since anatomy classes, clinical interests or chosen residency/specialization (surgical or non-surgical), length of anatomy course, grade earned during the anatomy course, participation in cadaver laboratory classes, and past membership in an anatomical, surgical, or any other clinical/scientific student association were independent variables. A correlation coefficient was used to check associations between parameters. A *P*-value of less than 0.05 was considered statistically significant. The power analysis indicated that 253 participants were needed to detect a statistical difference between two groups at a level of 10% (estimated SD=20% points) for 80% power with a 5% significance level (two-tailed; α=0.05; β=0.2). The calculated Cronbach Alpha was 0.76. The results of this test indicated that the model possessed internal validity.

3. Results

3.1. Profile and characteristics of the study group

A total of 1186 medical students and graduates (58.7% female) from all 12 Polish medical faculties partook in this study. The mean age of respondents was 23.3 ± 3.7 years and more detailed demographic characteristics are shown in Table 1. Most of the surveyors were undergraduate medical students (931 participants) of which 522 were pre-clinical (form 1st to 3rd year of study) and 409 were clinical (from 4th to 6th year of study). There were 119 pre-clinical participants who at the time of the survey were still enrolled in their anatomy course (they had not yet approached their final

Table 1 Study group and sub-groups characteristics.

	All	All students	Pre-clinical students	Clinical students	All graduates	Interns	Residents	Specialists	p-Value students vs. graduates
N (% of total)	1186 (100%)	931 (78.5%)	522 (44.0%)	409 (34.5%)	255 (21.5%)	119 (10.0%)	123 (10.4%)	13 (1.1%)	-
Males	490 (41.3%)	395 (42.4%)	220 (42.1%)	175 (42.8%)	95 (37.3%)	42 (35.3%)	48 (39.0%)	5 (38.5%)	-
Female	696 (58.7%)	536 (57.6%)	302 (57.9%)	234 (57.2%)	160 (62.7%)	77 (64.7%)	75 (61.0%)	8 (61.5%)	-
Mean age (years ± SD)	23.3 ± 3.7	22.1 ± 2.5	20.9 ± 2.5	23.6 ± 1.5	27.6 ± 2.4	25.7 ± 1.0	28.0 ± 4.0	39.5 ± 6.3	<0.001
Clinical interests/specialization		546 (58.6%)	290 (55.6%)	256 (62.6%)	162 (63.5%)	74 (62.2%)	81 (65.9%)	7 (53.8%)	0.159
		385 (41.4%)	232 (44.4%)	153 (37.4%)	93 (36.5%)	45 (37.8%)	42 (34.1%)	6 (46.2%)	
Non-surgical									
Surgical									
Final grade earned during the anatomy course ^a									
Failure (2.0)	250 (23.4%)	185 (22.8%)	99 (24.6%)	86 (21.0%)	65 (25.5%)	34 (28.6%)	27 (22.0%)	4 (30.8%)	<0.001
Satisfactory (3.0)	384 (36.0%)	277 (34.1%)	145 (36.0%)	132 (32.3%)	107 (42.0%)	52 (43.7%)	53 (43.1%)	2 (15.4%)	
Good (4.0)	317 (29.7%)	253 (31.2%)	109 (27.0%)	144 (35.2%)	64 (25.1%)	19 (16.0%)	38 (30.9%)	7 (53.8%)	
Excellent (5.0)	116 (10.9%)	97 (11.9%)	50 (12.4%)	47 (11.5%)	19 (7.5%)	14 (11.8%)	5 (4.1%)	0	
Failure (2.0)	290 (24.5%)	228 (24.5%)	99 (19.0%)	129 (24.7%)	62 (24.3%)	39 (32.8%)	21 (17.1%)	2 (15.4%)	0.984
Satisfactory (3.0)	673 (56.7%)	529 (56.8%)	307 (58.8%)	222 (42.5%)	144 (56.5%)	58 (48.7%)	79 (64.2%)	7 (53.8%)	
Good (4.0)	190 (16.0%)	149 (16.0%)	99 (19.0%)	50 (9.6%)	41 (16.1%)	16 (13.4%)	22 (17.9%)	3 (23.1%)	
Excellent (5.0)	33 (2.8%)	25 (2.7%)	17 (3.3%)	8 (1.5%)	8 (3.1%)	6 (6.0%)	1 (0.8%)	1 (7.7%)	
Length of anatomy course (in semesters)									
1	323 (27.2%)	319 (34.3%)	249 (47.7%)	70 (13.4%)	4 (1.6%)	1 (0.8%)	3 (2.4%)	0	<0.001
1.5	16 (1.3%)	13 (1.4%)	10 (1.9%)	3 (0.6%)	3 (1.2%)	1 (0.8%)	2 (1.6%)	0	
2	847 (71.4%)	599 (64.3%)	263 (50.4%)	336 (64.4%)	248 (97.3%)	117 (98.3%)	118 (95.9%)	13 (100%)	
Cadaver laboratory classes									
Member of students' scientific circle of anatomy	1158 (97.6%)	912 (98%)	513 (98.3%)	399 (76.4%)	246 (96.5%)	117 (98.3%)	116 (94.5%)	13 (100%)	0.165
Member of surgical students' scientific circles	88 (7.4%)	72 (7.7%)	34 (6.5%)	38 (7.3%)	16 (6.3%)	7 (5.9%)	9 (7.3%)	0	0.431
Member of other basic science students' scientific circles	276 (23.3%)	203 (21.8%)	69 (13.2%)	134 (25.7%)	73 (28.6%)	32 (26.9%)	38 (30.9%)	3 (23.1%)	0.022
Member of other non-surgical clinical students' scientific circles	58 (4.9%)	34 (3.7%)	17 (3.3%)	26 (5.0%)	15 (5.9%)	7 (5.9%)	6 (4.9%)	2 (15.4%)	0.407
Member of other pre-clinical students' scientific circles	286 (24.1%)	208 (22.3%)	56 (10.7%)	152 (29.1%)	78 (30.6%)	40 (33.6%)	34 (27.6%)	4 (30.8%)	0.006

