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Assessment of the utility of Mixed Reality in medical education

Radek Kolecki [a], Agnieszka Pręgowska [b], Julianna Dąbrowa [c], Jerzy Skuciński [c], Tomasz Pulanecki [c], Piotr Walecki [c], Peter M. van Dam [d], Dariusz Dudek [e], Piotr Richter [c], Klaudia Proniewska [e,*]

[a] University Hospital in Krakow, Poland
[b] Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw, Poland
[c] Jagiellonian University Medical College, Krakow, Poland
[d] UMC Utrecht, Cardiology, The Netherlands
[e] Jagiellonian University Medical College, Center for Digital Medicine and Robotics, Krakow, Poland

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ABSTRACT

Background: Immersive technologies like Mixed Reality (MR), Virtual Reality (VR) and Augmented Reality (AR) are becoming increasingly popular and gain user trust across various fields, particularly in medicine. In this paper we will use the general term Mixed Reality (MR) to refer to the various virtual reality methods, namely VR and AR. These new immersive technologies require varying degrees of instruction, both in their practice use, as well as in how to adjust to interacting with 3D virtual spaces. This study assesses the pedagogical value of these immersive technologies in medical education.
Method: We surveyed a group of 211 students and 47 academic faculty at a medical college regarding potential applications of MR in the medical curriculum by using a questionnaire comprised of eight questions. Results were analyzed accounting for user age and professional position, i.e., student vs faculty.
Results: 70% of students and 60% of the academic faculty think that MR-supplemented education is advantageous over a classical instruction. Most highly valued were the 3D visualization capabilities of MR, especially in anatomy classes. There was no significant statistical difference between students and faculty responders. Moreover, screensharing between faculty and students contributed to better, longer lasting absorption of knowledge. Surprisingly, the main issue was related to availability, i.e., only 5% of students had access to MR, while 17% of faculty use MR regularly, and 36% occasionally.
Conclusions: MR technology can be a valuable resource that supports traditional medical education, especially via 3D anatomy classes, however MR availability needs to be increased. Moreover, MR expands the capabilities and effectiveness of remote learning, which was normalized during the COVID-19 pandemic, to ensure effective student and patient education. MR-based lessons, or even select modules, provide a unique opportunity to exchange experiences inside and outside the medical community.

1. Introduction

The COVID-19 pandemic has caused a growing interest in alternative, involving online methods of medical education that disrupted the classic education model across all disciplines, impacting countless students. Anatomy is a critical component of medical education, therefore there is an urgent need and increasing interest in developing effective alternatives for anatomy lab instruction. The nature of human anatomy requires teaching material that can adequately reproduce the layout of anatomical structures relative to one another. Flat images of structures do not present this layout as effectively as in-person cadaver labs, because life is 3-dimensional. There is also a growing need to have an educational solution that offers utility in daily clinical practice. However, cadaver labs are expensive and require a lot of time thereby reducing the efficient teaching time.

Various virtual immersive technologies have become available to meet this need, e.g., virtual reality (VR) and augmented reality (AR), with mixed reality (MR) being a combination of the two. As high-speed internet becomes increasingly accessible, MR can even be utilized to remotely share live video and audio.

* Corresponding author. Jagiellonian University Medical College, Center for Digital Medicine and Robotics, Kopernika 7e, 33-332, Krakow, Poland.
E-mail address: klaudia.proniewska@uj.edu.pl (K. Proniewska).

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It is difficult to convert a traditional anatomy lesson into an online-only version because it would involve converting 3D into 2D visualizations using photos and videos. Alternative teaching tools are needed to overcome this shortcoming [Lo et al., 2019; [1], namely VR [2,3] and AR [4,5]. While AR/VR have been around for decades, technological advances in recent years and the emergence of MR devices like Microsoft HoloLens [MSC Holo], Magic Leap One [Magic Leap One] or AjnaLens [AjnaLens] enabled its effective dissemination into many fields, including engineering [6], physics [7], medicine [8] and biology [9] education.

The adoption of MR technologies in education, especially the medical curriculum, does highlight differences between generations in communication and learning styles [10]. Millennials (born in 1980–1994) are familiar with smartphones and tablets, but Generation Z (born after 1995) are more familiar with technologies such as MR (e.g. MR glasses) and 3D printers [11]. surveyed 145 medical students and found that although dissections are critical to gain an adequate understanding of anatomy, 74% stated that dissection should be supplemented by educational tools including simulators and MR.

