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Do Digital Technologies Enhance Anatomical Education?

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Abstract

Anatomy has been taught by traditional methods for centuries. However, there has been an explosion of a variety of digital training resources for anatomical education. There is also a requirement from regulatory bodies to embrace digital technologies in teaching, yet no formal analysis has been undertaken as to the effectiveness of these products and tools. A comprehensive electronic database search was performed to identify the use, and effectiveness or otherwise, of digital technologies in anatomy, medicine, surgery, dentistry and the allied health professions. The data was pooled, analysed and we identified 164 articles. We identified two groups – those that did, and those that did not, have empirical data for analysis of the effectiveness of digital technologies in anatomical education. We identified three categories within this –pro, neutral and against the use of digital technologies. For the pro category, there were 35 (21.3%) empirically tested articles, and 91 (55.5%) non-empirically tested articles identified. In the neutral category, there were 19 (11.6%) empirically tested articles, and 16 (9.8%) non-empirically tested articles. Only 3 articles were against the use of digital technologies, and were in the empirically tested category.

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The majority of literature related to digital technologies in anatomical education is supportive of its use. However, most of the literature is not supported with empirical data related to the use of digital technologies in anatomy specific education within the health and related disciplines. Further studies need to be conducted as to the effectiveness of technology in medical/healthcare related education.

Key words: Anatomy; digital; medical education; surgery; technology

Introduction

Anatomy has been the cornerstone of medical education for thousands of years, helping to ensure proficient and safe medical practice. Traditionally, the subject has been taught by didactic lectures and dissection. Dissection has been considered the 'gold standard' in education (Balogh et al., 2006) as it offers unique and detailed self-directed learning opportunities where the student can appreciate the three-dimensional (3D) human body through self-exploration, developing professionalism and teamwork (Turney, 2007). Dissection also allows students to develop a patient-centred approach while developing humanistic values, promoting maturity and empathy (Sugand, Abrahams & Khurana, 2010).

The teaching of anatomy is relevant across all healthcare specialties (Patel & Moxham, 2008), but the digital technologies that are now available has led to some debate over the methods of teaching. Turney suggests that anatomy has been slow to adapt to new developments and has subsequently come under pressure to revolutionise, in order to keep pace with the modern medical curriculum and to encourage student participation and interest (Turney, 2007).

Due to various extrinsic pressures, many medical schools have reduced the amount of time allocated to dissection, or abandoned it altogether, in favour of other teaching methods (Turney, 2007; Patel & Moxham, 2008; Sugand et al., 2010). The costs of running and maintaining a dissection laboratory and the holding and dispensing of cadavers are high, making dissection both costly and time consuming (Turney, 2007; McMenamin, Quayle, McHenry & Adams, 2014). In addition, reductions in qualified teaching staff and donors, along with stringent licensing make it more difficult for institutions to embrace the practice of dissection (Turney, 2007). Dissection can also require frequent access to laboratories by students, which can be difficult to achieve, particularly in institutions with restricted resources. Furthermore, in some countries dissection is prohibited on religious grounds (McMenamin et al., 2014). Such pressures therefore have invited the introduction of innovative teaching methods.

Since the creation of the Visible Human Project (VHP; Spitzer & Whitlock, 1998) on cross sectional anatomy, others have followed with similar ones like the Chinese Visible Human (CVH; Zhang et al., 2004) and the Korean Visible Human (KVH; Park, Chung, Hwang & Shin, 2006). Since then, there has been an explosion onto the market of a variety of tools and products to be used as digital training material (Ma, Bale & Rea, 2012; Manson, Poyade & Rea, 2015; Rea, 2016; Raffan, Guevar, Poyade & Rea, 2017; Visible Body; Primal Pictures; 3D4Medical; Cyber Anatomy Holographic™; BodyViz). It has also been stated that technologies could improve both assessment scores and student satisfaction (Sugand et al., 2010) but that is still controversial (Marsh, Giffin & Lowrie, 2008; Ruiz, Cook & Levison, 2009). Indeed, there is also a wide range of 3D virtual reality models (3D VRM; Visible Body; Primal Pictures; 3D4Medical; Cyber Anatomy Holographic™; BodyViz; Ruiz et al.; 2009); web based technology (Jastrow & Hollinderbäumer, 2004; Zhu et al., 2014; Raynor & Iggulden, 2008); tablet and mobile devices (Wallace, Clark & White., 2012; Lewis, Burnett, Tunstall & Abrahams, 2013; McCulloch, Hope, Loranger & Rea, 2016); surgical simulation (Madurska et al., 2017) and computer assisted learning (Ruiz et al., 2009; Varol & Basa, 2009)

However, despite a plethora of digital technologies available in anatomical, medical, dental and surgical related training, there does not appear to be an analysis as to the effectiveness of these products. There is no global consensus that has been presented as to the effectiveness (or otherwise) of the plethora of digital tools that are available for anatomical education in the healthcare disciplines. Therefore, the purpose of this study is to examine the current literature in this field to identify what the general consensus is, related to the use digital tools in anatomical education.

Method

Study design and data collection

We used the search engines Google Scholar, PubMed and CORE for entering our keywords. From the analysis of the literature, we selected the common words that appeared in articles related to the field of anatomy, medicine, dentistry, surgery and digital technologies. The first search using 10+ key words (row 1, Table 1) was overly ambitious, and we therefore identified up to 5 key words in each search category and combination (rows 2-7, Table 1), that generated articles across the three engines. We selected the first page review, of up to 20 articles in each category on each search engine.