N — number of participants, SD — standard deviation.
^a 119 pre-clinical students have not yet completed anatomy course.

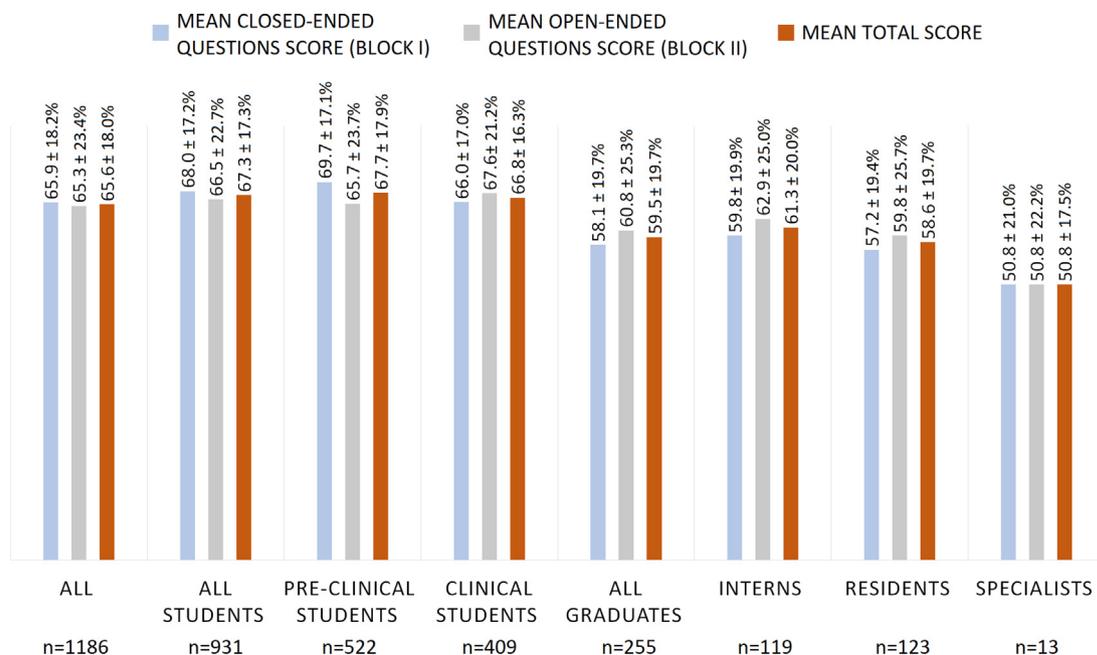


Fig. 2. Mean (\pm standard deviation) survey scores in study sub-groups. N – number of participants.

anatomy exam), but they completed the whole tag/pin test and their score results were included nonetheless. Moreover, 255 medical school graduates also participated in the survey (median time from graduation: 2 years, range: 1–28 years). This number encompassed 119 medical interns (within one year of graduation), 123 residents (median time of medical practice: 2 years, range: 2–6) and 13 specialists (median time of medical practice: 10 years, range: 7–28).

Overall, undergraduate students had higher final marks in their anatomy course than their graduate counterparts (3.32 ± 0.96 vs 3.14 ± 0.89 respectively; $P < 0.001$; Cohen's $D = 0.191$). Self-assessment scores were comparable in both groups (2.96 ± 0.71 vs 2.98 ± 0.73 , respectively; $P = 0.82$). In contrast to graduates, undergraduates accounted for a much higher percentage of participants with less than two semesters of anatomy training (55.4% vs. 2.8%; $P < 0.001$). Both students and graduates had near similar participation levels in cadaveric laboratory classes (98% vs. 96.5%, $P = 0.16$). There were also no significant differences in clinical interests/specialization (surgical or non-surgical) between the students and graduates who enrolled in the study (40.3%/59.7% vs. 36.5/63.5%, $P = 0.159$).