The future of education will be defined by integrated technologies, MR in particular offers the greatest potential and utility in this space. In light of the referenced studies and COVID-19 pandemic, we sought to analyze the viewpoints of students and faculty regarding MR technology mitigating the challenges of distance learning. We sought to check attitude towards these new technologies and whether the use of MR technology offers added value in medical education. Moreover, one of the main objectives of the study was to compare the differences, if any, between students and faculty.

2. Methods

We conducted an anonymous survey of 258 subjects, of which 211 were medical students (126 female; 85 male) with a mean age of 25 years old (19–30), and 47 were faculty (23 female; 24 male) with a mean age of 42 years old (26–60). The student group were primarily in their second or third year. A two-part electronic questionnaire was created to compare the attitudes of students and faculty toward the potential use of MR technology in the curriculum. The first part gathered data about demographics and general VR/AR knowledge. The second part was comprised of eight questions focused on MR in the medical curriculum. Responses were as a 4-point Likert scale ("I totally disagree", "I rather disagree", "I rather agree", "I totally agree"). Although the questions were about MR, we used the combined phrase "VR/AR" because these terms are more colloquially understandable.

3. Results

Of the student group, less than 7% indicated they had never come across AR/VR in response to the question "Have you heard/read about AR/VR technology?" More than 69% declared that they had heard about AR/VR, but their knowledge was basic, and about 24% declared that they were interested in this topic. 38% of the respondents answered no to: "Have you used AR/VR technology?" Over 56% answered that they occasionally use AR/VR. Only 10 students (less than 5%) stated they use this technology at home or work. The potential impact of AR/VR on medical education was assessed in the second part of the questionnaire, Tables 1–2.

Among the faculty, 7 (14.8%) stated they had never heard of AR/VR technology, and 25 (53.2%) had only heard about it. The remaining 15 (31.9%) knew and were interested in this technology. When asked if they use AR/VR, 22 (46.8%) stated "No," 17 (36.2%) stated that they used AR/VR sporadically, and 8 (17.0%) used it frequently at home or work.

To carry out a statistical analysis, we converted the 4-point Likert scale into scores, ranging from −2 to 2, where −2 means that the respondent strongly disagrees with the statement, −1 that they disagree, 1 that they agree, and 2 that they strongly agree. When constructing the survey, the value 0 was omitted. Statistical analysis was performed using STATISTICA 13. The Mann–Whitney *U* test was used to compare the results in both groups. There was no statistically significant difference between students and faculty [Table 3: Students vs faculty with p values,

Table 1
Student responses on the use of MR (AR/VR) technology in medical education.

Statement	I totally disagree	I rather disagree	I rather agree	I totally agree
Education using AR/VR technology has more advantages than classic education	5.7%	27.5%	53.6%	13.3%
The use of AR/VR technology in e-learning has more opportunities in teaching, because it ensures greater participation in classes.	6.6%	18.5%	54.0%	30.8%
The use of AR/VR technology in e-learning offers more possibilities in teaching while socially isolating during a pandemic, because it ensures greater participation in classes.	5.7%	13.7%	49.8%	30.8%
The AR/VR technology could be helpful in 3D visualization	2.8%	2.40%	37.4%	57.3%
The AR/VR technology could be helpful in learning anatomy	5.2%	9.0%	28.4%	57.3%
Screen sharing with students using AR/VR has added value in the education process	4.7%	10.9%	60.2%	24.2%
Enhanced lessons using AR/VR technology will improve the education process	4.7%	7.6%	49.3%	38.4%
The use of AR/VR technology in education will contribute to better learning by students	5.7%	8.1%	54.5%	31.8%

Table 2
Faculty responses on the use of MR (AR/VR) technology in medical education.