Table 1. Sets of keywords searched with using PubMed, CORE and Google Scholar.

PubMed Keyword Sets				**CORE Keyword Sets**			
Education, digital technology, technologies, learning, training, anatomy, anatomical, 3D visualisation, software	3Dsmax, animation, 3D surface visualisation, rendering, software programmes, education, digital technology, medicine, anatomy	Anatomy, medicine, computer, digital technology, internet, web-based, applications, tablet, medical visualisation	Education, digital technology, anatomy, medicine, surgery, haptic, surgical simulation, preoperative planning, 3D, 3D modelling	Education, digital technology, technologies, learning, training, anatomy, anatomical, 3D visualisation, software	3Dsmax, animation, 3D surface visualisation, rendering, software programmes, education, digital technology, medicine, anatomy	Anatomy, medicine, computer, digital technology, internet, web-based, applications, tablet, medical visualisation	Education, digital technology, anatomy, medicine, surgery, haptic, surgical simulation, preoperative planning, 3D, 3D modelling
Digital technology, anatomy, technologies, education	Animation, rendering, anatomy,	Anatomy, web based	Digital technology, 3D modelling, anatomy, medicine, 3D	Anatomy, 3D visualization	Anatomy, internet, web based, medical visualisation	Anatomy, internet, web based, medical visualisation	Digital technology, 3D modelling, anatomy, medicine, 3D
Digital technology, anatomy, technologies, education	Anatomy, education, software programmes	Anatomy, computer, medical visualization	Anatomy, surgery, preoperative planning, 3d modelling, surgical simulation	Anatomical, 3D visualisation	Applications, tablet, anatomy	Anatomy, surgery, preoperative planning, 3d modelling, surgical simulation	Anatomy, surgery, preoperative planning, 3d modelling, surgical simulation
Digital technology, anatomy, technologies, 3d visualization	3Dsmax, medicine	Anatomy, tablet, digital technology	Education, haptic, anatomy, 3D modelling	Anatomy, learning, training, technologies	Computer, applications, medicine, anatomy	Digital technology, web based, tablet, medicine, anatomy	Education, haptic, anatomy, 3D modelling
Learning, training, anatomical, technologies, education, software, anatomy	Rendering, anatomy	Anatomy, medicine, computer		Anatomy, software, education	Digital technology, web based, tablet, medicine, anatomy		
	3D surface visualisation, digital technology, anatomy, animation	Anatomy, internet, computer, medical visualisation					
	Animation, 3D surface visualisation, software programmes, medicine, anatomy						

Row 1 shows four matching sets of keywords initially searched on in PubMed and CORE. The four sets of keywords shown in **Row 1, Columns 1-4** are the same as those used in the four searches initiated through Google Scholar. **Rows 2-7** show the series of smaller sets of keywords subsequently searched upon in PubMed and CORE. In addition, we also applied the following criteria in our search to ensure current activities were applied to the anatomical and related fields:

1. Only research published within the last 10 years was included due to the ever changing field of digital technologies, and their applications
2. The article had to include at least one type of digital technology
3. It had to relate to education in the field of anatomy, medicine, dentistry, surgery, or a related health discipline
4. The article had to be original research

Data analysis

From the articles identified, we then separated them into empirically tested (ET) and non-empirically tested (NT). Research was considered empirically tested where the technology was tested on students or experts. Testing was established as either by formal testing e.g. learner's knowledge of anatomy and their spatial abilities, or measured user perception scores based on user satisfaction, ease of use and encouragement to learn. User perception was deemed a factor that could influence gain of anatomical knowledge, since being motivated or having access to additional digital resources to study from could potentially enhance student engagement. Articles were therefore categorized as pro, neutral or against digital technologies, based on the criteria established in Table 2. They were also identified as falling into one (or more) of the educational fields of anatomy, medicine, surgery, dentistry, or other health-related field. In addition, we identified the type of technology that has been presented by the article: 3D VRM, 3D printing, m-devices, web-based learning, surgical technologies, computer aided learning, medical imaging, or other technology, in order to assess the merits of the different types of digital technology across the various educational fields.

Table 2. Instructions on allocating articles to the categories 'pro', 'neutral' and 'against' for both the empirically tested (ET) and non-tested (NT) groups.

