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Communication

Does Immersive Virtual Reality with the Use of 3D Holography Improve Learning the Anatomy of the Heart?: Results of a Preliminary Study

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Abstract: Immersive virtual reality with the use of 3D holography is a new method that is being currently introduced for teaching anatomy, yet the actual educational benefits associated with its use remain unclear. Here, we present our preliminary observations and conclusions after the pilot phase of the study on a 3D holographic human heart. The study was conducted on a group of 96 students of medical faculty. Students were randomly divided into two groups: 57 students who were taught anatomy using traditional methods (plastinated human hearts, anatomical models, and atlases) and 39 students who were taught using 3D holographic hearts. Assessment of knowledge retention of the heart anatomy comprised 3 tests, which were performed 1 week and 3 and 6 months after the classes on heart anatomy. We have found that although anatomical classes with the use of immersive virtual reality were attractive for students; still, unsupervised teaching with the use of 3D holograms was not superior to traditional medical education. Differences between the groups in terms of anatomical knowledge retention were not statistically significant. Results of this pilot study suggest that in order to achieve better knowledge retention and understanding of the anatomy of the heart, classes should be precisely planned and strictly supervised by academic teachers. Moreover, students should get familiar with the use of virtual reality goggles before the classes.

Keywords: heart; teaching of anatomy; virtual reality; 3D holography

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1. Introduction

Although cadaveric dissections are still regarded as the basis of teaching anatomy at medical universities, nowadays this method is increasingly displaced by other educational tools. This is primarily associated with less time allocated by current curricula to teaching gross anatomy, in favor of clinically oriented education. The virtual immersive reality, which is a new and rapidly progressing educational method, has already been introduced with some success into postgraduate medical education, primarily associated with invasive procedures [1–7]. Similarly, this new method is currently being introduced for teaching anatomy at some medical universities throughout the world. Attractiveness for medical students, as well as no need for cadavers, appears to be the main benefit of such a teaching method. However, at the moment, virtual immersive reality as an educational tool is at its experimental stage and the benefits associated with the use of 3D holography for teaching anatomy remain unclear [8–11], even if preliminary reports are encouraging [9,12–16]. Our digital project was aimed at the evaluation of the educational value of an immersive virtual reality with the use of 3D holography of the human heart. In this paper, we present our preliminary observations and conclusions after the pilot phase of this study.

2. Materials and Methods

2.1. Digital Design of the Heart Holograms

Unlike typical 3D medical holograms that utilize anatomical 3D images that are derived from artist's drawings, or—in the case of 3D holograms of the brain—basing it on MRI images of this organ, in our project 3D images of the heart were created using a genuine porcine heart as a digital framework. Fresh animal hearts were scanned as whole organs and also after trans-sections at different levels. Thereafter, scans of the heart were digitally modified in order to create a more human appearance of the organ (Figure 1), although morphologically human and porcine hearts are very similar. Large vessels, such as the aorta and the pulmonary trunk, were digitally added and movements of heart chambers and heart valves were generated by a special software. Then, anatomical descriptions of the particular parts of the heart were embedded into the final 3D hologram. The final digital product comprised a 3D hologram of a beating heart, which exhibited a real-life appearance. Our digital heart consisted of the musculature of all four heart chambers, of the heart valves and also of the proximal part of the aorta with its major branches, the pulmonary trunk with proximal parts of the pulmonary arteries, the superior and inferior vena cava, and proximal parts of the pulmonary veins. Three-dimensional holograms of the heart could be displayed using special goggles for immersive virtual reality. These 3D holograms of the heart could be enlarged, moved, rotated, or seen from the inside of heart chambers. Additionally, the digital heart could be virtually cross-sectioned at different levels in order to better visualize its structures, particularly those situated inside the ventricles (Figures 2 and 3). Using special commands on the goggles, the descriptions of anatomical details could be displayed on the side of a 3D hologram. Simultaneously, these details were marked with color dots and could also be heard by a student through the headphones of the goggles (Figure 4).