Statement	I totally disagree	I rather disagree	I rather agree	I totally agree
Education using AR/VR technology has more advantages than classic education	0.0%	36.2%	51.1%	12.8%
The use of AR/VR technology in e-learning has more opportunities in teaching, because it ensures greater participation in classes.	2.1%	25.5%	57.4%	14.9%
The use of AR/VR technology in e-learning offers more possibilities in teaching while socially isolating during a pandemic, because it ensures greater participation in classes.	2.1%	12.8%	51.1%	34.0%
The AR/VR technology could be helpful in 3D visualization	0.0%	6.4%	46.8%	46.8%
The AR/VR technology could be helpful in learning anatomy	0.0%	6.4%	42.6%	51.1%
Screen sharing with students using AR/VR has added value in the education process	2.1%	6.4%	61.7%	29.8%
Enhanced lessons using AR/VR technology will improve the education process	0.0%	6.4%	57.4%	36.2%
The use of AR/VR technology in education will contribute to better learning by students	0.0%	14.9%	57.4%	27.7%

Table 3
Faculty vs student responses on the use of MR (AR/VR) technology in medical education-p values.

variable	Mann-Whitney *U* Test (w/ continuity correction) Marked tests are significant at $p < 0.05$								
	Rank Sum teachers	Rank Sum students	U	Z	p-value	Z adjusted	p-value	Valid N teachers	Valid N students
AGE	11015,00	22396,00	30,000	10,65176	0,000000	12,80735	0,000000	47	211
Have you heard or read about AR/VR technology?	6134,50	27276,50	4910,500	0,10267	0,918225	0,12346	0,901743	47	211
Have you used AR/VR technology?	6064,00	27347,00	4936,000	−0,04755	0,962073	−0,05363	0,957233	47	211
SUM 1	6099,50	27311,50	4945,500	0,02702	0,978445	0,02836	0,977378	47	211
Education using AR/VR technology has more advantages than classic education	6063,50	27347,50	4935,500	−0,04863	0,961212	−0,05352	0,957314	47	211
The use of AR/VR technology in e-learning has more opportunities in teaching because it ensures greater participation in classes	5830,00	27581,00	4702,000	−0,55334	0,580032	−0,61064	0,541441	47	211
The use of AR/VR technology in e-learning offers more possibilities in teaching while socially isolating during a pandemic, because it ensures greater participation in classes	6393,00	27018,00	4652,000	0,66141	0,508349	0,72104	0,470885	47	211
The AR/VR technology could be helpful in 3D visualization	5575,50	27835,50	4447,500	−1,10343	0,269840	−1,25772	0,208493	47	211
The AR/VR technology could be helpful in learning anatomy	6001,50	27409,50	4873,500	−0,18264	0,855077	−0,20523	0,837389	47	211
Screen sharing with students using AR/VR has added value in the education process	6593,00	26818,00	4452,000	1,09371	0,274084	1,25304	0,210193	47	211
Enhanced lessons using AR/VR technology will improve the education process	6186,50	27224,50	4858,500	0,21507	0,829715	0,23840	0,811573	47	211
The use of AR/VR technology in education will contribute to better learning by students	5914,50	27496,50	4786,500	−0,37069	0,710866	−0,41378	0,679032	47	211
SUM 2	5981,00	27430,00	4853,000	−0,22696	0,820459	−0,22759	0,819966	47	211

supplementary attachment] 66.9% of students and 63.9% of faculty agree that: “Education using AR/VR technology has more advantages than classic education”, and 84.8% of students and 72.3% of faculty believe that the use of AR/VR technology increases educational opportunities and improves participation in classes.

4. Discussion

This study concludes that MR offers a promising resource in medical education, specifically in the teaching of human anatomy, according to both faculty and students. Interestingly, more than a third of faculty did not have a positive opinion of MR technology in medical education, possibly because it requires retooling the traditional pedagogical framework to incorporate. Due to the complexity of interacting with the virtual reconstructions as well as hardware, such as the HoloLens 2, senior faculty may benefit from training support to best utilize potential these tools.

4.1. Academic use

Over the past two decades, medical schools around the world have steadily reduced the number of laboratory contact hours. The reduction in teaching time and the prevailing pandemic in recent years have forced curriculum directors to consider new ways of teaching anatomy to medical students, precisely using MR technology, among others.

