Research Square

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Augmented Reality in the Formation of Minimal Incision Podiatric Surgery.

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Abstract

BACKGROUND: This project shows that the use of augmented reality (AR) technology in the study of podiatric surgery has a positive impact on student outcomes. AR technology can help to enrich the information that provides elements such as X-rays or other diagnostic tools.

METHODS : A didactic material with augmented reality was created through the use of markers for the course subjects of Surgical Techniques II, e.g., the topic of hallux valgus surgery, and was compared with the didactic material for 5th metatarsal surgery using PowerPoint and video. The comparison was assessed by a validated questionnaire after providing 2 hours of teaching for each of the subjects to 80 students in a master of surgery program during the 2013-2017 academic years.

RESULTS: Analysis of the components of the questionnaire showed that component 1. training, attention and motivation; component 2. freelance work; and component 4. 3D compression were statistically significant at $p < 0.05$. However, component 3, which compared the technologies used with cadaveric material, was not statistically significant regarding any of its items.

CONCLUSION: The current study shows that using augmented reality technology for the study of minimally invasive surgery of the foot increases the attention, the motivation and therefore the learning of the students, in addition to providing three-dimensional images of the surgical movements that are more accurate regarding reality.

Background

In medicine, augmented reality (AR) systems can facilitate work in fields such as surgery [1] through [2] the use of magnetic resonance, ultrasound, and computed axial tomography (CAT). It is possible to collect data from inside the patient in a noninvasive way and perform a reconstruction [3] that can then be superimposed on the physical body in real time. In this way, it is possible to conduct operations with greater guarantees of safety for the patients.

In addition, AR can help to enrich the information that provides elements such as X-rays or other diagnostic tools. The field of medicine is potentially one of the areas in which AR can prompt a great revolution.

The surgery and teaching fields are the areas in which we can use AR to help students to learn with greater understanding and better three-dimensional positioning.

There have been multiple related studies conducted in medical fields, such as those regarding the rehabilitation of patients in different areas, such as cerebrovascular accidents or strokes [3][4][5, 6], vision disorders and phobia treatments.

In the same way, AR has been studied in teaching through the use of books [7–9], and more recently, some publishers, such as BooksARalive, Bienetec [10]Blume, Larousse, and MacMillan, have used AR as

an alternative to traditional texts in terms of books related to educational content.

The study results presented in this study were carried out at Valencia Catholic University Saint Vincent Martyr within the Surgical Technical II course subjects of the university's Master's Degree in Minimum Incision Podiatric Surgery program. This is a hybrid university master's program. The specific content blocks in which AR was implemented were those involving the technique for middle-stage hallux abductus valgus surgery.

The use of AR as a didactic resource will help to improve the visual representation of the different elements involved in the surgery.

In the university's Master's Degree in Minimum Incision Podiatric Surgery program, all necessary surgeries are explained and practised to obtain optimal outcomes for surgical reconstructions of the foot. As this is a type of surgery in which very small surgical incisions are made and the internal structures are not exposed, three-dimensional training regarding the anatomy and the perfect management of the surgical instruments is necessary to avoid injuring other important adjacent structures.

The main objective of this university master's program is to make it possible for students to generate mental images that enable them to perform minimal incision surgery. Since it is not possible to directly observe the different anatomical structures or the effects of the manipulation of the surgical materials in this type of surgery, it is hypothesized that it could be helpful to generate virtual images that would allow us to perceive the structures involved in a three-dimensional manner and to visualize the position of the surgical materials while influencing these structures.

Methods

Augmented Reality book

A specific didactic material based on the MagicBook format was developed. The MagicBook brand is one of the most popular examples of educational books that use an AR interface to mix reality with virtual images [11]

To make such a book with augmented reality, a 3D reconstruction of anatomical structures from medical images obtained by CAT was performed.

The images were processed by the software OsiriX®, which is a software distributed under a GNU license that incorporates a DICOM viewer, a PACS system and a third 3D reconstruction module.

Later, the LabHuman company together with Virtual Medical Vision 3D® used the *.stl files to perform the definitive reconstruction of all the structures and the subsequent codification of the augmented reality to be able to implement it in the book along with the necessary markers. To visualize the 3D aspects of the book, a computer with a dedicated graphic card, the capacity for 3D graphics supported by DirectX 9.0c or higher and a webcam that supports a minimum resolution of 640x480 at 30 fps is necessary.