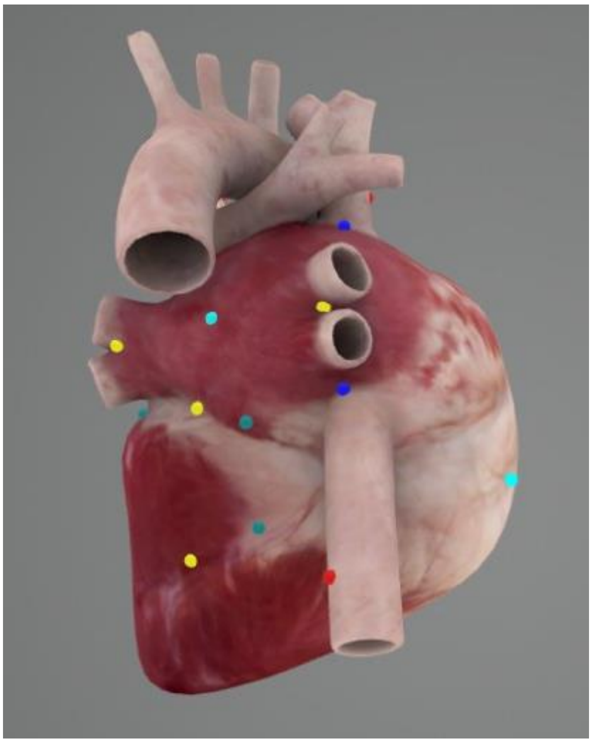

Figure 1. Our holographic 3-dimensional heart. This figure shows 2-dimensional representation of the view. Actually, with the use of goggles, it was possible to see 3-dimensional and moving heart. Color dots point to anatomical structures of the heart and their names can be heard through the headphones of goggles when these virtual structures are "touched" by student's sight.

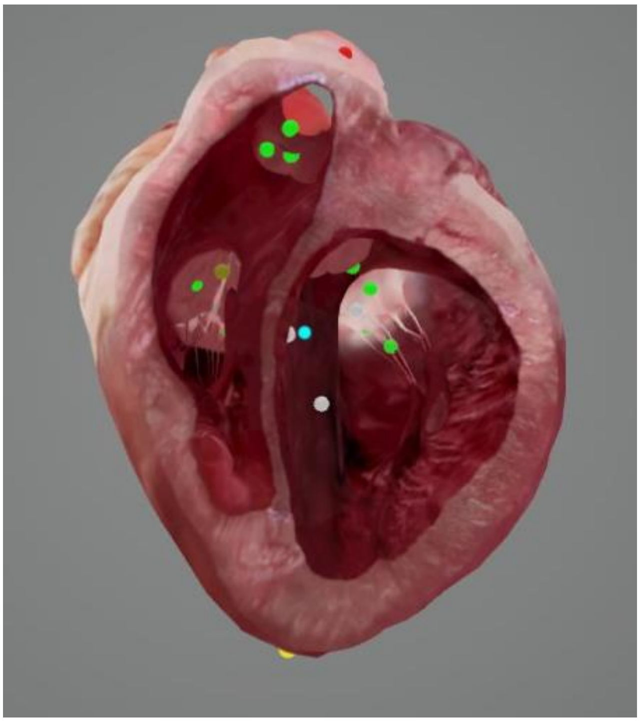

Figure 2. Three-dimensional hologram of the longitudinally cross-sectioned heart. Similarly to Figure 1, all structures were 3-dimensional, were moving, could be rotated around any axis, and could be cross-sectioned through several preset planes. Color dots point to structures located inside heart chambers.