Ref. [12] presents a systematic review of the application of AR in medical education, finding that only basic, sporadic uses have even been reported. Similar reports regarding anatomy were described by [Chytas et al., 2019], noting also that AR may have a positive impact on academic performance [13] proposed incorporating AR into neuroanatomy lessons as a 1-h course, divided into two parts for a group of 16 first-year medical students. The first part included the medial lemniscal pathway to the primary somatosensory cortex, and the second enabled users to follow the flow of cerebrospinal fluid from the ventricular system through to the subarachnoid space. After completing this course, more than 80% of students reported wanting to include AR into their traditional curriculum [14]. conducted a pre-test and post-test comparison among chiropractic students that demonstrated adding an anatomy e-learning tool significantly increased test scores in the majority of the students, and that online self-revision specifically enabled them to subsequently better identify anatomical structures. This implies e-learning tools are even more effective compared to a traditional anatomy lab [15]. used AR to train operating room scrub nurses. This unique feature enabled nurses to better anticipate the steps of a given surgical procedure, allowing them to more rapidly become effective members of the operating room team [16]. showed the advantage of using virtual dissection table-generated 3D models over CT scans alone in the diagnosis and classification of Le Fort fractures in a population of radiologists, radiology residents, and medical students [17] described the applications of MR in high-resolution, non-contrast CT image-based models of the mediastinum for medical education purposes. The study paid special attention to cognitive load theory where instructors reduced extraneous cognitive load and enhanced retention of anatomical and spatial relationships by using different model segment colors [18] concluded that AR can help students better understand spatial relationships of anatomical structures. They also reported the disadvantages of AR, such as mild eye strain, headaches, or motion sickness in some students.

In a metanalysis of several teaching modalities [19], noted that 44% of academic teachers used 3D tools, 16.60% near-peer tools, 5.55% flipped classroom tools, 5.55% applied neuroanatomy elective courses, 5.55% equivalence-based instruction-rote learning, 5.55% AR on mobile devices, 5.55% inquiry-based clinical cases, 5.55% cadaver dissections, and 5.55% used Twitter. Neuroanatomy in particular was found to be one of the most difficult topics for medical students. Spatial relationships were studied by [20], finding that including a 3D model to a 2D presentation was still less effective than physical models. An interesting study on the modeling of the User Experience in Virtual Reality was shown by [21], in which a group of 152 volunteers was asked to use the application Think and Shoot and then complete a virtual questionnaire [22]. presented a pilot study of AR technology in pharmacological education, specifically the study of naloxone in a MagicBook. The proposed tool led to a 42% improvement in student performance [8]. showed that more than two-thirds of the users preferred a VR table over an AR-based system in the study of anatomy.

4.2. Clinical use

Ref. [23] described the growing usefulness of AR in clinical practice, specifically in the intraoperative use of AR to influence the choice of surgical approach [24]. conducted a metanalysis focusing on AR in orthopedic surgery, finding that AR has the potential to be a timesaving, risk and radiation reducing, and accuracy-enhancing solution [25] conducted an analysis of over 6000 clinical studies from January 2009 through October 2020 referencing AR, VR, and MR and found that key areas of future research in surgery are forecast to include extended reality, navigation, and holographic image–related technologies [26] performed a metanalysis of 24 articles, finding that AR has utility and feasibility in clinical care delivery in patient care settings, in operating rooms and inpatient settings, and in education and training of emergency care providers, particularly notably in telehealth [27] analyzed over 8000 publications related to VR and AR in medicine, highlighting applications in related to pain, stroke, anxiety, depression, fear, cancer, and neurodegenerative disorders. Interestingly, references to MR in surgery, psychology, neurosciences, and rehabilitation had higher average numbers of citations than computer science or engineering, indicating rapid adoption of MR technologies throughout medical disciplines. Another interesting aspect was investigated by ref. [28], namely the value and acceptability of using the Microsoft HoloLens 2 mixed reality headset in a COVID-19 renal medicine ward. It turned out that the average ward round was significantly shorter with the use of the HoloLens 2 and the personal protective equipment usage was reduced by over a half. Both patients and staff were positive about the use of this device in clinical practice, despite raising some concerns.

4.3. MR models

A MR solution can be designed where one site uploads image data onto a cloud platform where the files are processed and converted into a 3D model (Figs. 1 and 2). From there remote access can be established where a user, or users, connect via a MR headset such as the HoloLens 2. This enables direct, real-time collaboration between physicians, teachers, and students using functions such as volume rendering, structure labeling, dimension computations, and customizing color and transparency of layers of anatomical structures to fully practice a surgical procedure or trace an anatomical feature with high fidelity.

