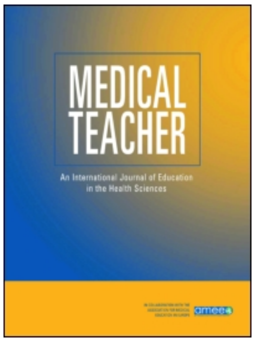

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BEME GUIDE

Effective methods of teaching and learning in anatomy as a basic science: A BEME systematic review: BEME guide no. 44

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ABSTRACT

Background: Anatomy is a subject essential to medical practice, yet time committed to teaching is on the decline, and resources required to teach anatomy is costly, particularly dissection. Advances in technology are a potential solution to the problem, while maintaining the quality of teaching required for eventual clinical application.
Aim: To identify methods used to teach anatomy, including those demonstrated to enhance knowledge acquisition and retention.
Methods: PubMed, CINAHL, ERIC, Academic OneFile, ProQuest, SAGE journals and Scopus were search from the earliest entry of each database to 31 August 2015. All included articles were assessed for methodological quality and low quality articles were excluded from the study. Studies were evaluated by assessment scores, qualitative outcomes where included as well as a modified Kirkpatrick model.
Results: A total of 17,820 articles were initially identified, with 29 included in the review. The review found a wide variety of teaching interventions represented in the range of studies, with CAI/CAL studies predominating in terms of teaching interventions, followed by simulation. In addition to this, CAI/CAL and simulation studies demonstrated better results overall compared to traditional teaching methods and there is evidence to support CAI/CAL as a partial replacement for dissection or a valuable tool in conjunction with dissection.
Conclusions: This review provides evidence in support of the use of alternatives to traditional teaching methods in anatomy, in particular, the use of CAI/CAL with a number of high quality, low risk of bias studies supporting this.

Introduction

Anatomy is considered a cornerstone of medical practice, particularly for those in surgical specialties as well as allied health professions, due to its direct relevance to clinical practice (Fredricks & Wegner 2003; Arraez-Aybar et al. 2010; Smith & Mathias 2011; Martin et al. 2014). Despite this importance, the teaching of anatomy in undergraduate programs is on the decline, with fewer contact hours and the rising costs associated with traditional methods such as dissection (Turney 2007; Collins 2008; Drake et al. 2009; Bergman et al. 2014).

Advancing technology in medical education, along with the decline in anatomy teaching, has led to increasing research on the effectiveness of various teaching methods (interventions) in anatomy (Lewis 2003; Tam et al. 2009; Yammine & Violato 2014, 2016). Emphasis is also being placed on student learning and the effects of student characteristics such as personality types, along with a reemergence of the concepts of student learning styles and learning approaches seen in much of the new literature on teaching and learning in anatomy (Smith & Mathias 2007; Finn et al. 2015; Liew et al. 2015), despite controversy over the validity of these concepts (Coffield et al. 2004a, b).

Teaching methods in anatomy may include didactic teaching, cadaveric dissection, inspection of prosected specimens, the use of models, surface anatomy and radiological anatomy (Kerby et al. 2011). Simulation tools such as ultrasound and arthroscopy are other teaching methods commonly utilized (Griksaitis et al. 2012; Knobe et al. 2012; Hammoudi et al. 2013; Jurjus et al. 2014). More modern methods of teaching anatomy such as computer-assisted instruction (CAI)/computer-assisted learning (CAL) are emerging as alternatives (Older 2004; McLachlan & Patten 2006; Turney 2007; Sugand et al. 2010; Papa & Vaccarezza 2013; Benly 2014), and most recently the use of 3D printed models has also emerged as a novel teaching tool for anatomy (AbouHashem et al. 2015; Adams et al. 2015; Lim et al. 2015; O'Reilly et al. 2015).

> **Practice points**
>
> - This review did not focus on the effectiveness of a single-teaching intervention category, but rather methods of teaching in anatomy across all categories.
> - The review found a number of high-quality studies supporting the use of CAI/CAL as a teaching intervention over traditional methods and even partial replacement of dissection with CAI/CAL.
> - Simulation showed favorable outcomes overall, but more rigorous studies evaluating simulation methods are required.

Effectiveness of teaching in anatomy is most commonly measured by knowledge acquisition (short-term, recall) or retention (long-term) through a variety of assessment methods. Other measures of effectiveness include qualitative measures typically evaluating student confidence levels

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in their knowledge as well as the enjoyment of the experience (Chen et al. 2010; Chinnah et al. 2011; Brown et al. 2012; Preece et al. 2013).

With the above in mind, it is timely to pose our primary systematic review question: What are the most effective methods of teaching anatomy? The objectives of this review were therefore to specifically identify: (i) methods used to teach anatomy and (ii) methods demonstrated to enhance knowledge acquisition (short-term) and retention (long-term) in anatomy.

The literature has revealed numerous studies that evaluate the effect of teaching methods in anatomy, with the majority of these being single-arm studies evaluating an intervention and its outcome. Previous literature reviews and recent meta-analyses have evaluated the effectiveness of teaching methods in anatomy with a particular focus on computer-assisted learning (CAL), 3D visualization technologies and physical models (Lewis 2003; Tam et al. 2009; Yammine & Violato 2014, 2016). This BEME systematic review differs from the previous reviews and meta-analyses in that it does not focus on a single-teaching intervention category, such as CAL or models, but rather seeks to review existing high-quality studies to identify the most effective methods of teaching in anatomy across all categories.

Methods

The protocol for this BEME systematic review was peer-reviewed and published online in 2014 (http://bemecollaboration.org/Reviews+In+Progress/Effectiveteaching/). In addition to this, the PRISMA guidelines (Moher et al. 2009) were utilized during the planning, conduct and writing of the review.

Study eligibility criteria

Inclusion and exclusion criteria are presented (Table 1) using the population, intervention(s), comparison, outcome(s) and study design (PICOS).

This review was aimed at anatomy as a basic science; therefore, only undergraduate medical or allied health student populations were evaluated and postgraduate activities excluded. Speech pathology and psychology as student populations were excluded as studies involving these student populations focused more on basic gross and functional anatomy rather than standard gross anatomy as seen in other included studies. Human gross anatomy as a topic was the focus of this review, excluding histology, embryology, veterinary and dental anatomy. The reason for such a stringent focus for the review was due to the vast amount of studies identified in medical and allied health undergraduate gross anatomy, and the need to allow for homogeneity of topics and populations.

Identification and selection of studies

Databases were searched beginning with the earliest entries of a given database. The inclusive dates by database were: PubMed (1946–2015), CINAHL (1937–2015), ERIC (1966–2015), Academic OneFile (1980–2013), ProQuest (all dates), SAGE Journals (1847–2015) and Scopus (1966–2015) were searched utilizing the terms presented in Table 2.

The complete search strategy for one database (PubMed) is presented as Table 3.

Gray literature from the Association for Medical Education in Europe (AMEE) and the Association for the Study of Medical Education (ASME) was not included in this review due to the breadth of articles captured in the initial identification and screening process.