3.2. Survey results

This study demonstrated that medical students achieve better results in a pin/tag test than medical graduates; however, both groups had moderate level scores (below 70%) and a significant number of participants failed the test. The mean total survey score for all participants was $65.6 \pm 18.0\%$; $65.9 \pm 18.2\%$ for closed-ended (block I) and $65.3 \pm 23.4\%$ for open-ended (fill-in the blank, block II) questions. The mean survey scores of the study sub-groups are summarized in Fig. 2. There were no differences in results between block I and block II questions in all study sub-groups ($P > 0.05$) except for the pre-clinical students ($P = 0.002$). Undergraduates had higher total test scores (67.3% vs. 59.5%, $P < 0.001$; Cohen's $D = 0.448$) and scored better within individual question blocks when compared to graduates (block I: 68% vs. 58.1%, $P < 0.001$, Cohen's $D = 0.556$; block II: 66.5% vs. 60.8%, $P < 0.001$, Cohen's $D = 0.245$). The only significant difference between pre-clinical and clinical students was observed for closed-ended questions (block

I); pre-clinical undergraduates did better in this section ($P = 0.001$; Cohen's $D = 0.217$). No differences were observed between interns, residents, and specialists ($P > 0.05$). A total of 247 (20.8%) participants did not pass the test (<11 pts); in total, 17.8% of medical students and an overwhelming 31.8% of graduates failed the test ($P < 0.001$). A very similar number of participants (332, 28.0% total) earned a grade of good or excellent ($\geq 80\%$), but there was also a noticeable discrepancy in score distribution between students and graduates (30.7% of students vs. 18.0% of graduates scored this well, $P < 0.001$). Differences were also observed between participants from different medical schools ($P < 0.001$; Cohen's $D = 0.576$), and the largest disparity in total score results between participants from two different schools was 25.6% (Table 2).

3.3. Factors affecting anatomical proficiency

3.3.1. Gender-specific differences

In comparison to female participants, male participants earned significantly higher mean scores in the survey (total: 68.9% vs. 63.3%, $P < 0.001$; block I: 68% vs. 64.4%, $P < 0.001$ and block II 69.8% vs. 62.2%, $P < 0.001$). Multivariable logistic regression analysis showed a similar trend (OR = 1.74, 95%CI = 1.33–2.26, $P < 0.001$).

3.3.2. Medical specialty/interest

Students or graduates interested in surgical specialties did not perform better than those in non-surgical specialties ($P > 0.05$). Interest in a surgical vs. a non-surgical field was also found to be a non-significant factor in the multivariable logistic regression model (OR = 0.87, 95%CI = 0.64–1.18, $P = 0.36$).

3.3.3. Duration of anatomy course

A comparison between participants enrolled in a one-semester vs. two-semester anatomy course revealed significantly higher mean scores in the former (total: 70.4% vs. 64.4%, $P < 0.001$; block I: 71.8% vs. 63.9%, $P < 0.001$; block II: 69% vs. 64.4%, $P = 0.002$). However, this group of participants was represented by students from only one medical school (medical school No. 4) and the mean total score for all participants from this university was second highest (70.2%) (Table 2).

Table 2
Mean \pm SD survey scores according to medical school and description of current anatomical curriculum of these schools.

Medical school	Number of participants	Mean \pm SD closed-ended questions score (block I)	Mean \pm SD open-ended questions score (block II)	Mean \pm SD total score	Length of anatomy course (in semesters) ^a	Number of anatomy lecture hours ^a	Number of anatomy seminar hours ^a	Number of cadaver laboratory classes hours ^a
1	75	63.5% \pm 20.4%	57.7% \pm 23.5%	60.6% \pm 19.4%	2	80	0	130
2	78	72.0% \pm 15.4%	72.0% \pm 22.4%	72.0% \pm 16.6%	2	90	0	120
3	22	49.1% \pm 17.7%	43.6% \pm 20.6%	46.4% \pm 16.6%	2	55	0	125
4	413	70.8% \pm 17.1%	69.5% \pm 22.0%	70.2% \pm 16.5%	1.5	40	20	120
5	37	60.8% \pm 13.8%	66.5% \pm 21.4%	63.7% \pm 15.1%	2	36	12	72
6	67	59.1% \pm 18.6%	54.0% \pm 25.4%	56.6% \pm 19.2%	2	40	0	130
7	38	59.7% \pm 13.7%	59.7% \pm 22.6%	59.8% \pm 15.1%	2	55	0	65
8	44	63.4% \pm 21.6%	69.3% \pm 23.6%	66.4% \pm 20.5%	2	20	0	175
9	64	62.5% \pm 17.7%	55.8% \pm 25.9%	59.2% \pm 18.6%	2	90	0	120
10	10	55.0% \pm 23.7%	55.0% \pm 19%	55.0% \pm 19.4%	2	40	0	160
11	146	66.6% \pm 17.4%	71.7% \pm 19.4%	69.2% \pm 15.3%	2	40	0	160
12	192	62.3% \pm 18.2%	61.8% \pm 24.1%	62.0% \pm 18.3%	2	30	60	110

SD – standard deviation.

^a Data for the academic year 2016/2017.

3.3.4. Participation in cadaver laboratory classes

The results also showed that participation in the cadaver laboratory course (as part of the curriculum of the gross anatomy class) significantly increased the mean survey score (total: 66% vs. 49.5%, $P < 0.001$; block I: 66.2% vs. 52.9%, $P < 0.001$; block II: 65.8% vs. 46%, $P < 0.001$). However, only a very small fraction of the surveyed participants did not attend this laboratory component (28 vs. 1158). Multivariable logistic regression analysis showed that among all analyzed factors, participation in cadaver laboratory classes most strongly affected the ability to recognize anatomical structures (OR = 5.30, 95%CI = 1.20–23.40, $P = 0.03$).