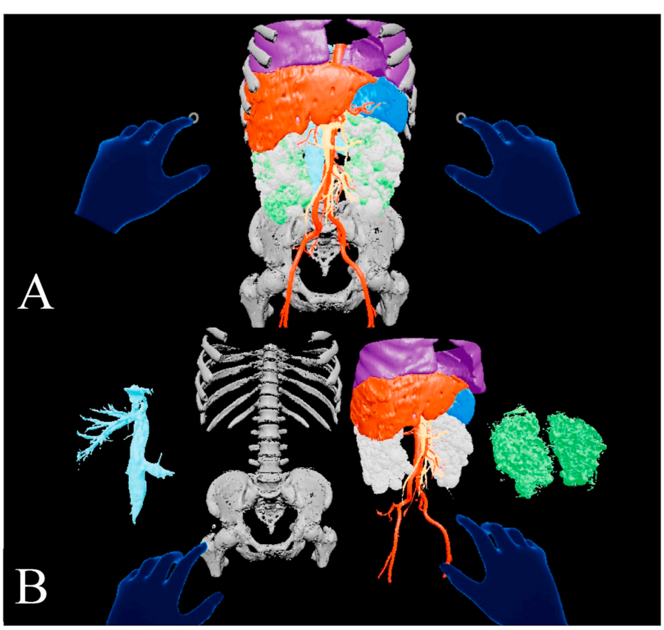

Fig. 1. Abdominal model of a patient with adult polycystic kidney disease. A. Merged. B. Segmented into component structures. With this 3D view, the student can compose and decompose the different organs in MR, thereby studying their anatomical relationships and physiological impact of the visible pathology. In this example, the kidney cysts are shown in green. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

MR models start at the level of a computer tomography (CT) or magnetic resonance imaging (MRI) file. Relevant anatomical structures are extracted into a 3D layer across all the CT/MRI slices the structure appears in via a process referred to as "segmentation." This involves a series of semi-automated algorithms in which voxels or Hounsfield units, an elementary volume element, are initially labeled and subsequently post processed by an engineer, physician, or technician, depending on anatomical complexity. As these algorithms depend on relative differences in the source image files, structures that stand out are easiest to segment into an MR model. These include bones, blood vessels (contrast-enhanced imaging), and solid organs. More difficult structures are those whose indication for ordering a CT/MRI inherently obfuscate the area of interest. An example would be an inflammation around the pancreas in the case of acute pancreatitis that may appear as a nonspecific greyed-out region on a CT scan. Dedicated staff utilizing hardware with sufficient computing power are required to process the large volume of images into a 3d model that is subsequently validated by anatomical experts. This poses a logistical challenge, but one that might be met through full automation via artificial intelligence and machine learning (AIML). By leveraging these tools, fascinating or "textbook" anatomy cases could be readily transformed into memorable teaching tools on an ad hoc basis.

4.4. Pilot study and present use

Our pilot studies have been performed in the surgical oncology population with conditions ranging from pancreatic head cancer causing widened biliary tracts proximally to the obstruction, to preoperative planning of transplants in adult polycystic kidney disease patients. Additional applications include various hepatic neoplasms, brain tumor resections, arteriovenous malformations, cardiothoracic surgeries, and patient education to mitigate preoperative stress through increased understanding of treatment plans. Comparable utility was demonstrated in these studies among the patient population.

Additionally, an MR teaching initiative was introduced at the university, and includes over 20 unique MR cases [29] along with 10 HoloLens 2 Microsoft glasses with full software support for the 3D visualization of CT/MRI data. This initiative led to the creation of a MR laboratory where students learn about modern medical imaging, 3D image processing, and learn to work with high-fidelity 3D models.

The COVID-19 pandemic has caused a significant rethinking of online education as schools were forced to reduce in-person lectures and to cease all laboratory classes to flatten the infection curve [30] Technologies based on MR offer a promising new direction to maintain a quality curriculum without being constrained by physical proximity. The main advantages of MR in education include an increased degree of student engagement and motivation, a greater understanding of 3D anatomy and relationships between anatomic structures, and more rapid rate of material mastery. The disadvantages of this technology are acquisition costs of MR devices along with their availability constraints limiting scalability [10].