Additional records were identified through two other sources, both being reviews of the literature (Lewis 2003;

Table 2. Search terms utilized across the seven databases.

Anatomy	AND teaching	AND effective[a]
	OR method[a]	OR instructional effectiveness
	OR pedagogy	OR knowledge
	OR teaching/trends	OR knowledge retention
	OR education	OR learning
	OR technology	OR retention
	OR educational technology	OR retention (psychology)
	OR computer-assisted instruction	OR enhance[a]
	OR computer simulation[a]	
	OR simulation	
	OR educational models	
	OR web-based learning	
	OR asynchronous learning	

[a]Truncation to allow for variation of the root word.

Table 1. PICOS description of inclusion and exclusion criteria.

PICOS	Inclusion criteria	Exclusion criteria
Population	(Medical or allied health) students, undergraduate	Technical college/TAFE student, postgraduate (speech pathology or psychology) students, anatomy and physiology combined
Intervention	(Human, gross) anatomy teaching in conjunction with: Method Pedagogy Teaching/trends Education/technology Educational technology Computer-assisted instruction Computer simulation Educational models Web-based learning Asynchronous learning	Veterinary anatomy Histology Embryology Dental anatomy Shadowing Peer teaching Practice audits Feedback alone
Comparison	Any comparison of teaching methods described in the intervention inclusion criteria that investigates a measurable outcome of knowledge acquisition or retention in anatomy as a basic science	
Outcome	• Levels of knowledge retention as • Quantified through assessment scores: immediate (knowledge acquisition) or after a specified interval (knowledge retention) • Reported outcomes according to modification of Kirkpatrick's levels of educational outcomes (qualitative) presented in Table 3	Qualitative outcome measures only assessments where anatomy was not the major component
Study design	Randomized controlled trials (RCTs) Comparative studies Cross-over design on a single group	Single-arm trials Retrospective studies Case series

Table 3. Complete search strategy for one database (PubMed).

Search {[anatomy (Title/Abstract)] AND [(teaching OR method[a] OR pedagogy OR teaching/trends OR education OR technology OR educational technology OR computer-assisted instruction OR computer simulation[a] OR simulation OR educational models OR web-based learning OR asynchronous learning)]} AND [(effective[a] OR instructional effectiveness OR knowledge OR knowledge retention OR learning OR retention OR retention AND (psychology) OR enhance[a])]. Superscript "a" indicates truncation to allow for variation of the root word.

The search strategy was modified accordingly for all other databases. Filters included were "Humans" and "English"

Tam et al. 2010). In addition, references of all included studies were screened for any further relevant articles cited. A rich site summary (RSS) feed (Dubuque 2011) was additionally established once data extraction begun, to allow any newer articles to be considered for inclusion. The cutoff date for this feed was 31 August 2015, ensuring the studies presented in this review were as recent as possible.

Data extraction process

The lead investigator (C.D.L.) screened all titles, removing only obviously irrelevant titles. Two investigators (A.A. and C.D.L.) then assessed the full-text of articles remaining for eligibility in duplicate and independently summarized study characteristics, outcomes, quality and risk of bias for each article using the electronic data extraction (coding) sheet developed for this review, discussed further below. Disagreements at any stage were evaluated and resolved by a third reviewer (A.J.M.).

An electronic data extraction (coding) sheet (Supplementary Table S1, available online as Supplemental data) using Microsoft Excel Software was developed by adhering to instructions found in BEME Guide 13 (Hammick et al. 2010). Analysis of coding sheets utilized in existing and similar BEME reviews (Issenberg et al. 2005; Hean et al. 2012) were also used as a benchmark, as was the Cochrane Collaboration's Data collection form for intervention reviews (Higgins 2011). Finally, the authors also used the CONSORT 2010 checklist (Schulz et al. 2010) for reporting of randomized trials to include any missing elements not already added. Using the above methods resulted in the development of a comprehensive coding sheet for the purpose of this review (Supplementary Table S1, available as Supplemental data).

Assessment of risk of bias and study quality

Risk of bias within studies and study quality was determined independently by two investigators (A.A. and C.D.0.L) using appropriate criteria from the Cochrane Collaboration's tool for assessing risk of bias (Higgins 2011), namely random sequence generation (allocation process), blinding of outcome assessment and "other" biases. Random sequence generation refers to the participant allocation process and subsequent risk of selection bias (biased allocation to interventions) and is determined by the randomization process utilized, where as an example use of a computer random number generator or sequentially numbered, opaque, sealed envelopes is judged as low risk and sequencing by date of birth or based on a test or series of tests is judged as high risk. Blinding of outcome assessment refers to knowledge of the allocated interventions by outcome assessors and subsequent risk of detection bias. Other bias in this review refers to potential bias related to the specific study design used.

Risk of bias of studies was reported as "high", "low" or "unclear". A judgment of "unclear" was made in cases where insufficient information was reported to permit judgment of high or low risk. Any disagreements were yet again evaluated and resolved by a third reviewer (A.J.M.). Risk of bias across studies was assessed during data analysis to ensure no selective reporting within the included studies had taken place, as recommended by the PRISMA guidelines (Moher et al. 2009).

Given the scope of this review, assessment of study quality was determined by incorporating risk of bias and then additionally critiquing the reported study design and methodology (internal validity). This process is recommended by Hammick et al. (2010) in that applicable components of a validated scale (Cochrane Collaboration's tool for assessing risk of bias) have been incorporated, a similar means of reporting article quality is also recommended by Colthart et al. (2008) and Aspegren (1999). Methodological quality was reported as "high", "medium" or "low". High-quality studies were predominantly pretest post-test RCT's, with all criteria for quality met, unless it was clear that meeting the given criteria would not influence the outcomes. Medium quality studies were those not meeting one criterion likely to influence outcomes and low quality lacked additional criteria as well as having high risk of bias. Low quality articles were excluded from the study.

Outcome measures

Hammick et al. (2010) recommends the use of Kirkpatrick's levels as a means of classifying and measuring effectiveness of educational interventions. The BEME collaboration suggests use of a modified version of Kirkpatrick's levels (Table 4) to grade the impact of educational interventions in a hierarchy. Grading ranges through four levels, with Level 1 being participants' views on the learning experience given, Level 2 a demonstrable change in attitudes and perceptions (2a) or knowledge and skills (2b), and Level 3 a demonstration of a change in behaviors such as applying new knowledge and skills. Levels 4a and 4b are described in the table but were not relevant to this review. Due to the broad nature of the studies included, grouping and reporting of studies using the modified version of Kirkpatrick's levels of educational outcomes was suitably employed (Kirkpatrick & Brodwell 1974).

Pilot review

A pilot review of 8–10 papers was conducted by two reviewers (A.A. and C.D.L.) utilizing BEME Guides 4 and 13 (Haig & Dozier 2003; Hammick et al. 2010). Two specific primary aims of the pilot review process were (i) piloting the coding sheet for data extraction in order to ensure all necessary data were identified and (ii) familiarize the two reviewers who would perform the final review with the data extraction tasks. Minor modifications were made to the coding sheet following the pilot review and the above aims were achieved.