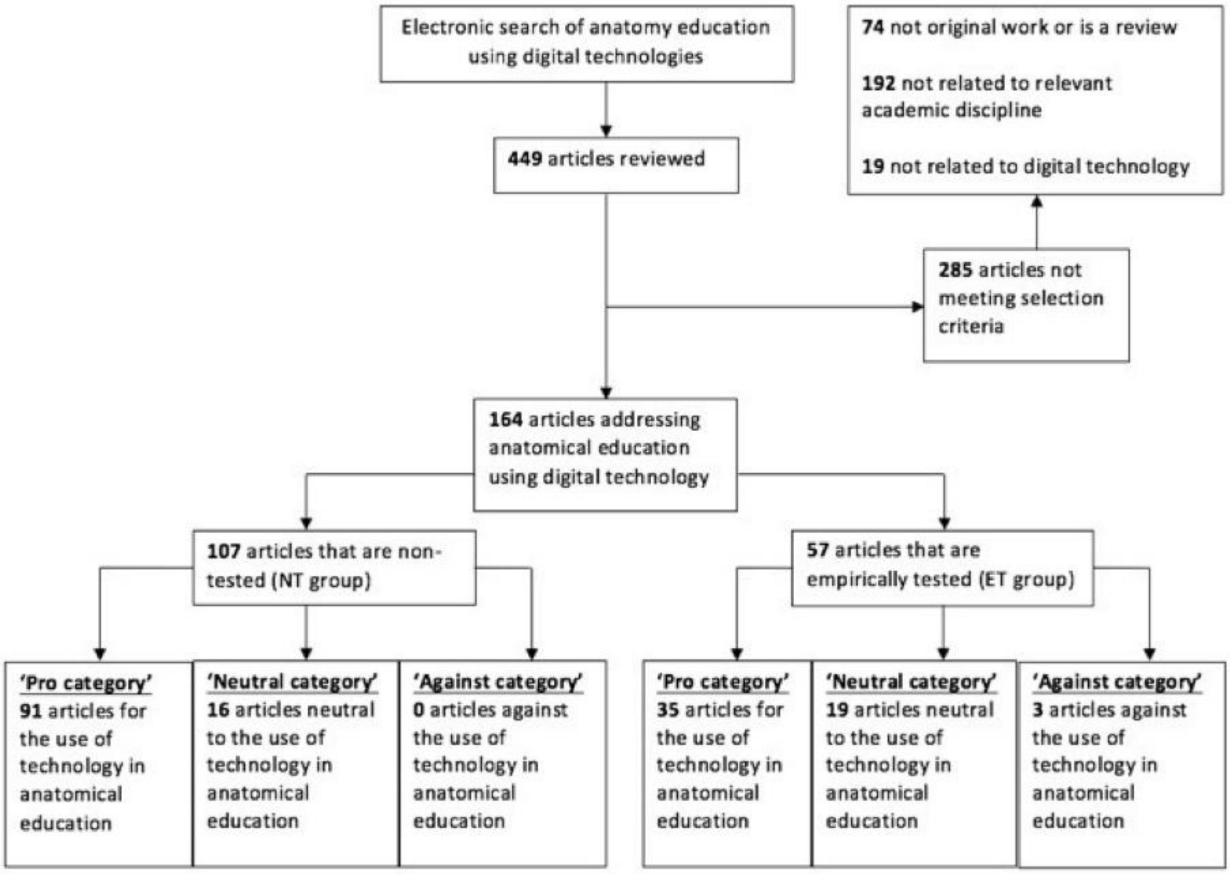
Category	ET	NT
Pro	Articles that had positive results from all empirical testing carried out	Articles that showed positive development of a technology with very few limitations
Neutral	Articles that had some positive and some negative/neutral results from testing	Articles that presented both advantages and disadvantages in the technology developed
Against	Articles that had showed no advantages whatsoever after testing	Articles that had all negative reports about the technology developed

Results

Empirically tested – v – non-empirically tested

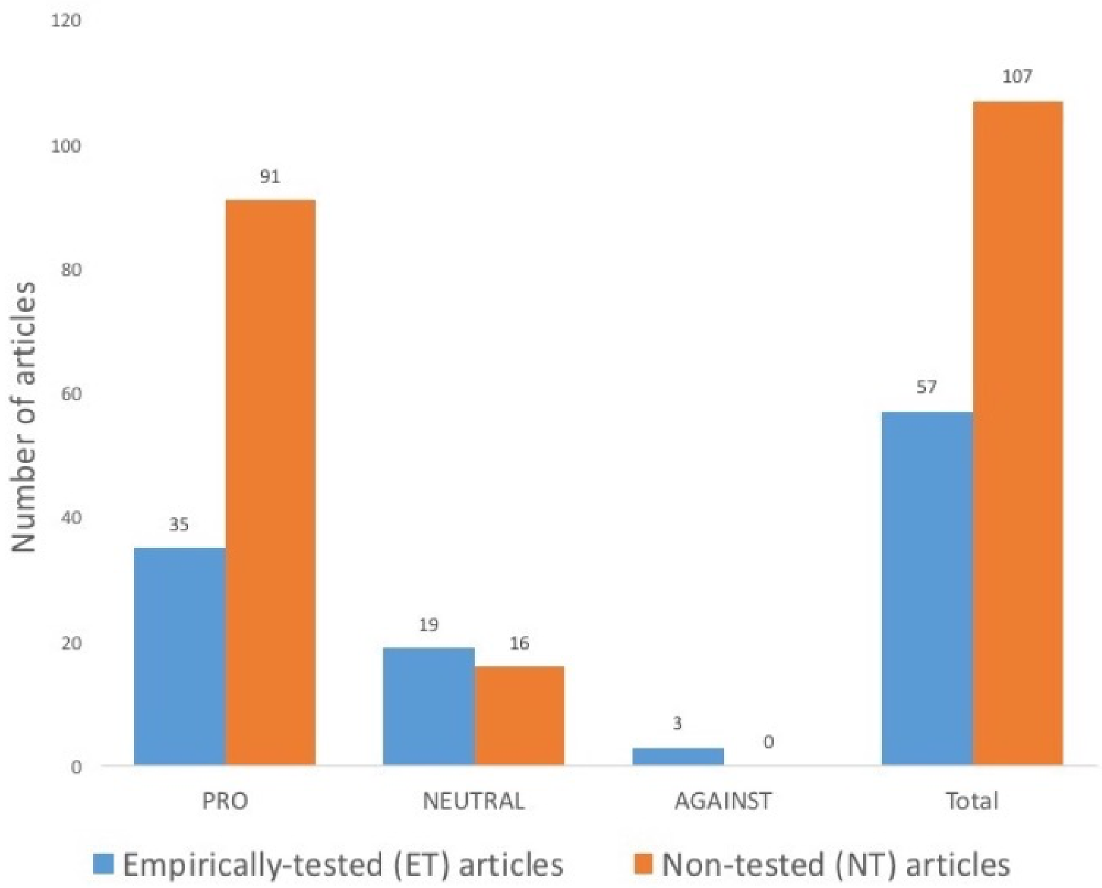
A total of 449 articles were identified across the three search engines using the key words search in Table 1 (rows 2-7). However, only 164 articles met the selection criteria as 74 were not original work; 192 were not related to the disciplines of anatomy, medicine, dentistry, surgery, or a related health discipline and 19 were not related to digital technologies (Figure 1). Of the 164 articles analysed, the majority (107; 65.2%) of those were non-empirically tested (NT) with only a third having been empirically tested (ET; 57; 34.8%).