The study was carried out during the COVID-19 pandemic in Poland and may have introduced bias as participants could not participate in traditional classes.

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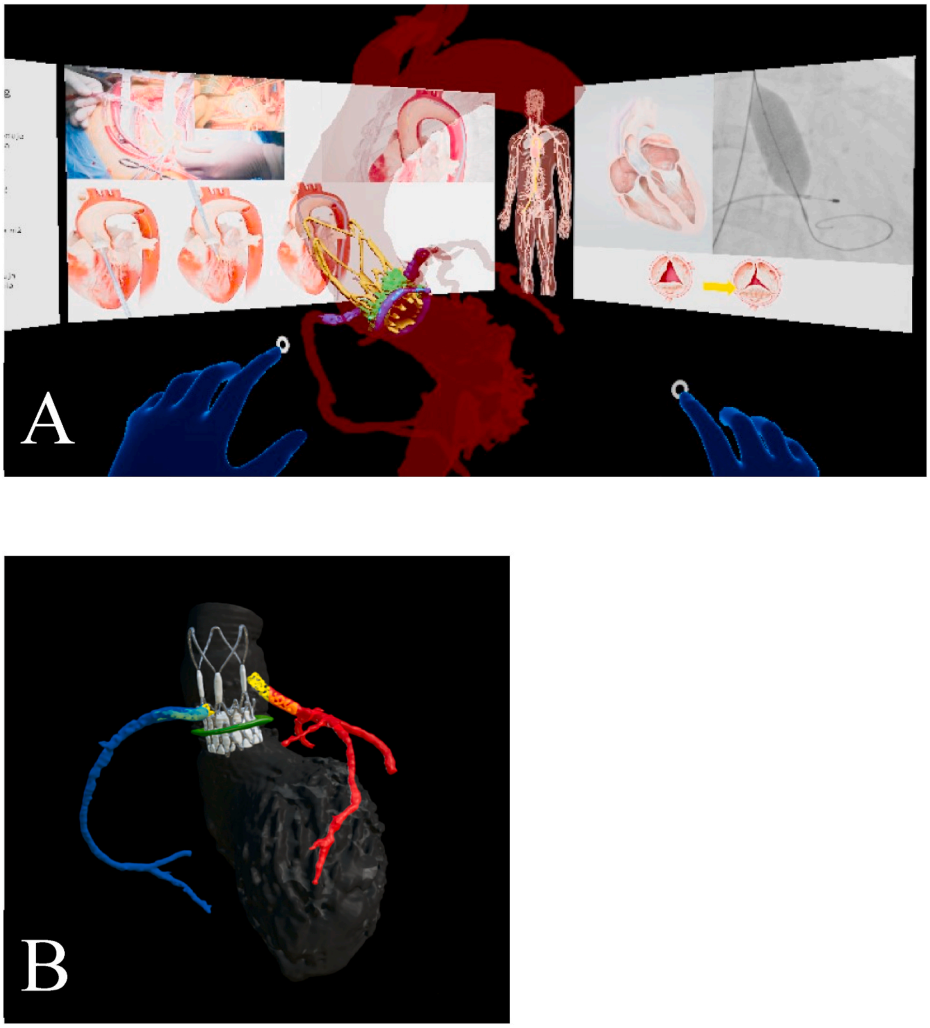

Fig. 2. Model of a patient qualified for TAVI (transaortic valve implantation), where the artificial valve is shown in yellow. The program provides different views, including a 3D model of the aorta and heart from Google HoloLens 2 perspective (A) and superior-inferior oblique view on the heart with the left anterior descending and right circumflex arteries from simulator perspective (B). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

teaching medical skills”, number [2020-1-PL01-KA203-HE-082077].

Author statement

RK - drafted the manuscript, processing and analyzing data critically assessed the manuscript.

JD - drafted the manuscript.

JS - drafted the manuscript.

TP - drafted the manuscript.

AP - drafted the manuscript.

PW – preparing survey and analyzing data.

PvD - critically assessed the manuscript.

DD - critically assessed the manuscript.

PR - critically assessed the manuscript.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Klaudia Proniewska reports financial support was provided by Erasmus Plus.

KP - supervised the study, critically assessed the manuscript, prepared the concept of the study.Acknowledgement

None.

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Further reading

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