Analysis and synthesis of included studies

The data in this review were not of sufficient homogeneity to combine (similar interventions, comparisons, outcomes and study designs); therefore, standard methods for quantitative pooling through meta-analysis (Higgins 2011) could not be employed.

Results

Search results and study selection

A PRISMA flow diagram of the study selection process is found in Figure 1. Studies retrieved were imported into EndNote X7 software (Thompson Reuters, NY), duplicates removed and manual screening for duplicates additionally performed. Two reviews of the literature on CAL (Lewis 2003; Tam et al. 2009) were identified as additional sources, presenting a further 17 articles in total for consideration. Four articles were duplicates of those already included in the review and of the remaining 13 only one article met the inclusion criteria. Inter-rater agreement on studies assessed for eligibility from full-text by raters A.A. and C.D.L. was determined with a Cohen's kappa of $\kappa = 0.86$, indicating an excellent level of agreement (Field 2009).

Table 4. BEME modification of Kirkpatrick's levels of educational outcomes.

Level 1	Participation: participants' views on the learning experience, its organization, presentation, content, teaching methods and quality of instruction
Level 2a	Modification of attitudes/perceptions: changes in the attitudes or perceptions among participant groups towards the teaching and learning
Level 2b	Modification of knowledge/skills: for knowledge, this relates to the acquisition of concepts, procedures and principles; for skills this relates to the acquisition of thinking/problem-solving, psychomotor and social skills
Level 3	Behavioral change: documents the transfer of learning to the workplace or willingness of learners to apply new knowledge and skills
Level 4a[a]	Change in organizational practice: wider changes in the organization or delivery of care, attributable to an educational program
Level 4b[a]	Benefits to patient/clients: any improvement in the health and well-being of patients/clients as a direct result of an educational program

[a]Levels not applicable to the context of this systematic review.

Overview of studies included in the review

A total of 17,820 articles were initially identified, with 29 included in the review. There were a wide variety of teaching interventions represented in the range of studies (presented in Supplementary Table S2, available online as Supplemental data). Randomized, controlled study designs predominated, as did medium study quality with a low risk of bias. CAI/CAL dominated as a teaching intervention, followed by simulation, models and other interventions respectively. Following data extraction and synthesis of results, studies could clearly be grouped by teaching intervention into six categories (as seen in Supplementary Table S2, available online on the Journal website as Supplemental data). Categories are not mutually exclusive as six comparative studies combined these (Qayumi et al. 2004; Donnelly et al. 2009; Griksaitis et al. 2012; Bareither et al. 2013; Chung et al. 2013; Kooloos et al. 2014). Where this was the case, it has been described in the text. Further information on the number of studies for each intervention as well as information on quality of studies is presented in

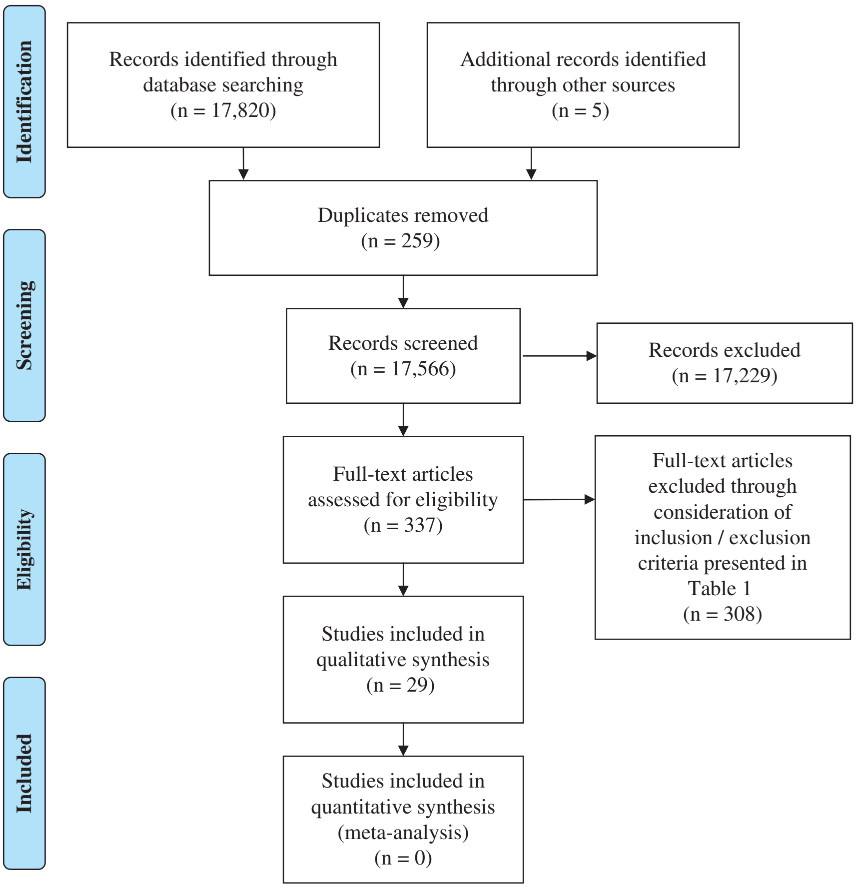

Figure 1. PRISMA diagram of the study selection process.

each category below. The categories were as follows, with associated outcomes presented narratively under each:

1. CAI/ CAL

The terms CAI and CAL are not separated in this review as in combination they represent both an intervention type and associated learning on behalf of the student. A total of 16 (majority by category) of the studies presented utilized CAI/CAL. Computer-assisted instruction was largely 3D (Glittenberg & Binder 2006; Nicholson et al. 2006; Donnelly et al. 2009; Hampton & Sung 2010; Tam et al. 2010; Venkatiah 2010; Fritz et al. 2011; Keedy et al. 2011; Pani et al. 2012; Pani et al. 2014; Saltarelli et al. 2014; Stirling & Birt 2014), some classifying themselves as "virtual reality" (Codd & Choudhury 2011; Hopkins et al. 2011) and two studies being 2D but still interactive (Stanford et al. 1994; Qayumi et al. 2004). Virtual reality (VR), 2D and 3D are denoted in each study presented in Supplementary Table S2 where applicable.

A number of studies demonstrated better results questionnaire/survey results and/or multiple choice or short-answer style assessments and questionnaire/survey results with 3D or interactive CAI/CAL as a teaching intervention over traditional teaching methods such as lectures (Glittenberg & Binder 2006; Hampton & Sung 2010), traditional practical sessions using models or prosections (Stirling & Birt 2014) or compared to 2D or non-interactive materials (Nicholson et al. 2006). Students' attitude scores to a 3D trainer intervention were significantly higher compared with conventional teaching methods (Glittenberg & Binder 2006), and in the study by Stirling and Birt (2014) students agreed that eBook technology complemented their practical sessions.