Figure 1. Workflow chart showing the step-by-step approach to the search. Results on the number of articles found at each step are shown.



For those articles that were "pro" for the use of digital technologies in discipline specific specialties, the majority of articles were non-empirically tested (91; 72.2%) compared to empirically tested (35; 27.8%). Following this, there were approximately equal numbers of articles that were neutral in their support for digital technologies between non-empirically tested (16; 45.7%) and empirically tested (19; 54.3%). For those articles against the use of digital technologies in the related disciplines, only 3 articles were identified, and all of these were empirically tested. This is summarised in Figure 2.

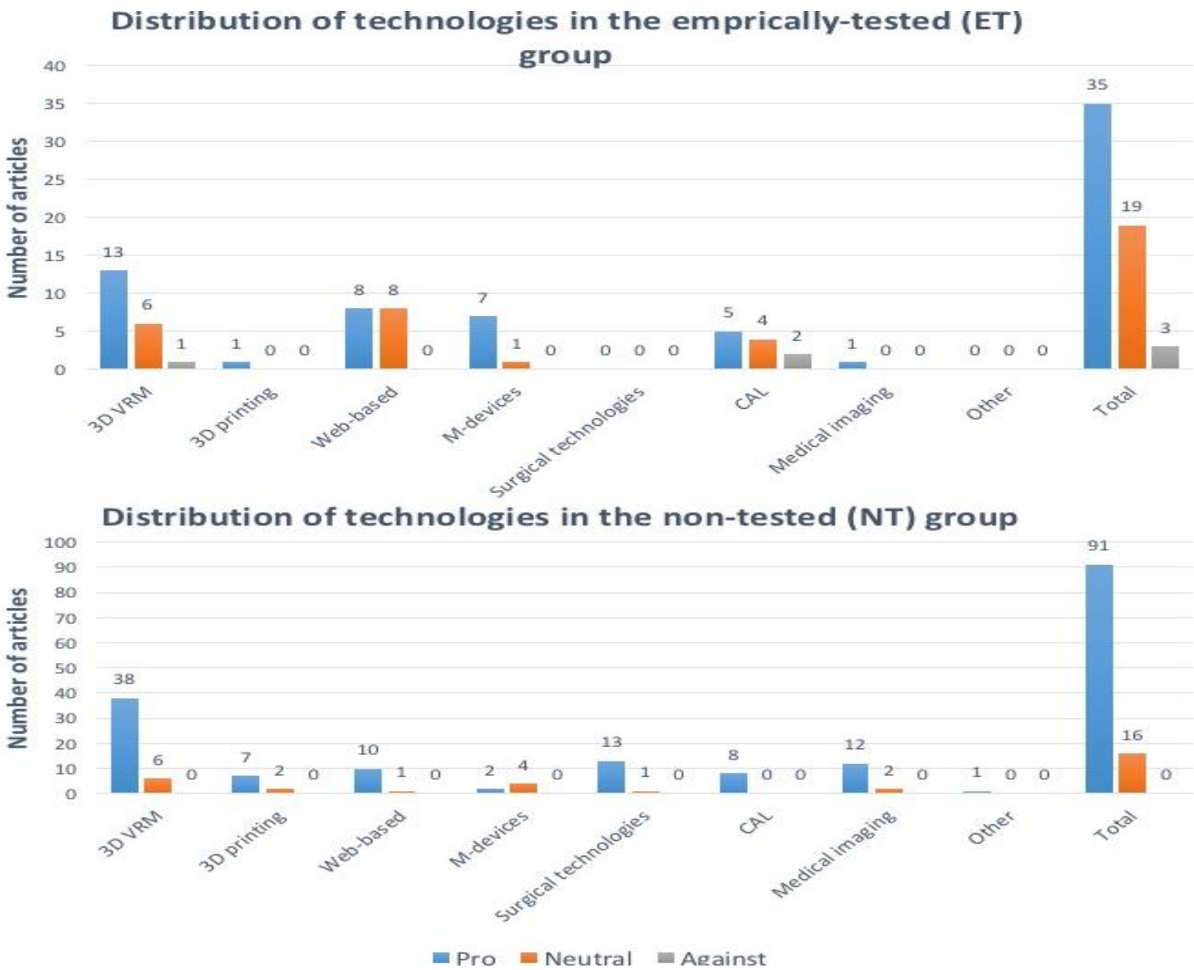
Figure 2. Graph showing the number of articles for pro, neutral and against categories for both empirically-tested (ET) and non-empirically tested (NT) groups.