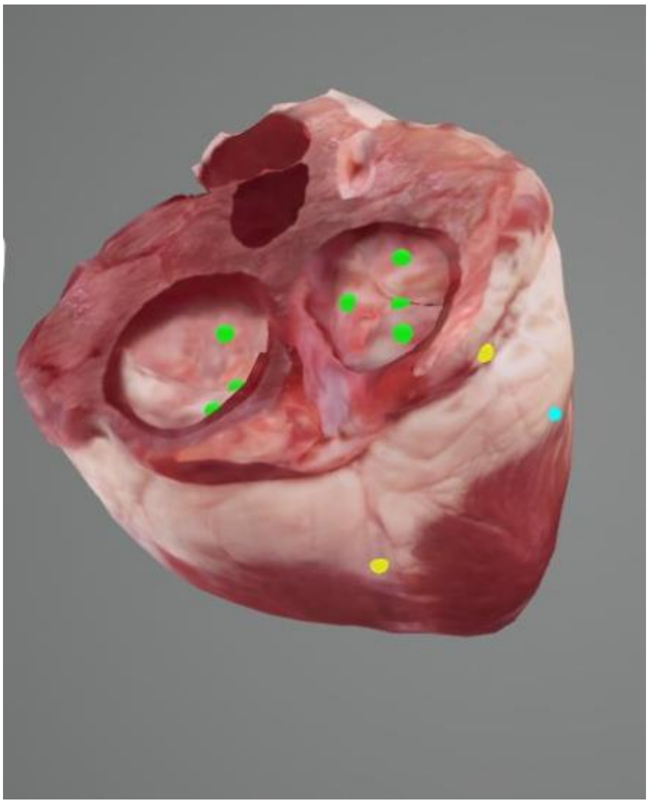

Figure 3. Three-dimensional hologram of the transversally cross-sectioned heart.

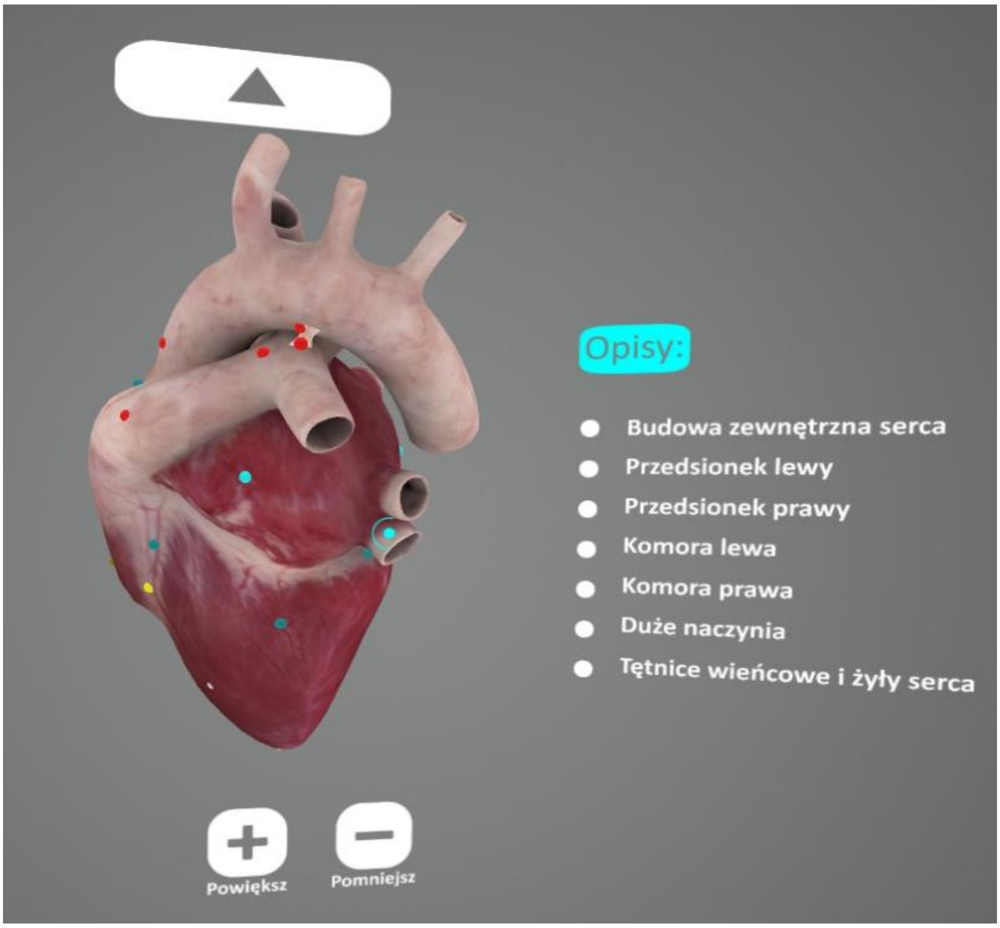

Figure 4. Using special commands on the goggles, the descriptions of anatomical details could be displayed on the side of the hologram. Manipulation of the images and anatomical descriptions is either using the sight of the user (looking at the detail activates the function) or using the remote control. Similarly to the previous figures, these written descriptions are also 3-dimensional; thus, in this 2-dimensional figure, they seem distorted. In this figure anatomical terms in the Polish language are visible. With the buttons (+) and (−), it is possible to enlarge or reduce the hologram; button (Δ) leads to the previous menu.