Pani et al. (2012, 2014) further evaluated specifics of CAI/CAL presentation of anatomical views, comparing whole and sectional presentations and found that interleaving whole and sectional views was superior to sectional views alone, supporting the concept of 3D over 2D once more. Pani et al. (2012), however, only found this performance to be short-term.

Stanford et al. (1994) evaluated a multimedia 2D computer application and found it superior in combination with dissection for structure identification on CT images and cadaveric specimens to using computer program or the dissection alone. Venkatiah (2010) reports the partial replacement of dissection activities with CAI/CAL improves assessment outcomes, though this article was rated medium quality since it presented an unclear risk of bias due to the limited information provided, therefore no clear conclusions could be drawn, even with its large sample size ($n = 150$). Students in this study did report finding the combined activities both useful and enjoyable. One study showed that interactive CAI/CAL proved more successful on its own or in combination with text (read/write) intervention than text alone (Qayumi et al. 2004), but only for MCQ (knowledge) assessment with no difference in scores at OSCE (procedural) examination. Text-only students in this study were additionally left dissatisfied on qualitative evaluation.

Two high quality/low risk of bias studies in this review reported equivalent effects of CAI/CAL to typical teaching interventions such as prosections (Hopkins et al. 2011), though students reported a preference for a combination of the two, and 2D interventions (Keedy et al. 2011) previously discussed above. One other study reported no difference in outcomes for CAI/CAL in a crossover pretest post-test design using the "Virtual Human Dissector" platform (Donnelly et al. 2009), though the use of this platform was through self-directed study rather than as a teaching intervention and as such may be prone to other sources of bias due to student learning or study approaches. The risk of bias in this particular study was also deemed unclear due to limited information regarding randomization procedures and group characteristics/demographics. Codd and Choudhury (2011) demonstrated no difference in outcomes for 3D virtual reality (VR) compared to traditional methods such as dissection and textbooks. This study is considered to have a low risk of bias; therefore, the results are clear and most likely valid, but the potential impact of small group learning such as is seen with dissection and stated in this study (groups of four students) may enhance the effect of dissection when compared with non-small group learning activities such as CAI/CAL interventions. In addition to the quantitative findings, students actually reported that VR was not as good as using dissection or prosection despite the outcomes. Tam et al. (2010) reported equal outcomes from a different perspective, both groups having 3D CAI/CAL interventions but rather examining self-directed compared to worksheet-guided access, with students providing positive feedback on the computer program used.

In contrast to the predominant study findings above, two studies reported poorer (short-term) outcomes with CAI/CAL interventions. Fritz et al. (2011), a follow-up study to Hu et al. (2010), compared 3D CAI/CAL with standard written instruction and found the 3D intervention had a poorer outcome in the short-term, but that they were equivalent in the long-term (6 months). This prospective RCT was considered high quality/low risk of bias and is one of the few in this review that considered longer-term outcomes. Despite these short-term differences, students rated the 3D model more enjoyable than written instruction. Saltarelli et al. (2014) reports a multimedia learning system "Anatomy and Physiology Revealed" as having poorer outcomes compared to dissection. This may be due to the potential small group effect previously mentioned or may be due to haptic learning experiences potentially associated with dissection itself, but being a quasi-experimental post-test study it was viewed as having a high risk of bias.

In comparing 2D versus 3D CAI/CAL interventions, Keedy et al. (2011) report an equivalent effect of 2D and 3D interventions, with students however reporting a significantly (statistically) higher satisfaction with a 3D intervention. Pani et al. (2014) reported students supporting the use of CAI/CAL (both 2D and 3D) as superior for learning neuroanatomy in particular.

In conclusion, CAI/CAL yielded better results both over traditional lectures or practicals using models and/or prosection. The studies support potential partial replacement of dissection with CAI/CAL or a combination of CAI/CAL with dissection. There was no significant difference in outcomes for 2D compared to 3D technology; however, students report a higher level of enjoyment/satisfaction with 3D interventions. Qualitative ratings of CAI/CAL were largely positive overall.

2. Simulation

Simulation was decided on as a category that incorporated any activity that simulated examination or a procedure the students were to encounter in their studies or practice (contextual). Simulation included video (AlNassar et al. 2012; Chung et al. 2013; Kooloos et al. 2014) demonstration (Wilson et al. 2009; Böckers et al. 2014) and real patients (Takkunen et al. 2011). Activities utilizing imaging procedures such as ultrasound (Griksaitis et al. 2012) and arthroscopy (Knobe et al. 2012) were additionally considered simulation, with ultrasound seen in the literature as a modern, non-invasive teaching supplementary or alternative modality (McLachlan & Patten 2006; Benly 2014).

All but one comparative study by Takkunen et al. (2011) demonstrated superior or at least equal outcomes with the use of simulation, though none evaluated any longer-term outcomes. Two of the studies presented were deemed to have a high risk of bias; both due to their quasi- experimental design and subsequent lack of randomization (Wilson et al. 2009; Böckers et al. 2014) and their results are further discussed below.

The use of more dynamic or "real-time" imaging techniques such as thoracoscopy, arthroscopy and ultrasound are emerging as a teaching intervention. As an example, AlNassar et al. (2012) compared a radiology (3D) lecture on the thorax with the use of a thoracoscopy video, demonstrating a significant increase in MCQ results for the thoracoscopy group. The majority of students reporting the thoracoscopy video considered it to be beneficial to their learning of anatomy. Knobe et al. (2012), in a large sample post-test RCT with crossover deemed medium quality/low risk of bias compared ultrasound with arthroscopy for the knee and shoulder joint, showing improved examination results for the arthroscopy over ultrasound, but the results were limited in this case to the shoulder region only. Regardless of this limitation, students reported that arthroscopy provided higher spatial imagination benefits than ultrasound. However, results following crossover were statistically non-significant.

Wilson et al. (2009) evaluated the effect of adding procedural demonstrations and practice of clinical procedures to an anatomy review laboratory, showing an increase in both anatomy and clinical MCQ scores with this addition. Students also agreed the procedural laboratory to be a positive experience. The study design was quasi-experimental with a lack of randomization, which led to a designation of high risk of bias.

Böckers et al. (2014) analyzed the effect of an elective course where students performed an active role and observed demonstrations performed on cadavers. They concluded that there was no significant difference in overall performance in the anatomy course. This study additionally utilized measures of student learning styles and approaches to study, with learning styles favorable in the elective course group for enhanced learning, though appearing to have no effect on the overall outcome. Another consideration for this study is its high risk of bias due to its quasi-experimental design with lack of randomization. An interesting finding in this study though was an increase in a "deep" and decrease in a "superficial" approach in the intervention group participants' learning.

Takkunen et al. (2011) evaluated two groups presented with a patient case, with the experimental (simulation) group encountering the real patient in an interview and examination scenario. They showed no difference between simulation and the control group. The risk of bias in this study was unclear due to very limited information presented, but a large sample was utilized, therefore if risk of bias could be accurately assessed these results could be valuable. Interestingly, students did report that the real patient was more interesting and improved their study motivation.