3.3.5. Involvement in student scientific circles/societies

In addition, members belonging to the students' scientific circle of anatomy achieved higher mean scores in comparison to other participants ($P < 0.05$); however, this difference was insignificant in the graduates group ($P > 0.05$). A similar trend was observed for members who belonged to surgical scientific circles. Both trends were confirmed by the multivariable logistic regression model: membership in students' scientific circle of anatomy (OR = 2.18, 95%CI = 1.10–2.20, $P = 0.001$); membership in surgical students' scientific circles (OR = 1.56, 95%CI = 1.11–2.20, $P = 0.01$).

3.3.6. Time elapsed since gross anatomy course

The amount of time that had passed since completion of the gross anatomy course was negatively correlated with the total survey score ($r = -0.15$, $P < 0.001$). Multivariable logistic regression analysis confirmed this negative trend on the anatomical competency score (OR = 0.86, 95%CI = 0.81–0.92, $P < 0.001$).

3.3.7. Self-assessment scores and previous anatomy grades

This study showed a correlation between survey score and grade earned in medical gross anatomy course ($P < 0.001$) (Table 3) as well as a correlation between survey score and each participant's self-assessment score ($P < 0.001$) (Table 4). The correspondence analyses of the above-mentioned relationships (Fig. 3A and B) showed a meaningful correlation, except in the case of participants which reported an excellent (5.0) self-grade. Participants who rated their current anatomical knowledge as excellent tended to overestimate their knowledge. Multivariable logistic regression analysis showed that a good or higher grade earned during the anatomy course was an independent factor that positively affects anatomical competencies (OR = 1.38, 95%CI = 1.18–1.60, $P < 0.001$).

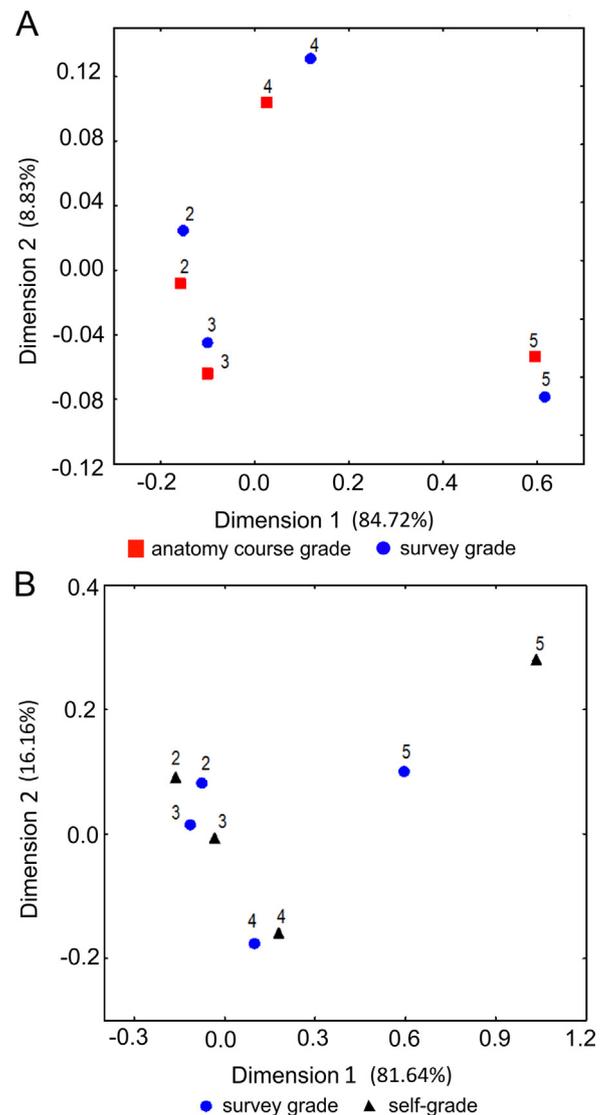


Fig. 3. The resulting correspondence analysis biplots (scatter plots) showing dependence between: (A) grades gained in the survey and grades gained in the anatomy course ($P < 0.001$) as well as (B) survey grades and current self-grades ($P < 0.001$).

Table 3
Association between grades earned in our survey and grades earned in the anatomy course.

Grades earned in our survey	Grades earned in the anatomy course				
	Failure (2.0)	Satisfactory (3.0)	Good (4.0)	Excellent (5.0)	Total
Failure (2.0)	66 (6.2%)	75 (7.0%)	63 (5.9%)	15 (1.4%)	219 (20.5%)
Satisfactory (3.0)	129 (12.1%)	218 (20.4%)	151 (14.2%)	44 (4.1%)	542 (50.8%)
Good (4.0)	40 (3.7%)	64 (6%)	75 (7%)	27 (2.5%)	206 (19.3%)
Excellent (5.0)	15 (1.4%)	27 (2.5%)	28 (2.6%)	30 (2.8%)	100 (9.4%)
Total	250 (23.4%)	384 (36%)	317 (29.7%)	116 (10.9%)	1067 ^a (100%)

^a 119 pre-clinical students have not yet completed anatomy course.

Table 4
Association between grades earned in our survey and current self-grades.