2.2. Study Design

The study was conducted on a group of 96 students of the medical faculty. The primary endpoint of this educational study was the assessment of the value of this e-learning tool in terms of:

- Improvement of short-term anatomical knowledge retention;
- Improvement of long-term anatomical knowledge retention.
- Secondary endpoints of this study comprised:
- Prevalence of adverse events associated with an immersive virtual reality (such as headache, vertigo, or nausea);
- Attractiveness of anatomical classes with the use of 3D holography;
- Identification of problems associated with teaching anatomy using this particular method.

For the purpose of this study, we used the Samsung Gear VR goggles for immersive virtual reality (Samsung Electronics, Suwon, Republic of Korea) and our digital heart software. The entire study has been approved by the Committee on Ethics of Scientific Investigations of our university.

Students were randomly allocated into two groups. Group 1 consisted of 57 students, who were taught the anatomy of the heart using traditional methods (plastinated human hearts, anatomical models of the heart, and anatomical atlases). Academic teachers supervising the classes in Group 1, similarly to their students, had no previous contact with the 3D holographic heart. Group 2 comprised 39 students who were taught using our 3D holographic heart. In both groups, the classes on heart anatomy were performed in 8–10 person subgroups and lasted 3 h. It should be emphasized, however, that in Group 2 the use of goggles was not strictly supervised by academic teachers, and students were allowed to study 3D holograms on their own, while the teachers helped them to use the goggles properly, but did not focus on anatomical aspects of the holograms. This primarily resulted from the fact that this e-learning tool was new, both for the students and academic teachers, and at that time it remained unclear how such teaching should be conducted to achieve the desired educational effects. After the classes students from Group 2 were asked if there were any unpleasant sensations associated with the use of goggles. Of note is that the above-described classes on heart anatomy, both with the use of 3D holography and the traditional ones, were performed a few weeks after standard anatomical classes on this topic and were seen as additional ones. At our medical university, the approach to anatomical curriculum is the regional one. The anatomy of the heart is taught within the block dedicated to chest anatomy.

An assessment of anatomical knowledge retention by the students consisted of four standard anatomical tests; each of them consisted of 40 questions that evaluated students' knowledge. The first test regarded anatomical knowledge not associated with the heart (anatomy of the extremities). It was conducted about one month before the classes on the anatomy of the heart and served the purpose of comparing the groups. Then, there were three tests assessing knowledge of heart anatomy. The first one was conducted one week after the classes and served the purpose of the assessment of short-term knowledge retention. Other tests, utilizing the same questions, were performed 3 and 6 months after the classes on heart anatomy. They were aimed at the assessment of long-term anatomical knowledge retention. After 6 months the students from both groups were also asked about their opinions on the benefits and obstacles associated with the use of 3D holograms.

For the assessment of the results of this study, another test evaluating students' knowledge, which initially was not a part of the protocol, was also utilized. It was a test comprising 100 questions regarding the entire human anatomy, which was performed about 3 months after the classes on heart anatomy. The reason why the results of this test were also taken into account will be discussed in the Results section of this paper.

2.3. Statistical Analysis

The two-sample t-test was used to test the null hypothesis that the anatomical knowledge retention in both groups of students was equal, against the alternative hypothesis that there were significant differences between study groups. In addition, the F-test was used to find out whether there was a significant difference between variances within the groups. The significance of the p values was set at $p < 0.05$. This statistical analysis was performed using the PAST data analysis package (version 2.09; University of Oslo, Oslo, Norway).