Types of digital technology

The majority of articles were related to 3D VRM (64; 39%) followed by web-based resources (27; 16.5%) and then computer aided learning activities (19; 11.6%). The distribution of digital technology types across “pro”, neutral and against in both ET and NT groups is summarised in Figure 3.

Figure 3. Graph showing the distribution of digital technologies based on their individual technology type (3D VRM = 3D virtual reality models, 3D printing, web-based technologies, M-devices=mobile and tablet devices, surgical technologies, CAL = computer-assisted learning, medical imaging and other technologies in the pro, neutral and against categories, in both empirically and non-empirically tested (NT) group.



Non-empirically tested (NT)

Of those articles related to 3D VRM, most were non-empirically tested (44; 68.8%), and of these, the majority was "pro" use of this digital technology (38; 86.4%), and only 6 articles were neutral and none were against this technology. The proportion of articles related to 3D printing, web-based technology, surgery, computer aided learning and medical imaging was low, with those "pro" use representing only 7 – 13 articles, with those found to be neutral in their opinion from 0 – 2 articles. The number of articles related to m-devices was also low and this digital technology was the only type in the NT group to have more articles in the 'neutral' category than the 'pro' category (four and two articles respectively).

Empirically tested (ET)

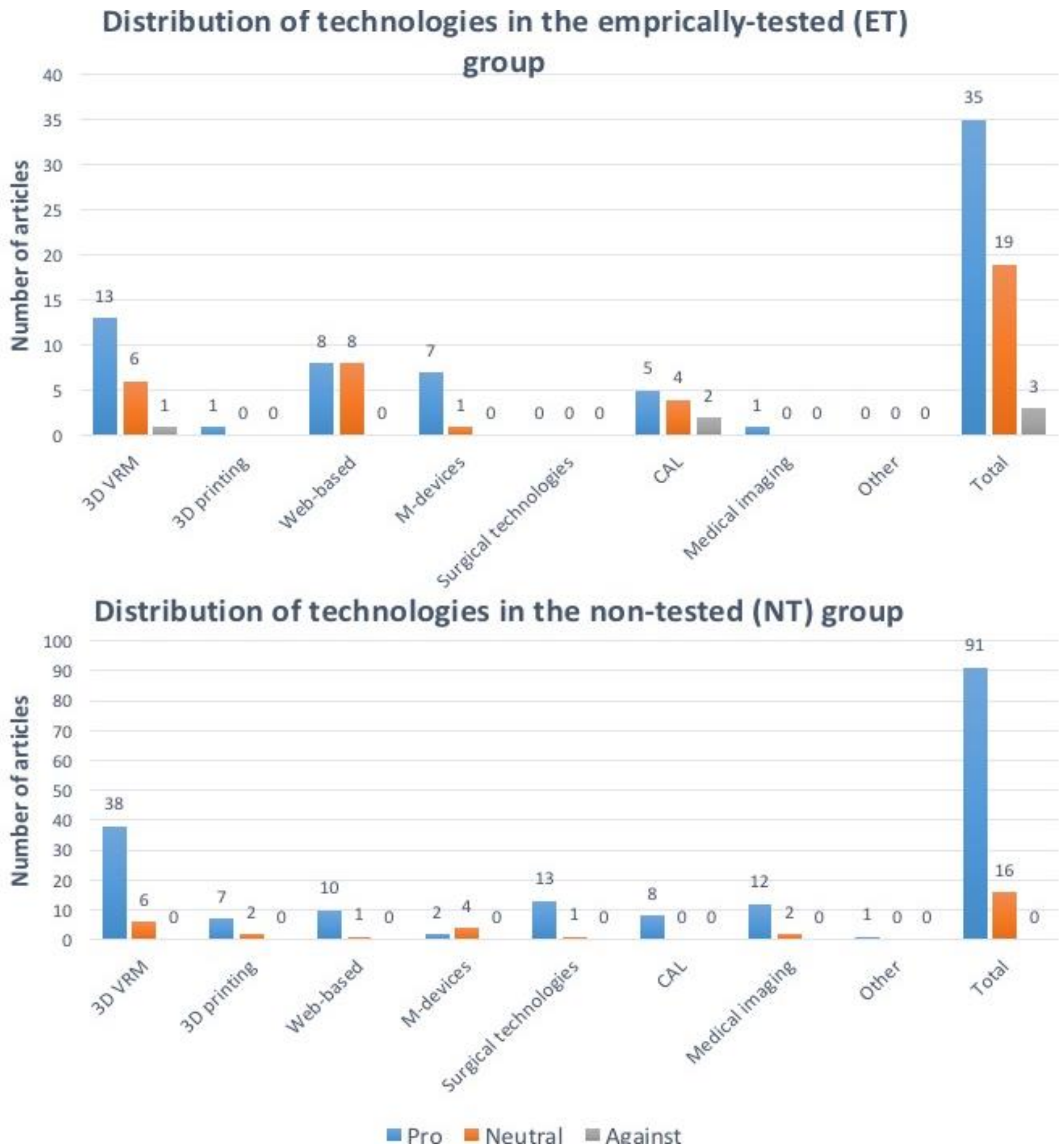
Again, the highest proportion of articles in this category was related to 3D VRM (20; 31.2%). Of these, the majority was "pro" the use of the digital technology (13; 65%), six neutral (30%) and only one was against 3D VRM technology. For web-based technology, there were an equal number of articles that were "pro" and neutral for the specific digital technology, with 8 articles in each category. The third largest category for empirically tested digital technologies was for computer aided learning packages where five articles were "pro", four neutral and two against this technology. Eight articles were identified which were empirically tested for m-devices; seven of which were "pro" and one against this type of digital technology. There was only one article each related to 3D printed models and medical imaging, both of which were "pro" use based on empirically tested data. No articles for surgical technologies were found however in this category.