Grades earned in our survey	Current self-grades				
	Failure (2.0)	Satisfactory (3.0)	Good (4.0)	Excellent (5.0)	Total
Failure (2.0)	73 (6.2%)	134 (11.3%)	34 (2.9%)	6 (0.5%)	247 (20.8%)
Satisfactory (3.0)	159 (13.4%)	358 (30.2%)	82 (6.9%)	8 (0.7%)	607 (51.2%)
Good (4.0)	42 (3.5%)	125 (10.5%)	51 (4.3%)	6 (0.5%)	224 (18.9%)
Excellent (5.0)	16 (1.3%)	56 (4.7%)	23 (1.9%)	13 (1.1%)	108 (9.1%)
Total	290 (24.5%)	673 (56.7%)	190 (16%)	33 (2.8%)	1186 (100%)

4. Discussion

To date, this is the largest study to use a pin/tag online tool to assess the anatomical knowledge of medical students and practitioners at different stages of their career. Our results show that the overall competency in recognizing anatomical structures is low. One advantage of our survey is that it was conducted on a relatively homogeneous group with respect to anatomical training. Since all our participants were Polish medical students/graduates, all had undergone a subject-based gross anatomy course taught during their first year of medical school. Furthermore, our survey assessed the anatomical proficiency amongst the participants, but it also studied and compared other factors which could influence anatomical acquisition and retention.

The current study revealed that males have greater success in recognizing anatomical structures and achieve better results in pin/tag anatomical examinations than their female counterparts. Although there was significantly more female than male participants in our study, this numerical imbalance is also observed in the demographic fractioning of Polish doctors, thus it should not affect the general conclusions of our analyses. Moreover, the disparity between male and female subjects cannot be attributed to an increased surgical interest seen among males, since this study showed that interest in surgery did not result in better recognition of anatomical structures. This intersex difference was also observed by [Doomernik et al. \(2017\)](#) who showed that male students scored slightly higher during anatomical examinations than female students. Males also seemed to show less forgetfulness when recalling anatomical structures ([Doomernik et al., 2017](#)). This could be due to enhanced spatial predispositions encountered in men, which affect the understanding of three-dimensional structures and positions of objects ([Vorstenbosch et al., 2013](#)).

Among all independent factors studied, our multivariable regression model showed that participation in cadaver laboratory classes had the most significant impact on anatomical structure identification. Students, clinicians, and teachers agree that cadaveric dissections are the most beneficial way of learning anatomy ([Davis et al., 2014](#); [Sheikh et al., 2016](#)). Participation in these sorts of classes offers unique and important three-dimensional views of human anatomy ([Aziz et al., 2002](#)). This is encouraging news for Polish medical schools which incorporate cadavers into their medical anatomy curriculum. Unfortunately, reduced contact hours and reduced access to cadaveric-based teaching is a common worldwide trend ([Halliday et al., 2015](#)). Some medi-

cal schools have even stopped using cadavers entirely ([McLachlan et al., 2004](#)). Instead, new, complementary, alternative teaching methods such as video-demonstrations, virtual 3D visualizations, or even augmented reality have been incorporated to make-up for their absence. Unfortunately, none of these tools provide the same kinesthetic experience ([Patel et al., 2015](#)). Excluding cadavers from the standard anatomy curricula may decrease anatomical proficiency and can negatively impact routine medical practice. Moreover, research indicates that students prefer traditional teaching resources (including dissections and prosected specimens) over computer-assisted anatomical learning resources ([Choi-Lundberg et al., 2016](#)). Previously published data suggested that cadaveric-based education should be restored in all medical schools to maintain anatomical competencies ([Gürses et al., 2018](#)). Unfortunately, our study has shown that this component is not enough to ensure satisfactory anatomical knowledge. Most of the participants in our survey had cadaver-based anatomy training, but their overall scores were far from impressive. It seems that although cadaver-based anatomical education improves competency in recognizing structures, it does not prevent the significant deterioration of anatomical knowledge over time.

Overall, in this survey, practicing physicians earned fewer points than undergraduate medical students. Our results were synchronous with other studies, showing that time is one of the most negative factors affecting anatomical competency ([Custers, 2010](#); [McBride and Drake, 2016](#)). Our results showed that specialists identified up to 25% less structures than pre-clinical medical students. Our findings further support recommendations to teach anatomy throughout the entire medical curriculum and not only during the first year of the medical education. ([Fillmore et al., 2016](#)).

In Poland, anatomy is traditionally taught in the first year of medical school. Afterwards, students have little to no exposure to any additional anatomy classes. Our survey showed that this subject-based approach is insufficient, and retention of anatomical knowledge is poor, especially amongst medical professionals. One possible solution to this problem may be to integrate anatomy vertically into medical education so that students are exposed to repeated anatomy concepts all throughout their undergraduate training ([Turney, 2007](#)). A second option to help strengthen anatomical proficiency amongst practicing physicians is to add refresher courses which would be integrated with all major clinical programs and made available to all graduates; for added benefit, these refresher courses could use cadavers to help reinforce previously acquired knowledge. ([Fillmore et al., 2016](#)). Even short

but intensive anatomical courses could be advantageous, and they would contribute to better patient care (Sarkis et al., 2014). Gross anatomy courses embedded with clinical context are considered useful, interesting, and relevant by their participants (Cabrera et al., 2011). Adding more applicability to the theoretical component could also facilitate anatomical retention.