3. Results

The results of the tests performed are presented in Table 1. While all students (i.e., 57 students from Group 1 and 39 students from Group 2) were present during the first test on heart anatomy, for different reasons some students were missing during other tests. Still, the number of missing students was not high (see: Table 1). The internal consistency of the test on heart anatomy was assessed with Cronbach's Alpha index, and the average value of the three examinations performed was 0.89, indicating its good consistency.

Table 1. Results of anatomical tests; *p* values considered statistically significant if <0.05.

		Group 1 (Traditional Teaching)	Group 2 (3D Holography)	*p* Value (Two-Sample t-Test)	*p* Value (F-Test)
Test not associated with heart anatomy	number of students	56	36	-	-
	mean result	27.8	27.3	0.72	-
	95% confidence interval	26.0–29.7	24.9–29.7	-	0.95
Test on heart anatomy after 1 week	number of students	57	39	-	-
	mean result	25.1	20.4	0.02	-
	95% confidence interval	22.5–27.8	17.6–23.1	-	0.34
Test on heart anatomy after 3 months	number of students	55	38	-	-
	mean result	24.5	20.6	0.02	
	95% confidence interval	22.8–26.3	17.2–23.9	-	0.002
Test on heart anatomy after 6 months	number of students	46	34	-	-
	mean result	22.4	18.5	0.01	-
	95% confidence interval	20.1–24.7	16.7–20.4	-	0.03

An initial test on the anatomy of the extremities revealed similar anatomical knowledge in both groups (Table 1), which indicated that the groups were comparable. Regarding further tests, unexpectedly, the students who were taught using 3D holography performed significantly worse than those who had their classes on heart anatomy with the use of traditional educational tools. These worse results were seen during all three tests on heart anatomy. However, statistical analysis of the results with the F-test has also revealed significant differences between the groups regarding variances. Consequently, the results of another test that was performed about 3 months after the classes on heart anatomy were also taken into account. This test, consisting of 100 questions on the entire human anatomy, revealed a trend ($p = 0.06$) towards worse results in Group 2. The mean difference in students' performance during this test was at the level of 10%, in favor of Group 1. Since this statistical analysis suggested that the groups were not actually equal (on average, there were stronger students in Group 1 and weaker ones in Group 2), we adjusted the results of the tests on heart anatomy, taking into account the difference revealed by the test on entire human anatomy. After this adjustment, there were no statistically significant differences between the groups (Table 2).

Analysis of the secondary endpoints of this study revealed that only one student from the Group 2 (2.6%) complained of a headache during the use of goggles. This symptom, although mild, was likely to be associated with immersive virtual reality. There we no other adverse events reported by students. All students found the 3D holography as an attractive educational method. The possibility to study the organ in three dimensions, to rotate it, or to cross-sect the heart, was particularly seen as an advantage of this learning tool. However, some students found the navigation of holograms difficult. It was especially troubling for those presenting with mixed astigmatism, where the proper use of immersive virtual reality goggles was not possible. In addition, students felt that in order to fully benefit from this new educational method more time than just a 3 h class was needed.

Table 2. Results of the tests on heart anatomy after adjustment according to the results of the test on the entire human anatomy.

		Group 1	Group 2 (Adjusted Results)	p Value (Two-Sample t-Test)	p Value (F-Test)
Test on heart anatomy after 1 week	number of students	57	39	-	-
	mean result	25.1	22.4	0.17	-
	95% confidence interval	22.5–27.8	19.4–25.4	-	0.75
Test on heart anatomy after 3 months	number of students	55	38	-	-
	mean result	24.5	22.6	0.29	
	95% confidence interval	22.8–26.3	18.9–26.3	-	0.0002
Test on heart anatomy after 6 months	number of students	46	34	-	-
	mean result	22.4	20.4	0.20	-
	95% confidence interval	20.1–24.7	18.3–22.4	-	0.09

4. Discussion

In this pilot study, it has been demonstrated that although anatomical classes with the use of immersive virtual reality can be attractive for students, unsupervised teaching with the use of 3D holograms was still not superior to traditional medical education. We have also found that this educational method was relatively safe, but in some individuals, adverse events, such as headaches, can occur. In addition, some students with astigmatism could not fully benefit from this method, at least using currently available virtual reality goggles.