3. Models

Models included the use of prosected specimens (Donnelly et al. 2009; Griksaitis et al. 2012; Chung et al. 2013) as well as clay modeling (Bareither et al. 2013; Kooloos et al. 2014). No single study evaluated compared models in isolation with conventional teaching methods, but rather all utilized comparative study designs to compare them to other methods such as simulation. The majority of outcomes in these studies demonstrated them to be equal to other methods tested.

Chung et al. (2013) in a medium quality/low risk of bias comparative study explored the use of advance organizers (AO) in both video and prosection formats. Advance organizers are a concept originally developed by David Ausubel and are described in the study as "more abstract, general and comprehensive materials used to highlight key learning objectives linking prior knowledge to new learning material". They demonstrated significantly higher achievement scores in the prosection AO group in a sample of 141 students. This sample size is notably higher in comparison to most educational studies of this type. Students' perception of the learning experience was correspondingly greater in the prosection group. Advance organizers come in various formats and can include introduction of a new topic with a story (narrative), graphic (such as a Venn diagram or concept map), in an exploratory manner where known concepts are used to build new knowledge. Ultimately, they provide a framework on which to add new information from a newly presented topic.

A study by Kooloos et al. (2014), considered medium quality/low risk of bias and with a large sample, analyzed clay modeling with live or video observation of the modeling (classified in this review as simulation) but is discussed here as it focuses around modeling as the primary intervention. The study concluded that live observations were superior to both modeling and video observation, with live observation outperforming video. Bareither et al. (2013) investigated the use of clay models and written modules in applied health sciences students and found them to be matched in their outcomes, with significantly better outcomes for both groups above dissection alone in the short-term but no significant difference in the long-term (3 months). This study incorporated the use of a VARK questionnaire (Fleming 2006) to identify student-learning styles and found no significant relationship between student learning styles and outcomes, and was regarded as medium quality/low risk of bias, further strengthening the results presented.

Finally, Griksaitis et al. (2012) in a medium quality/low risk of bias study compared the use of prosections to live ultrasound images in cardiac anatomy, with ultrasound performing as well as the prosection group.

4. Dissection (other)

Traditional dissection in anatomy education involves the use of human cadavers, and where students work in small groups (Singh & Kharb 2013; Benly 2014), facilitating an improved understanding of 3D relationships in the human body (Older 2004; Singh & Kharb 2013) as well as a lesser-recognized benefit (hidden curriculum) of introducing the concept of humanistic care (Rizzolo 2002). This category of dissection (other) is that of dissection not typical to most human anatomy courses. In this review, these specifically included the use of animal specimens (Musumeci et al. 2014) as well as 3D laparoscopic dissection models in contrast to the traditionally prepared cadaver (ten Brinke et al. 2014).

Both studies, looking at alternative dissection models, showed positive (quantitative only) outcomes when compared to conventional teaching. Musumeci et al. (2014) found better results with the use of porcine hearts for practical training over usual didactic lectures incorporating the use of plastic models. This study, however, had an unclear risk of bias as information regarding randomization was not reported and it is also worth noting that the porcine hearts intervention added 3 h to the usual teaching time, increasing the students' exposure to the topic. ten Brinke et al. (2014) demonstrates improved outcomes with dissection using 3D laparoscopic dissection models alone over the use of such models in combination with lectures in the short-term; however, this difference did not remain at 2-week follow-up. This pretest post-test RCT was deemed medium quality/low risk of bias.

5. Read/write

Read/write included any written modules (Bareither et al. 2013), written forms of instruction (Hofer et al. 2011) or text version of a usually interactive intervention (Qayumi et al. 2004).

Read/write intervention studies demonstrated superior or equivocal outcomes. In a medium quality/low risk of bias crossover post-test design, Hofer et al. (2011) evaluated the use of hard copy checklists with a directive to use them in the dissection class, in comparison with electronic checklists with no directive, and found them to have a significantly positive result on assessment scores. Students preferred the use of the hard copy checklists, stating it made dissection more efficient and increased their performance in the laboratory. The results from a read/write intervention compared to models by Bareither et al. (2013) was previously discussed under the heading of models.

6. Course integration

The final category of course integration refers to integration of a related unit into anatomy studies, in this case specifically a physical examination course (Adibi et al. 2007). Ganguly (2010) reports integration as a means to allow for a thorough understanding of the topic in question and briefly lists various methods of doing so. Course integration can be seen as a form of contextual learning, a constructivist theory concept originally developed by John Dewey, allowing students to see the meaning in their academic material and therefore be motivated to gain the knowledge (Johnson 2002).

The single study identified in this review showed potentially positive outcomes with course integration. Adibi et al. (2007) reports significantly higher scores in theoretical anatomy in students participating in an integrated course of physical examination and trunk anatomy over lectures and case-based discussions using problem-based learning (PBL). This study was allocated an unclear risk of bias due to lack of group characteristics and blinding information and that the integrated course learning took place in small groups, which may have impact on the overall effect. Students also provided positive feedback on the course. Boon et al. 2001 support the notion of clinical integration in previous literature reporting clinical exposure enhances the learning of anatomy.

It is worth noting here that the categories presented above are not dissimilar to the categories described by Sugand et al. (2010) for optimal learning in anatomy, being (i) dissection/prosection, (ii) interactive multimedia, (iii) procedural anatomy, (iv) surface and clinical anatomy, and (v) imaging, as well as the importance of multimodal teaching.

As CAI/CAL dominated the intervention types, we decided to additionally present studies graphically by year of publication and categorized by intervention type (Supplementary Figure S1, available online as Supplemental data) to demonstrate a move toward these possible alternatives to traditional dissection in the last few years. Supplementary Figure S1 shows an increase in the number of CAI/CAL interventions in studies, with a movement from 2D to 3D from 2006 as well as studies on simulation and models as interventions emerging frequently from 2009.

Discussion

This review found a broad range of methods utilized in teaching anatomy. CAI/CAL and simulation methods predominated, with ultrasound and arthroscopy emerging as teaching tools under the simulation category. CAI/CAL interventions ranged from 3D, including virtual reality, to 2D. Other teaching methods included using models, the use of advance organizers, non-traditional dissection such as the use of animal specimens and laparoscopic dissection models, read/write interventions and course integration. Six studies in total compared teaching interventions to each other.

The findings on CAI/CAL as a teaching intervention were positive, proving better than traditional methods such as lectures, models or in some cases prosections. CAI/CAL as a viable partial replacement for dissection, and in combination with dissection yields at least equivalent or even better results than dissection alone. This supports the concept of introducing CAI/CAL into curricula due to limited time and/or resources in anatomy courses. Qualitative ratings of CAI/CAL were largely positive, providing yet another incentive for its use in anatomy teaching.