Our results also demonstrated that survey participants who attended one-semester anatomy courses had significantly higher mean scores than those who had a two-semester course. However, this phenomenon was not confirmed by the multivariable logistic regression analysis. This unexpected result was driven by students from one medical school (medical school No. 4) who attended a one-semester anatomy course. Students from this medical school also scored the second highest score in this survey. In 2012, medical school No. 4 shortened the anatomy curriculum to one semester and has kept it as such for the past 5 years. The new curriculum probably stressed the more clinically relevant structures in anatomy and must have omitted certain secondary structures to make up for the reduced teaching hours. Surprisingly, these adjustments increased students' memory of anatomical structures. Students were most likely less preoccupied by the smaller details and could focus on the more essential structures. A more in-depth investigation of their curriculum would be necessary to understand this alternative way of teaching. McBride and Drake (2016) also recently concluded that intense anatomy courses with reduced hours using a nontraditional format and cadaver demonstrations would help students build a strong anatomical foundation. In light of this, it would be worth to consider implementing short anatomy refresher courses at different stages of undergraduate and graduate education with heavy emphasis on clinically relevant structures.

Lastly, this study also showed that participants who belonged to scientific societies (especially members belonging to anatomy and/or surgery clubs) tended to score higher on our survey. Involvement in elective anatomy classes/extracurricular activities had the second highest impact on heightened scores in our survey. This comes as no surprise – participation in these clubs promotes constant reinforcement of previously learned material and provides more contact time with cadaveric specimens. Anatomy is the foundation of surgery, and a solid knowledge of anatomy is essential for surgical training and further practice (Tibrewal, 2006). Unfortunately, these positive effects tended to decrease as a function of time. Interestingly, being involved in a surgery club boosted anatomical knowledge, but being interested in surgery or working in that specialty had no influence on anatomical proficiency. These results show that personal preferences for medical specialties have little influence on anatomical proficiency; rigorous training is what truly determines one's proficiency.

This study has several limitations. First, the use of an internet-based testing tool may have provided some bias. Three-dimensional recognition cannot be entirely and adequately assessed via an assessment which uses two-dimensional images. Also, the use of an online survey could have disadvantaged older participants that were not so familiar with this testing format. Nonetheless, we should not exaggerate this limitation since all participants were given clear instructions on how to complete the test prior to the commencement of the survey.

Second, this was a survey-based study that only included volunteers, and this could make it susceptible to bias. Most of the respondents might have already had an avid interest in anatomy and/or surgery, and therefore the scores might have been slightly inflated. Moreover, although distributing the survey via the Internet helped reach a larger number of respondents, it also made it impossible to supervise the participants while they were completing the questionnaire. Authors were aware that using an Internet-based survey to assess anatomical knowledge could create the temptation to use external resources while answering ques-

tions. However, limiting the answer time to 45 s for each question and preventing participants from completing the survey more than once from a given hardware (Internet Protocol address verification) helped prevent students from using additional resources to answer the questions. Another drawback of our study was that our group included a relatively small number of medical graduates and even fewer specialists. This could have been a potential source of bias. Also, this survey focused only on Polish participants. Due to the presence of participants from different medical schools and of different ages, a detailed comparison between anatomical curricula in medical schools in Poland was not performed; thus, generalization of the results must be performed cautiously due to the differences in medical school curricula.

A further limitation of the study lies in the uneven representation of the different organ systems. The choice of anatomical structures used for our survey was solely based on the difficulty criterion, which was chosen from 100 major anatomical structures. A similar study testing clinically relevant structures could prove extremely useful, although some sort of inquiry would have to be made to identify the latter. Finally, it is important to acknowledge that experienced clinicians may use anatomical knowledge in a different way from students (applying anatomical knowledge in a clinical context vs. pure factual knowledge). The type of questions that were used in our study (pure factual) did not account for this reality and may have contributed to the score differences amongst undergraduate and graduate participants. If some clinical context had been given, specialists would have probably obtained higher marks.

5. Conclusions

Knowledge of anatomical structures gained during a subject-based anatomical curriculum is moderate, and it decreases significantly with time. Proficiency in anatomical structure identification is associated with participation in cadaver laboratory classes, a high grade in the gross anatomy course, as well as involvement in student scientific interest groups in anatomy and surgery; however, this last positive effect is suppressed as a function of time. Students with clinical interests in surgery as well as surgical residents/specialists do not possess higher anatomical proficiency than non-surgical enthusiasts.

Our study also showed that medical undergraduates scored better in our pin/tag test than practicing physicians. To avoid further deterioration of anatomical knowledge amongst clinicians, subject-based anatomy courses should be replaced with system-based (integrated) anatomical curricula at the undergraduate level. Furthermore, short refresher anatomy courses should be offered during different stages of postgraduate training.

Acknowledgements

Dr. Mateusz Hołda was supported by the Foundation for Polish Science (FNP). The funders had no role in the study's design, data collection, or analysis, decision to publish, or preparation of the manuscript.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.aanat.2018.09.004>.