Health-related fields

The majority of the articles examined were related to anatomy as a subject, or anatomy taught for medicine. This represented 66.5% of all 164 articles examined in this study. Again, the majority of those were "pro" use of the digital technologies (80; 73.4%). This is summarised in Figures 4a and b.

The results displayed in Figure 4a show that in the non-empirically tested group, a high number of articles found in the "pro" category for digital technologies were found in the surgery field (34 articles) and was comparable to anatomy as a specialty for the "pro" category (32 articles). However, in the empirically tested group, the number of articles related to surgery in the "pro" category was very low, with only two articles identified. The numbers of articles related to surgery in the neutral or against categories was very low in both the NT and ET groups (0 – 2 articles). For dentistry, only 6 articles were identified in the "pro" (all NT) group, and 4 identified in the neutral (all ET) group for digital technologies (Figure 4b).

Figure 4. Graph showing the academic disciplines and the amount of research completed into the use of digital technology in education for each subject. Results are split into pro, neutral and against categories as well as the non-tested (NT) and empirically tested (ET) groups. Figure 4b. Pie chart showing the percentage proportion of digital technologies relating to academic disciplines.



Discussion

This study has defined some key elements with reference to publishing in the field of anatomical education using digital technologies. First, the majority of published literature that has been analysed in this study has been broadly supportive of digital technologies in anatomy education and training. However, this is not quite as straightforward as may be first thought.

The majority of the literature analysed here has indeed shown support for digital technologies in anatomy and education. However, most of the articles related to this are not actually empirically tested. Of a total 164 articles in this study, we have shown that 107 articles were not empirically tested, and of those 91 articles were “pro” for the digital technology discussed, representing 85.1%. For those 57 articles which were empirically tested, 35 were identified as “pro” for the technology, representing a lower 61.4%. It may well be that some researchers and authors are overly confident in their created products, or digital technologies analysed or used.

However, contrast this with the empirically tested group, which appears more balanced in its approach to the pros and cons of digital technologies in anatomical education. In the empirically tested group, 19 articles were identified as neutral, and 35 “pro” the use of the digital technology discussed. This compares with 16 neutral and 91 “pro” technology in the non-empirically tested group. This could suggest that the employment of digital technologies may not be appropriate in all situations, and that educators should consider carefully when to use them to the best advantage.

Most of the articles we identified were related to the fields of anatomy, and anatomy within medicine (109; 66.5%), and the majority of those were “pro” use of digital technologies. A quarter (41) of the articles related to surgical education, and improving surgical performance, but only two of those were empirically tested. Dentistry on the other hand was under-represented in the literature, with only 6.1% of articles related to anatomy within dentistry.

However, some of the articles in the neutral category consisted of research with conflicting results, such as Vuchkova, Maybury and Farah (2011). They showed research on 3D VRM showed no significant difference in improvement through quantitative assessment yet questionnaire evaluations showed a very positive attitude from students towards the technology as it enhanced their learning and interpretation skills. This suggests digital technologies have an advantage if only by perceived effectiveness through encouraging student learning.

On the other hand, the immediate delivery of information in a new format may require a different set of interpretation skills and thus students might require more time to acclimatise to new technologies before testing (Vuchkova et al., 2011).

The small number of articles that were against the use of digital technologies in education from the empirically tested group (3) argued that there is no correlation between 3D VRM and enhanced skill acquisition or increased surgical performance (Roach et al., 2012). Indeed, Khot, Quinlan, Norman and Wainman (2013) had shown that virtual reality had no advantage over static images, and mentioned “significant disadvantages” compared to traditional anatomical specimens.

However, with an overwhelming amount of positive evidence for the employment of digital technologies in education, it is difficult not to be skeptical that these studies are an exception. Yet, it does indicate that not all digital technologies might be effective in education, which is important for educators to consider when selecting teaching tools.

3D virtual reality models

3D Virtual Reality Models (3D VRM) had the largest proportion of articles with 64 articles (39.02%) out of a total of 164. Of these, 38 articles were described as ‘pro’ in the non-empirically tested group, and 13 articles identified as ‘pro’ in the empirically tested group. This suggests that valuable benefits could be gained from its use as a learning aid, including the ability to understand human anatomy in 3D.

It has been proposed that 3D VRM facilitates understanding of anatomy, with students reporting higher levels of confidence when describing anatomy and has been recommended for use in education by many (Huang, Chen & Chen, 2010; Brown, Hamilton & Denison, 2012). Most 3D VRM models allow for user interaction allowing the models to be enlarged, minimised, rotated and even virtually dissected to provide a deeper understanding of the anatomy than physical models and 2D images which are limited to specific sizes, viewpoints and cut parts (Falah et al., 2014).

3D VRM offers significant advantages when visualising certain aspects of the body that may be difficult or impossible to dissect or learn from static images, such as the middle and inner ear, cerebral ventricular system and the pelvic region. The middle and inner ear are highly complex and minute in addition to being embedded in bone making dissection difficult. Nicholson, Chalk, Funnell and Daniel (2006) created a computer 3D anatomical model to study the ear which significantly enhanced student scores and was considered a valuable teaching tool. Additionally, the cerebral ventricular system is difficult to visualise due to its location within the body, making study of its anatomy difficult. However, the development of 3D virtual models has allowed its full structure to be visualised in relation to other anatomical parts and enabled spatial orientation to be grasped. These models have huge potential to aid education and to allow students to better understand complex anatomy (Adams & Wilson, 2011; Manson et al., 2015).