The review findings on CAI/CAL are consistent with previous studies presented chronologically below. Lewis (2003) reviewed the literature for CAL use (1994–2002) and associated outcomes in anatomy and physiology in subjects allied to health and concluded that four of nine studies evaluated demonstrated improved quantitative outcomes associated with CAL use, two studies having equivalent outcomes to traditional methods of teaching and one with poorer outcomes compared to didactic lectures. A more recent review of the literature by Tam et al. (2009) for the effectiveness of CAL in undergraduate medical anatomy tuition presented eight studies that tended to report favorably for CAL use. Most recently, a meta-analysis of 3D technologies by Yammine and Violato (2014), demonstrated these interventions yield significantly better factual and spatial knowledge outcomes. This systematic review presents additional studies on CAI/CAL not reported in these reviews, as well as further support for the concept of partial replacement of dissection or a combined approach of CAI/CAL with dissection where only one study in the review by Tam et al. (2009) presented the concept. Once more, this is an important finding to consider given the potential positive impact such replacement can have on time and resource allocation.

In addition, the qualitative findings presented in this review for CAI/CAL are consistent with the findings in previous reviews. Lewis (2003), in his review of the literature for CAL use, reports one study with positive qualitative assessment by students for online materials. In the review of the literature by Tam et al. (2009) for the effectiveness of CAL in anatomy tuition, qualitative outcomes measures showed student attitudes in terms of satisfaction and enjoyment for CAL use were favorable. These findings are relevant as if we are to consider using more CAI/CAL in our curricula it is valuable knowing that students find it enjoyable regardless of whether results are better or equivocal, as student enjoyment, engagement and motivation all have a role to play in student learning (Brophy 2013).

Simulation showed favorable outcomes overall, with the use of imaging techniques such as arthroscopy and ultrasound emerging as contemporary teaching tools, though more rigorous studies evaluating simulation interventions are required.

Other studies less commonly identified utilized models and read/write interventions. The use of models mostly seemed to have variable outcomes when compared with simulation or read/write interventions. A recent meta-analysis of eight studies by Yammine and Violato (2016) examined outcomes associated with the use of physical models as a low-cost alternative to 3D CAI/CAL interventions. They reported significantly better overall results (including long-term) and spatial knowledge acquisition, but no significant difference for factual knowledge acquisition; therefore, still presenting an effective viable low-cost alternative for teaching. Positive outcomes for course integration and alternatives to traditional dissection were also noted, though studies for such interventions were few.

Most studies evaluated short-term outcomes only, discussed in this review as knowledge acquisition or recall. Those evaluating longer-term outcomes (ranging from 1–6 months) demonstrated that longer-term outcomes were not as positive as short-term, with knowledge declining over time (Fritz et al. 2011; Pani et al. 2012; Bareither et al. 2013; Gradl-Dietsch et al. 2016).

Finally, though it was not an aim of this review to evaluate assessment methods or their validity and role in student learning, it became clear it was necessary to document these for each study to assist in the interpretation of outcomes/results of each study (Supplementary Table S2, available online on the Journal website as Supplemental data). Assessment as a driver of student learning is already documented in the literature (Wormald et al. 2009; Chappuis et al. 2013) and is therefore a necessary component to consider in student learning and interventional study outcomes where assessment scores are the primary outcome measure.

Conclusion

This review adds to the body of knowledge demonstrating benefits of a variety of teaching methods or multimodal teaching and emerging technologies in the teaching of anatomy. Demonstration of "effective" interventions in this review could be those considered superior to traditional teaching methods, but more importantly those at least equal to or no lesser than traditional methods are just as important, as many of these interventions are less expensive, require fewer resources to support them and can be delivered in ways that would be time efficient. CAI/CAL therefore provides the ability to replace didactic lectures with more efficient use of teaching time where necessary (tutorials, workshops), reduces the number of contact hours or offers online alternatives to students in a busy world where technology is easily accessible by most.

Tam et al. (2009) state in the conclusion of their review that there is insufficient evidence that CAL can replace traditional teaching methods and that further research is needed to determine how such methods can be integrated into anatomy teaching. This systematic review along with earlier reviews and meta-analysis (Yammine & Violato 2014) therefore adds to this necessary body of information to allow those teaching in anatomy to understand the impact and potential uses of such interventions.

Strengths and limitations of the review

This review was conducted using best practice (http://www.bemecollaboration.org) including a peer-reviewed review protocol and pilot review, independent data abstraction (in duplicate) with a third reviewer for negotiating differences, and a very broad search strategy, which meant that most relevant articles could be captured. This was evident when reviewing references in the studies as well as other reviews and meta-analyses conducted at that time. The addition of a late cutoff date of 31 August 2015 for articles included ensured the review could be as current as possible at the time of publication. The Cochrane handbook (Higgins 2011) was employed for evaluation of risk of bias, with a previous BEME review (Hammick et al. 2010) additionally used to establish quality criteria. The PRISMA checklist (http://www.prisma-statement.org) was additionally consulted in the reporting of this systematic review.

One limitation was that the search strategy did not allow for direct consideration of PBL as a teaching intervention, a teaching method that seems to be on the increase in anatomy curricula. The search strategy additionally did not include terms such as "video" (which would incorporate entities such as YouTube), though the term "technology" may have encompassed this. It is worth noting again that 3D printing emerged in the literature as the review process was underway and was therefore not included, but has been captured and reported in this review as a novel teaching tool in anatomy.

Future research in this area could include an update on CAI/CAL and new or emerging simulation or model technologies (such as 3D printing and virtual cadavers). Newer CAI/CAL virtual reality technologies have the potential to replace (and in some cases have replaced) traditional dissection. If we are to consider these interventions/teaching methods a substitute for dissection then it is essential we compare them to traditional dissection first in our anatomy teaching environments, as this seems yet to have been done.

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The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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References

AbouHashem Y, Dayal M, Savanah S, Strkalj G. 2015. The application of 3D printing in anatomy education. Med Educ Online. 20:29847.

Adams JW, Paxton L, Dawes K, Burlak K, Quayle M, McMenamin PG. 2015. 3D printed reproductions of orbital dissections: a novel mode of visualising anatomy for trainees in ophthalmology or optometry. Br J Ophthalmol. 99:1162–1167.

Adibi I, Hasani N, Ashoorioun V, Sadrearhami S, Monajemi AR. 2007. Integrating physical examination and trunk anatomy; a new course for second year medical students. Med Teach. 29:975–977.

AlNassar SA, Hajjar W, Rahal S, Clifton J, Finley R, Sidhu R. 2012. The use of thoracoscopy to enhance medical students' interest and understanding of thoracic anatomy. Ann Thorac Med. 7:145–148.

Arraez-Aybar LA, Sanchez-Montesinos I, Mirapeix RM, Mompeo-Corredera B, Sanudo-Tejero JR. 2010. Relevance of human anatomy in daily clinical practice. Ann Anat. 192:341–348.

Aspegren K. 1999. BEME Guide No. 2: teaching and learning communication skills in medicine-a review with quality grading of articles. Med Teach. 21:563–570.

Bareither ML, Arbel V, Growe M, Muszczynski E, Rudd A, Marone JR. 2013. Clay modeling versus written modules as effective interventions in understanding human anatomy. Anat Sci Educ. 6:170–176.

Benly P. 2014. Teaching methodologies on anatomy-a review. J Pharm Sci Res. 6:242–243.