References

- Ates, M., Kinaci, E., Kose, E., Soyer, V., Sarici, B., Cuglan, S., Korkmaz, F., Dirican, A., 2016. Corona mortis: in vivo anatomical knowledge and the risk of injury in

- totally extraperitoneal inguinal hernia repair. *Hernia* 20, 659–665, <http://dx.doi.org/10.1007/s10029-015-1444-8>.
- Aziz, M.A., Mckenzie, J.C., Wilson, J.S., Cowie, R.J., Ayeni, S.A., Dunn, B.K., 2002. The human cadaver in the age of biomedical informatics. *Anat. Rec.* 269, 20–32, <http://dx.doi.org/10.1002/ar.10046>.
- Bergman, E.M., van der Vleuten, C.P., Scherpbier, A.J., 2011. Why don't they know enough about anatomy? A narrative review. *Med. Teach.* 33, 403–409, <http://dx.doi.org/10.3109/0142159X.2010.536276>.
- Bergman, E.M., Verheijen, I.W., Scherpbier, A.J., van der Vleuten, C.P., De Bruin, A.B., 2014. Influences on anatomical knowledge: the complete arguments. *Clin. Anat.* 27, 296–303, <http://dx.doi.org/10.1002/ca.22341>.
- Burgess, A.W., Ramsey-Stewart, G., May, J., Mellis, C., 2012. Team-based learning methods in teaching topographical anatomy by dissection. *ANZ J. Surg.* 82, 457–460, <http://dx.doi.org/10.1111/j.1445-2197.2012.06077.x>.
- Cabrera, A.R., Lee, W.R., Madden, R., Sims, E., Hoang, J.K., White, L.E., Marks, L.B., Chino, J.P., 2011. Incorporating gross anatomy education into radiation oncology residency: a 2-year curriculum with evaluation of resident satisfaction. *J. Am. Coll. Radiol.* 8, 335–340, <http://dx.doi.org/10.1016/j.jacr.2010.10.005>.
- Choi-Lundberg, D.L., Low, T.F., Patman, P., Turner, P., Sinha, S.N., 2016. Medical student preferences for self-directed study resources in gross anatomy. *Anat. Sci. Educ.* 9, 150–160, <http://dx.doi.org/10.1002/ase.1549>.
- Cronbach, L.J., 1951. Coefficient alpha and the internal structure of tests. *Psychometrika* 16, 297–334, <http://dx.doi.org/10.1007/BF02310555>.
- Custers, E.J.F.M., 2010. Long-term retention of basic science knowledge: a review study. *Adv. Health Sci. Educ. Theory Pract.* 15, 109–128, <http://dx.doi.org/10.1007/s10459-008-9101-y>.
- Davis, C.R., Bates, A.S., Ellis, H., Roberts, A.M., 2014. Human anatomy: let the students tell us how to teach. *Anat. Sci. Educ.* 7, 262–272, <http://dx.doi.org/10.1002/ase.1424>.
- Dickson, J.K., Morris, G., Heron, M., 2009. The importance of hand anatomy in the accident and emergency department: assessment of hand anatomy knowledge in doctors in training. *J. Hand Surg. Eur. Vol.* 34, 682–684, <http://dx.doi.org/10.1177/1753193409104947>.
- Dixon, F., Juszcak, M., Magee, T., Woodgate, F., 2018. Why anatomy knowledge is important: a case report of a pseudoaneurysm secondary to peripheral venous cannula insertion. *J. Vasc. Endovasc. Surg.* 3, 1–3, <http://dx.doi.org/10.21767/2573-4482.100071>.
- Doomernik, D.E., van Goor, H., Kooloos, J.G.M., Ten Broek, R.P., 2017. Longitudinal retention of anatomical knowledge in second-year medical students. *Anat. Sci. Educ.* 10, 242–248, <http://dx.doi.org/10.1002/ase.1656>.
- Estai, M., Bunt, S., 2016. Best teaching practices in anatomy education: a critical review. *Ann. Anat.* 208, 151–157, <http://dx.doi.org/10.1016/j.aanat.2016.02.010>.
- Fillmore, E.P., Brokaw, J.J., Kochhar, K., Nalin, P.M., 2016. Understanding the current anatomical competence landscape: comparing perceptions of program directors, residents, and fourth-year medical students. *Anat. Sci. Educ.* 9, 307–318, <http://dx.doi.org/10.1002/ase.1578>.
- Fischer, G.H., Molenaar, I.W. (Eds.), 2012. *Springer Science & Business Media*.
- Gürses, İ.A., Coşkun, O., Öztürk, A., 2018. Current status of cadaver sources in Turkey and a wake-up call for Turkish anatomists. *Anat. Sci. Educ.* 11, 155–165, <http://dx.doi.org/10.1002/ase.1713>.
- Halliday, N., O'Donoghue, D., Klump, K.E., Thompson, B., 2015. Human structure in six and one-half weeks: one approach to providing foundational anatomical competency in an era of compressed medical school anatomy curricula. *Anat. Sci. Educ.* 8, 149–157, <http://dx.doi.org/10.1002/ase.1476>.
- Harrison, A.M., Hilmi, O.J., 2014. Isolated partial, transient hypoglossal nerve injury following acupuncture. *J. Surg. Case Rep.* 5, 10–12, <http://dx.doi.org/10.1093/jscr/rju055>.