Web-based technologies

Web-based technology articles represented the second largest category of digital technologies (Ruiz et al., 2009), showing this to be a popular method of teaching. This correlates with research that declares web based technologies as favourable to many other teaching methods (Jastrow & Hollinderbäumer, 2004). This type of digital technology can offer a great amount of visual material with easy accessibility, enabling students to engage in self-directed learning at a time convenient to them.

An equal number of articles across “pro” and neutral categories in the empirically tested group was in contrast to the non-empirically tested group for which ten articles were “pro” and only one was neutral. This ratio suggests that in practice the employment of web-based technologies has limitations. It has been suggested that web-based technologies are not comprehensive enough to teach whole anatomy courses and the amount of anatomical detail is lacking in some of these online resources (Salajan et al., 2009). Over-simplification of concepts and topics will not advance knowledge, in addition reports of navigation and user interactivity problems may discourage students from learning using such resources (Salajan et al., 2009).

However, there is evidence to suggest web-based technologies assist with anatomical learning, as Marker, Juluru, Long and Magdid (2012) incorporated web-based resources into a programme to improve students’ gross anatomy knowledge. The programme was well organised and corresponded to coursework and learning objectives, creating a user friendly and valuable resource that increased student satisfaction and utilisation (Marker et al., 2012).

This suggests web-based technologies are more useful and favourable by tailoring their structure to learning outcomes. A great advantage to web-based technologies includes the substantial accessibility to learning resources they permit, demonstrated by Attardi and Rogers who suggest these tools also have great pedagogical value enhancing accessibility, manipulability of models, repeatability and reproducibility (Attardi & Rogers, 2014).

Additionally, they showed online anatomy courses are equally effective as traditionally taught courses, which is useful as an alternative method of teaching when access to institutions and facilities is limited, and aids in the promotion of distance learning.

Computer aided learning

Computer aided learning was ranked third in the overall number of articles identified related to digital technologies. 19 articles were identified across both the empirically and non-empirically tested groups, with most in the “pro” category (13), 4 neutral and only two against their use.

The concept of computer aided learning sounds ideal when there is a declining number of staff qualified to teach anatomy, coupled with the reduction in hours dedicated to the teaching of anatomy within curricula (Foreman, Morton, Musolino & Albertine, 2005). Indeed, computer aided learning is being used with an increasing frequency to supplement traditional anatomical teaching methods, mainly due to improved technology and steadily increasing needs for alternative teaching methods (Gould, Terrell & Fleming, 2008). In addition, student performance has also been identified as equal to, or better, with the incorporation of this type of teaching methodology (Shomaker, Ricks & Dale, 2002)

However, there is not always full support of this type of technology, with some preferring traditional lecture material, textbooks and atlases stated that virtual reality computer based modules had no benefit over static views, and could actually disadvantage the user (Khot, Quinlan, Norman & Wainman, 2013; Choi-Lundberg et al., 2016).

Conversely, by identifying the initial problems and limitations of the technologies (e.g. screen space, annotations obstructing images, and restricted interactivity) could allow for effective products to be developed (Foreman et al., 2005). The resultant technology, following user review and validation, could actually be made easier to navigate, and improve structure identification through enhanced learning and interaction (Foreman et al., 2005).

Tablets and mobile devices

Mobile, or m-devices, was the only category of digital technologies that had a higher number of articles in the neutral category (4) than the “pro” category (2), within the non-empirically tested group. In contrast, there were a higher proportion of articles (7) in the “pro” category with only one in the neutral category for those technologies that had been empirically tested.

The use of this type of technology in the literature is questionable to its integrity. No evidence has been presented within those articles analysed that anatomical accuracy across all applications exists. Although some offer highly detailed and accurate models, accuracy in microstructures has been reported to be below satisfactory (Lewis et al., 2013) Indeed, concerns have also been raised as to whether the ability to access extensive information on an immediate basis may hinder internalisation of knowledge creating ‘superficial learners’ (Wallace et al., 2012). Furthermore, there is potential for m-devices to be highly distracting to students where usage for non-academic purposes may reduce efficiency of learning.

However, against this, there is considerable evidence which also supports the use of m-devices. Mayfield et al. (Mayfield, Ohara & O’Sullivan, 2012) and Wilkinson and Barter[49] both found significant improvements stemming from the use of iPads in anatomy classes, showing increased ability to achieve dissection goals and permitting greater learner independence (Mayfield et al., 2012) in addition to having a positive effect on attendance, achievement and progression (Wilkinson & Barter, 2016). M-devices have a clear role in medical and anatomical education and can be used alongside traditional techniques and methods of training (Lewis et al., 2013). This ensures that the traditional methods still expose the students to the ‘visual, auditory and tactile pathways’ of dissection which cannot be replicated with technology (Granger, 2004). In this situation, digital technologies could actually be used as a perfect adjunct for differing learner styles and encourage engagement from a larger audience than just using a single technique for teaching.

Medical imaging, 3D printing and surgical technologies

The majority of articles relating to medical imaging, 3D printing and surgical technologies were found in the non-empirically tested category, making it difficult to objectively evaluate the effectiveness of these digital technologies in education. However, most were supportive of the technologies, implying there are perceived benefits for their use in education.