In spite of the possible great potential of immersive virtual reality in the medical curriculum, currently, this educational method is used by a minority of medical universities. It is primarily related to the lack of evidence demonstrating its educational efficacy. Unfortunately, at the moment only a few studies comparing traditional teaching with new 3D modalities have been published [13,17]. Moreover, the results of these studies are not congruent. Moro et al., who compared virtual reality with augmented reality and 3D tablet application for teaching the anatomy of the skull, did not reveal significant differences between study groups in terms of anatomical knowledge retention, although students found virtual reality to be a very attractive method [18]. Additionally, these authors found quite a high prevalence of adverse events (headache, drowsiness, fatigue and general discomfort) associated with the use of virtual reality. Similarly, Stepan et al. found the 3D virtual reality to be equally effective as the traditional methods during learning neuroanatomy [19]. Hackett et al. demonstrated a better approach to learning heart anatomy after the classes with the use of 3D holograms, in comparison with monoscopic 3D visualizations and 2D printed images of the heart [12]. This study, however, was conducted on a group of nursing students. Thus, detailed knowledge of heart anatomy (at the level required from future doctors) was probably not evaluated. In another study, Weinman et al. found that traditional teaching of the female pelvis with the use of physical anatomical models was better than 3D visualizations [20]. Yet, in this study 3D images were displayed on computer screens; thus, it was not a real 3D immersive virtual reality method. Of note is that it has already been revealed that 3D computer models projected on flat screens are actually perceived by students as two-dimensional images. Consequently, learning anatomy using such 3D models can be inferior to learning by utilizing anatomical models or cadaver specimens, which are really three-dimensional [14]. In this context, it remains unclear whether 3D holograms are actually perceived by students as 3D objects since holograms cannot be touched, but touch is probably an important part of learning. An interesting observation comes from the study performed by Miller. He found that the learning benefits associated with the use of 3D holography were primarily regarding weak students, while there was no additional benefit of this method among strong students [21]. He suggested that this educational tool can be of particular value for those medical students who are challenged to learn a lot of material using traditional methods, and consequently, are performing worse in comparison with their better-skilled peers.

Our preliminary educational study on the use of our 3D holographic heart for teaching anatomy indicates that in order to achieve better knowledge retention and understanding of the anatomy of this organ by students, anatomical classes should probably be strictly supervised by academic teachers. The same conclusion comes from the pilot study by Fairén et al. [11]. They found that the real-time interplay between medical students and teachers is of crucial importance while studying anatomy using this new educational tool. Consequently, in the context of the study by Miller [21], perhaps this novel didactic modality should be primarily offered to weaker students, though not for them to perform at home, but rather under the supervision of the academic teachers.

Of note is that students should get familiar with the use of goggles for immersive virtual reality before anatomical classes. They should learn how to move, rotate and increase objects, or activate special functions of the virtual application. Testing a simpler virtual anatomical application could probably serve this purpose. Additionally, classes on heart anatomy with the use of virtual reality should be precisely planned. Anatomical problems that could be easier explained with 3D holograms in comparison with traditional educational methods should be identified, including, for example, the shape and topography of coronary arteries in relation to the topography of heart chambers, or blood supply provided by a particular coronary branch in relation to its topography. Hopefully, such designed anatomical classes, with the participation of students who are familiar with the goggles, would result in better learning of human anatomy. Yet, whether such a goal is actually achievable should be validated by the next phase of our study.

We acknowledge that there are some limitations to our study. Firstly, the number of our students was not very high. Secondly, in our study, students' anatomical knowledge was assessed through tests. A practical examination of gross anatomy, as well as the radiological anatomy of the heart, would undoubtedly provide more information on the actual didactic value of 3D holography. Thirdly, in this study, the use of 3D holography was not supervised and moderated by academic teachers. Such a moderation of a new didactic modality is desirable and should be included in future studies on this method.

5. Conclusions

Anatomical classes with the use of 3D immersive virtual reality, although attractive for medical students, are not superior to traditional learning in terms of knowledge retention, if such classes are not precisely designed, not strictly supervised by academic teachers and the students did not get familiar with the use of virtual reality goggles before anatomical classes.

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