- Holland, J., O'Sullivan, R., Arnett, R., 2015. Is a picture worth a thousand words: an analysis of the difficulty and discrimination parameters of illustrated vs. text-alone vignettes in histology multiple choice questions. *BMC Med. Educ.* 15, 184, <http://dx.doi.org/10.1186/s12909-015-0452-9>.
- Ikah, D.S.K., Finn, G.M., Swamy, M., White, P.M., McLachlan, J.C., 2015. Clinical vignettes improve performance in anatomy practical assessment. *Anat. Sci. Educ.* 8, 221–229, <http://dx.doi.org/10.1002/ase.1471>.
- Janczukowicz, J., 2013. Medical education in Poland. *Med. Teach.* 35, 537–543, <http://dx.doi.org/10.3109/0142159X.2013.789133>.
- McBride, J.M., Drake, R.L., 2016. Longitudinal cohort study on medical student retention of anatomical knowledge in an integrated problem-based learning curriculum. *Med. Teach.* 38, 1209–1213, <http://dx.doi.org/10.1080/0142159X.2016.1210113>.
- McLachlan, J.C., Bligh, J., Bradley, P., Searle, J., 2004. Teaching anatomy without cadavers. *Med. Educ.*, <http://dx.doi.org/10.1046/j.1365-2923.2004.01795.x>.
- Meyer, A.J., Innes, S.I., Stomski, N.J., Armson, A.J., 2016. Student performance on practical gross anatomy examinations is not affected by assessment modality. *Anat. Sci. Educ.* 9, 111–120, <http://dx.doi.org/10.1002/ase.1542>.
- Nguyen, N., Nelson, A.J., Wilson, T.D., 2012. Computer visualizations: factors that influence spatial anatomy comprehension. *Anat. Sci. Educ.* 5, 98–108, <http://dx.doi.org/10.1002/ase.1258>.
- Orsbon, C.P., Kaiser, R.S., Ross, C.F., 2014. Physician opinions about an anatomy core curriculum: a case for medical imaging and vertical integration. *Anat. Sci. Educ.* 7, 251–261, <http://dx.doi.org/10.1002/ase.1401>.
- Patel, S.B., Mauro, D., Fenn, J., Sharkey, D.R., Jones, C., 2015. Is dissection the only way to learn anatomy? Thoughts from students at a non-dissecting based medical school. *Perspect. Med. Educ.* 4, 259–260, <http://dx.doi.org/10.1007/s40037-015-0206-8>.
- Rowland, S., Ahmed, K., Davies, D.C., Ashrafian, H., Patel, V., Darzi, A., Paraskeva, P.A., Athanasiou, T., 2011. Assessment of anatomical knowledge for clinical practice: perceptions of clinicians and students. *Surg. Radiol. Anat.* 33, 263–269, <http://dx.doi.org/10.1007/s00276-010-0748-8>.
- Sarkis, L.M., Treble, A., Wing, L.W., Ramsey-Stewart, G., 2014. Retention of topographical anatomical knowledge following surgeon-facilitated whole-body dissection. *ANZ J. Surg.* 11, 820–822, <http://dx.doi.org/10.1111/ans.12826>.
- Savran, M.M., Tranum-Jensen, J., Clementsen, P.F., Svendsen, J.H., Pedersen, J.H., Poulsen, S.S., Arendrup, H., Konge, L., 2015. Are medical students being taught anatomy in a way that best prepares them to be a physician? *Clin. Anat.* 28, 568–575, <http://dx.doi.org/10.1002/ca.22557>.
- Sheikh, A.H., Barry, D.S., Gutierrez, H., Cryan, J.F., O'Keefe, G.W., 2016. Cadaveric anatomy in the future of medical education: what is the surgeons view? *Anat. Sci. Educ.* 9, 203–208, <http://dx.doi.org/10.1002/ase.1560>.
- Tibrewal, S., 2006. The anatomy knowledge of surgical trainees: the trainer's view. *Bull. Roy Coll. Surg. Engl.* 88, 240–242, <http://dx.doi.org/10.1308/147363506X113857>.
- Turney, B.W., 2007. Anatomy in a modern medical curriculum. *Ann. R. Coll. Surg. Engl.* 89, 104–107, <http://dx.doi.org/10.1308/003588407X168244>.
- Vorstenbosch, M.A., Klaassen, T.P., Kooloos, J.G., Bolhuis, S.M., Laan, R.F., 2013. Do images influence assessment in anatomy? Exploring the effect of images on item difficulty and item discrimination. *Anat. Sci. Educ.* 6, 29–41, <http://dx.doi.org/10.1002/ase.1290>.
- Vorstenbosch, M.A., Kooloos, J.G., Bolhuis, S.M., Laan, R.F., 2016. An investigation of anatomical competence in junior medical doctors. *Anat. Sci. Educ.* 9, 8–17, <http://dx.doi.org/10.1002/ase.1513>.
- Yammine, K., 2014. The current status of anatomy knowledge: where are we now? Where do we need to go and how do we get there? *Teach. Learn. Med.* 26, 184–188, <http://dx.doi.org/10.1080/10401334.2014.883985>.
- Zurada, A., Gielecki, J.S., Osman, N., Tubbs, R.S., Loukas, M., Zurada-Zielinska, A., Bedi, N., Nowak, D., 2011. The study techniques of Asian, American, and European medical students during gross anatomy and neuroanatomy courses in Poland. *Surg. Radiol. Anat.* 33, 161–169, <http://dx.doi.org/10.1007/s00276-010-0721-6>.