Medical imaging techniques like computerised tomography (CT), magnetic resonance imaging (MRI) and digital reconstructions from these datasets are ideal for training. Scans produce high spatial resolution, good contrast between tissues (Rana et al., 2006) and high level of detail, offering a more effective method than traditional resources for education[52, 53](Anastasi et al., 2007; Macahdo, Barbosa & Ferreira, 2013). Medical imaging also offers study of living subjects and can show the variation of different pathologies, enabling students to grasp a strong understanding of how anatomy and pathologies relate.

A rapidly expanding field is that of 3D printing. This can be employed to create highly accurate physical 3D replicas of anatomical structures, which have applications in medical and dental education (McMenamin et al., 2014; Cantin, Munoz & Olate, 2015) and surgical training and planning (Watson, 2014). These models may be highly effective in institutions where dissection or prosection is not feasible due to a reduction in the numbers of donors or funding, or in countries where dissection is banned due to religious reasons. 3D printed models offer an additional element over virtual 3D images in that they allow manual manipulation and sense of touch.

Another area showing considerable growth is that of haptic technologies. The development of haptic technologies in surgical training has delivered a revolutionary transformation in procedural training, helping to provide safer, repeatable and improved facilities for surgical practice. A need for innovative tools was identified in order to develop spatial anatomy and to prepare for the practical demands of surgery (Hochman et al., 2014) and many studies have shown surgical technologies can enhance surgical training (Birr et al., 2013; Cohen et al., 2013). However, future studies both in this field, and for medical imaging and 3D printing, should aim to evaluate their effectiveness as educational tools, investigating the ratio of employment of digital technologies to traditional methods in the classroom, since it has been suggested that surgical technologies act as an aid to anatomical education, rather than as a replacement to dissection (Hochman et al., 2013).

Considerations

It is important for developers and educators to consider how students learn when producing or employing digital technologies in education. The cognitive load theory states working memory only accommodates a limited amount of information and when exceeded, it creates a ‘cognitive overload’ that impairs future learning (Ruiz et al., 2009). It has been suggested that some technologies are too detailed and complex to follow and impede learning due to increasing cognitive load (Ruiz et al., 2009), therefore, it is important for developers to incorporate only essential information.

Another consideration is that the benefits gained from using digital technologies may vary according to learner characteristics, such as prior knowledge and spatial ability (Ruiz et al., 2009) These have been identified to affect learning, however there are valid arguments for both experienced and novice learners as to who would benefit the most from their use (Ruiz et al., 2009).

Furthermore, individuals with better spatial ability are argued to gain more from digital technologies, since those with lower spatial abilities may find it difficult learning from complex and multi-frame resources (Ruiz et al., 2009). On the other hand, studies have shown no significant difference between learners with high and low visuospatial ability (Palomera et al., 2012). Consideration should therefore be given as to what and when digital technologies should be employed in education in order to ensure that their use is effective by matching them to individuals’ learning characteristics.

Limitations and future work

There was a degree of subjectivity when deciding whether articles were *'pro', 'neutral'* or *'against'*, despite having guidelines in place to address this (see Table 2). To reduce subjectivity, in future a Likert scale could be introduced to rank articles. Additionally, the allocation of articles to *'pro', 'neutral'* or *'against'* categories could only be made according to the level of information given within the article. There were varied approaches to expressing limitations within articles, implying data may not be equally robust across all articles; an issue which could apply to any research which examines published data.

The low number of articles in the *'against'* category may be due to a lack of publication rather than lack of research. This could lead to biased opinion if it is assumed that published research shows digital technologies to be highly effective in education and might also mean that educators would be unaware which technology to treat with caution.

In contrast to 3D VRM, there appears to have been much less research conducted on some of the other digital technologies used for anatomical education in health-related fields. For example, there is a need for more research to investigate the efficacy of individual products, such as surgical technologies and medical imaging within the fields of surgery and dentistry.

Future studies that review the use of digital technologies in anatomical education should focus on gathering information from those less researched types, and where research has been empirically tested in order to adequately evaluate the use of them.

Conclusions

The primary objective of this study was to analyse existing research in order to gather the majority opinion from educators, students and experts as to whether digital technologies enhance anatomical education in health-related fields. The majority opinion is that digital technologies do offer considerable advantages in anatomical education, however there are limitations to these technologies that should be addressed in future technological developments, and which educators should consider before deploying in education.

Furthermore, it was found that researchers might be over-confident in use of digital technologies, highlighting the importance of empirically testing technologies in an educational setting. It was found that anatomy and medicine benefit greatly from the use of digital technologies and in surgical education is very important to ensure the satisfactory development of surgical skills. However, there is a lack of published research that tests both surgical and dental technologies in an educational setting and this should be addressed. 3D VRM was found to be the most prevalent and influential digital technology used, followed by web-based resources and computer aided learning.

The rapid development of digital technologies has resulted in a great impact on anatomical education offering a unique and alternative learning method, bypassing the limitations of dissection. To ensure students reach their academic potentials, learning outcomes should be assessed against the technology in use, in addition to giving an introduction and allowing time to acclimatise to the new method that has been employed.

Digital technologies undeniably offer educational enhancement, but traditional teaching and learning methods remain valuable. It is unlikely that technological products will completely replace traditional methods in anatomical education due to the unique knowledge and skills that can be acquired through dissection. However, they do increase the range of resources suitable for a wide variety of learner styles.

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