Bergman EM, Verheijen IWH, Scherpbier AJJA, Van der Vleuten CPM, Bruin ABH. 2014. Influences on anatomical knowledge: the complete arguments. Clin Anat. 27:296–303.

Böckers A, Mayer C, Böckers TM. 2014. Does learning in clinical context in anatomical sciences improve examination results, learning motivation, or learning orientation? Anat Sci Educ. 7:3–11.

Boon JM, Meiring JH, Richards PA, Jacobs CJ. 2001. Evaluation of clinical relevance of problem-oriented teaching in undergraduate anatomy at the University of Pretoria. Surg Radiol Anat. 23:57–60.

Brophy JE. 2013. Motivating students to learn, New York: Routledge.

Brown PM, Hamilton NM, Denison AR. 2012. A novel 3D stereoscopic anatomy tutorial. Clin Teach. 9:50–53.

Chappuis J, Stiggins RJ, Chappuis S, Arter JA. 2013. Classroom assessment for student learning: doing it right-using it well. Pearson New International Edition. Upper Saddle River, NJ: Pearson Higher Ed.

Chen KC, Glicksman JT, Haase P, Johnson M, Wilson T, Fung K. 2010. Introduction of a novel teaching paradigm for head and neck anatomy. J Otolaryngol Head Neck Surg. 39:349–355.

Chinnah TI, De Bere SR, Collett T. 2011. Students' views on the impact of peer physical examination and palpation as a pedagogic tool for teaching and learning living human anatomy. Med Teach. 33:e27–e36.

Chung E-K, Nam K-I, Oh S-A, Han E-R, Woo Y-J, Hitchcock MA. 2013. Advance organizers in a gross anatomy dissection course and their effects on academic achievement. Clin Anat. 26:327–332.

Codd AM, Choudhury B. 2011. Virtual reality anatomy: is it comparable with traditional methods in the teaching of human forearm musculoskeletal anatomy? Anat Sci Educ. 4:119–125.

Coffield F, Moseley D, Hall E, Ecclestone K. 2004a. Learning styles and pedagogy in post 16 learning: a systematic and critical review. LSRC Reference. London: The Learning and Skills Research Centre.

Coffield F, Moseley D, Hall E, Ecclestone K. 2004b. Should we be using learning styles? What research has to say to practice. LSRC Reference. London: The Learning and Skills Research Centre.

Collins J. 2008. Modern approaches to teaching and learning anatomy. BMJ 337:665.

Colthart I, Bagnall G, Evans A, Allbutt H, Haig A, Illing J, McKinstry B. 2008. The effectiveness of self-assessment on the identification of learner needs, learner activity, and impact on clinical practice: BEME guide no. 10. Med Teach. 30:124–145.

Donnelly L, Patten D, White P, Finn G. 2009. Virtual human dissector as a learning tool for studying cross-sectional anatomy. Med Teach. 31:553.

Drake RL, McBride JM, Lachman N, Pawlina W. 2009. Medical education in the anatomical sciences: the winds of change continue to blow. Anat Sci Educ. 2:253–259.

Dubuque EM. 2011. Automating academic literature searches with RSS feeds and Google Reader™. Behav Anal Pract. 4:63.

Field A. 2009. Discovering statistics using SPSS. London: Sage publications.

Finn GM, Walker SJ, Carter M, Cox DR, Hewitson R, Smith CF. 2015. Exploring relationships between personality and anatomy performance. Anat Sci Educ. 8:547–554.

Fleming ND. 2006. Teaching and learning styles: VARK strategies. Christchurch, New Zeeland: ND Fleming.

Fredricks KT, Wegner WM. 2003. Clinical relevance of anatomy and physiology: a senior/freshman mentoring experience. Nurse Educ. 28:197–199.

Fritz D, Hu A, Wilson T, Ladak H, Haase P, Fung K. 2011. Long-term retention of a 3-dimensional educational computer model of the larynx: a follow-up study. Arch Otolaryngol Head Neck Surg. 137:598–603.

Ganguly PK. 2010. Teaching and learning of anatomy in the 21st century: direction and the strategies. Open Med Educ J. 3:5–10.

Glittenberg C, Binder S. 2006. Using 3D computer simulations to enhance ophthalmic training. Ophthalmic Physiol Opt. 26:40–49.

Gradl-Dietsch G, Korden T, Modabber A, Sönmez TT, Stromps J-P, Ganse B, Pape H-C, Knobe M. 2016. Multidimensional approach to teaching anatomy—do gender and learning style matter? Ann Anat. 208:158–164.

Griksaitis MJ, Sawdon MA, Finn GM. 2012. Ultrasound and cadaveric prosections as methods for teaching cardiac anatomy: a comparative study. Anat Sci Educ. 5:20–26.

Haig A, Dozier M. 2003. BEME Guide no 3: systematic searching for evidence in medical education-Part 1: sources of information. Med Teach. 25:352–363.

Hammick M, Dornan T, Steinert Y. 2010. Conducting a best evidence systematic review. Part 1: from idea to data coding. BEME guide no. 13. Med Teach. 32:3–15.

Hammoudi N, Arangalage D, Boubrit L, Renaud MC, Isnard R, Collet JP, Cohen A, Duguet A. 2013. Ultrasound-based teaching of cardiac anatomy and physiology to undergraduate medical students. Arch Cardiovasc Dis. 106:487–491.

Hampton BS, Sung VW. 2010. Improving medical student knowledge of female pelvic floor dysfunction and anatomy: a randomized trial. Am J Obstet Gynecol. 202:601.e601–608.

Hean S, Anderson L, Green C, O'Halloran C, Pitt R, Morris D, John C, Temple J. 2012. Protocol: a systematic review of the contribution of theory to the development & delivery of effective interprofessional curricula in health professional education.

Higgins J. 2011. Green S. Cochrane handbook for systematic reviews of interventions version 5.1.0. The Cochrane Collaboration 5, updated March 2011. The Cochrane Collaboration.

Hofer RE, Brant Nikolaus O, Pawlina W. 2011. Using checklists in a gross anatomy laboratory improves learning outcomes and dissection quality. Anat Sci Educ. 4:249–255.

Hopkins R, Regehr G, Wilson TD. 2011. Exploring the changing learning environment of the gross anatomy lab. Acad Med. 86:883–888.

Hu A, Wilson T, Ladak H, Haase P, Doyle P, Fung K. 2010. Evaluation of a three-dimensional educational computer model of the larynx: voicing a new direction. J Otolaryngol Head Neck Surg. 39:315–322.

Issenberg BS, McGaghie WC, Petrusa ER, Lee Gordon D, Scalese RJ. 2005. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. Med Teach. 27:10–28.

Johnson EB. 2002. Contextual teaching and learning: what it is and why it's here to stay. Thousand Oaks (CA): Corwin Press.

Jurjus RA, Dimorier K, Brown K, Slaby F, Shokoohi H, Boniface K, Liu YT. 2014. Can anatomists teach living anatomy using ultrasound as a teaching tool? Anat Sci Educ. 7:340–349.

Keedy AW, Durack JC, Sandhu P, Chen EM, O'Sullivan PS, Breiman RS. 2011. Comparison of traditional methods with 3D computer models in the instruction of hepatobiliary anatomy. Anat Sci Educ. 4:84–91.

Kerby J, Shukur ZN, Shalhoub J. 2011. The relationships between learning outcomes and methods of teaching anatomy as perceived by medical students. Clin Anat. 24:489–497.

Kirkpatrick DL, Brodwell M. 1974. Evaluation of training. CREDR Corporation. San Francisco: Berrett-Koehler Publishers.

Knobe M, Carow JB, Ruesseler M, Leu BM, Simon M, Beckers SK, Ghassemi A, Sönmez TT, Pape H-C. 2012. Arthroscopy or ultrasound in undergraduate anatomy education: a randomized cross-over controlled trial. BMC Med Educ. 12:85.

Kooloos JG, Schepens-Franke AN, Bergman EM, Donders RA, Vorstenbosch MA. 2014. Anatomical knowledge gain through a clay-modeling exercise compared to live and video observations. Anat Sci Educ. 7:420–429.

Lewis MJ. 2003. Computer-assisted learning for teaching anatomy and physiology in subjects allied to medicine. Med Teach. 25:204–206.

Liew SC, Sidhu J, Barua A. 2015. The relationship between learning preferences (styles and approaches) and learning outcomes among pre-clinical undergraduate medical students. BMC Med Educ 15:44.

Lim KH, Loo ZY, Goldie SJ, Adams JW, McMenamin PG. 2015. Use of 3D printed models in medical education: a randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy. Anat Sci Educ. 9:213–221.

Martin K, Bessell NJ, Scholten I. 2014. The perceived importance of anatomy and neuroanatomy in the practice of speech-language pathology. Anat Sci Educ. 7:28–37.

McLachlan JC, Patten D. 2006. Anatomy teaching: ghosts of the past, present and future. Med Educ. 40:243–253.

Moher D, Liberati A, Tetzlaff J, Altman DG. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Int Med. 338:264–269.

Musumeci G, Loreto C, Mazzone V, Szychlinska MA, Castrogiovanni P, Castorina S. 2014. Practical training on porcine hearts enhances students' knowledge of human cardiac anatomy. Ann Anat. 196:92–99.

Nicholson DT, Chalk C, Funnell WR, Daniel SJ. 2006. Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. Med Educ. 40:1081–1087.

O'Reilly MK, Reese S, Herlihy T, Geoghegan T, Cantwell CP, Feeney RN, Jones JF. 2015. Fabrication and assessment of 3D printed anatomical models of the lower limb for anatomical teaching and femoral vessel access training in medicine. Anat Sci Educ. 9:71–79.

Older J. 2004. Anatomy: a must for teaching the next generation. Surgeon. 2:79–90.

Pani JR, Chariker JH, Naaz F. 2012. Computer-based learning: interleaving whole and sectional representation of neuroanatomy. Anat Sci Educ. 6:11–18.

Pani JR, Chariker JH, Naaz F, Mattingly W, Roberts J, Sephton SE. 2014. Learning with interactive computer graphics in the undergraduate neuroscience classroom. Adv Health Sci Educ Theory Pract. 19:507–528.

Papa V, Vaccarezza M. 2013. Teaching anatomy in the XXI century: new aspects and pitfalls. ScientificWorldJournal. 2013:310348

Preece D, Williams SB, Lam R, Weller R. 2013. "Let's get physical advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy". Anat Sci Educ. 6:216–224.

Qayumi A, Kurihara Y, Imai M, Pachev G, Seo H, Hoshino Y, Cheifetz R, Matsuura K, Momoi M, Saleem M. 2004. Comparison of computer-assisted instruction (CAI) versus traditional textbook methods for training in abdominal examination (Japanese experience). Med Educ. 38:1080–1088.

Rizzolo LJ. 2002. Human dissection: an approach to interweaving the traditional and humanistic goals of medical education. Anat Rec. 269:242–248.

Saltarelli AJ, Roseth CJ, Saltarelli WA. 2014. Human cadavers vs. multimedia simulation: a study of student learning in anatomy. Anat Sci Educ. 7:331–339.

Schulz KF, Altman DG, Moher D. 2010. CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. BMC Med. 8:18.

Singh V, Kharb P. 2013. A paradigm shift from teaching to learning gross anatomy: meta-analysis of implications for instructional methods. J Anatom Soc India. 62:84–89.

Smith C, Mathias H. 2007. Educational perspectives on learning anatomy. J Anat. 210:774–775.

Smith CF, Mathias HS. 2011. What impact does anatomy education have on clinical practice? Clin Anat. 24:113–119.

Stanford W, Erkonen WE, Cassell MD, Moran BD, Easley G, Carris RL, Albanese MA. 1994. Evaluation of a computer-based program for teaching cardiac anatomy. Invest Radiol. 29:248–252.

Stirling A, Birt J. 2014. An enriched multimedia eBook application to facilitate learning of anatomy. Anat Sci Educ. 7:19–27.

Sugand K, Abrahams P, Khurana A. 2010. The anatomy of anatomy: a review for its modernization. Anat Sci Educ. 3:83–93.

Takkunen M, Turpeinen H, Viisanen H, Wigren HK, Aarnio M, Pitkaniemi J. 2011. Introduction of real patients into problem-based learning in preclinical first-year anatomy curriculum. Med Teach. 33:854–856.

Tam MD, Hart AR, Williams S, Heylings D, Leinster S. 2009. Is learning anatomy facilitated by computer-aided learning? A review of the literature. Med Teach. 31:e393–e396.

Tam MD, Hart AR, Williams SM, Holland R, Heylings D, Leinster S. 2010. Evaluation of a computer program ('disect') to consolidate anatomy knowledge: a randomised-controlled trial. Med Teach. 32:e138–e142.

ten Brinke B, Klitsie PJ, Timman R, Busschbach JJ, Lange JF, Kleinrensink GJ. 2014. Anatomy education and classroom versus laparoscopic dissection-based training: a randomized study at one medical school. Acad Med. 89:806–810.

Turney B. 2007. Anatomy in a modern medical curriculum. Ann R Coll Surg Engl. 89:104.

Venkatiah J. 2010. Computer-assisted modules to enhance the learning of anatomy by dissection. Med Educ. 44:523–524.

Wilson AB, Ross C, Petty M, Williams JM, Thorp LE. 2009. Bridging the transfer gap: laboratory exercise combines clinical exposure and anatomy review. Med Educ. 43:790–798.

Wormald BW, Schoeman S, Somasunderam A, Penn M. 2009. Assessment drives learning: an unavoidable truth? Anat Sci Educ. 2:199–204.

Yammine K, Violato C. 2014. A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. Anat Sci Educ. 8:525–538.

Yammine K, Violato C. 2016. The effectiveness of physical models in teaching anatomy: a meta-analysis of comparative studies. Adv Health Sci Educ Theory Pract. 21:883–895.