This study consists of level 1 augmented reality because the book has the ability to be viewed on the computer. At this level of AR, the activators are markers, i.e., figures that when we scan them normally, provide a 3D model that overlaps with the real image. In addition to having interaction ability, the didactic material shows the surgery step-by-step as the user successively presses the "enter" key of the computer. In this way, the student can take the necessary time to assimilate each surgical step.

Thus, a textbook with print markers of AR is the object of the main interface. Students can turn the book pages, look at the photos and read the text without the need for any additional technology. However, if users look at the pages on a computer screen and use a webcam, they can see virtual 3D models appear on the pages (Figure 1), thereby introducing an interesting path for the development of new didactic materials.

Teaching Application

Ethical approval was obtained from the Research Ethics Committee of Valencia Catholic University (ref. no. UCV2017-2018-114).

Within the classes taught in the university's master program is that of Surgical Techniques II, which includes the topic of traditional 5th metatarsal surgery using PowerPoint and video presentations; for the use of augmented reality, the topic of middle-stage hallux valgus surgery was chosen. The sessions lasted approximately 2 hours for each topic.

Augmented reality use allows greater flexibility and adaptation to the students´ interests. The book enriched with augmented reality provided the possibility of connecting with what was said in other sessions, of emphasizing and influencing key elements, of integrating different perspectives and of building better mental images to accompany the interactive narrative of the teacher for the student groups. The use of small groups helped to highlight the issues that emerged and, unlike video presentations, where the sequence of images is predetermined, augmented reality allowed real-time interaction regarding both the surgical sequence and the foot view.

Second, the students had the same material used by the teacher in class available for deeper understanding and self-study. This self-study work is essential to create the necessary mental images that allow podiatrists to generate virtual mental images during minimal incision surgeries where the intervention should take into account the presence of structures that are not going to be directly visible.

To evaluate the didactic materials, a questionnaire [12] validated both by the Delphi method before and by statistical analyses afterwards (Cronbach's alpha, ANOVA with the Friedman and Tukey's tests and factorial analysis) provided relevant information on how the use of augmented reality material contributed to the students' learning.

The Cronbach's alpha calculation was performed for the internal validation of the questionnaire, which obtained a value of 0.875; in addition, the questionnaire was grouped into 4 components, which explained 65% of the variability.

Participants

The experiment was carried out during the last 4 courses in the 2013-2017 academic years, with a total of 80 students, of which 48 were men and 32 were women. The average age was 32.37 years old.

The results were analysed using the statistical software package SPSS version 21 (SPSS, Inc., an IBM Company, Chicago, IL), and $p \leq .05$ was considered significant.

A t-test was performed for related samples by comparison of the means of two variables of a single group.

Results

We observe in the first component of the questionnaire (see Table 1) concerning training, attention and motivation that the AR group averages (post-test) increased across all items, suggesting that the use of augmented reality helped the students to have better attention levels, to have more motivation to study and to understand much better what was explained.

We also note that the differences were significant (see Table 2) for all items in component 1.

In Component 2 of the questionnaire (see Table 3), we observe again how the use of AR substantially improved autonomous work; the students reported an increase in their perception that they can go back home and be able to repeat different explanations without a professor present to a greater extent after using AR than after using the traditional material. The average scores of items related to teaching material with AR are 0.80 higher for the questions within this component compared with traditional materials.

We further emphasize Question 10, the results of which show that almost 86% of the students consider that AR either often or always boosts their self-study abilities compared to 48.75% for traditional teaching materials.

After performing a t-test for related samples, we observe again that there are significant differences between the questions of component 2 (P-value = 0.000) (see Table 4)

In component 3 of the questionnaire, where we value the didactic materials used with the cadaveric material, we find no differences in average between the groups.

We can observe in component 3 (see Table 5) that the didactic material does not replace the cadaveric material, which still has an unbeatable function in the formation of surgery. All students think that the best surgical teaching is obtained with cadaveric material.

In addition, we observe that the P-values are not significantly statistical for any of the questions in component 3. (see Table 6)

Finally, in component 4 (see Table 7), we see that there is an increase in scores of more than 20% in all questions when using AR, suggesting that more than 65% of students are able to understand three-dimensional surgical movements, the function of muscles and their anatomy. Again, we observe in t-tests of related samples that there are significant differences between the traditional didactic material and material using AR (see Table 8).

Discussion

The student profiles in this case correspond with those of podiatry professionals with a certain level of surgical experience; therefore, the initial valuations of the didactic material in this study could be of lower intensity when based on the previously determined high profiles of the theoretical-practical formations of the study subjects if we compared the outcomes of the current study with those from a study focused on the anatomy formation of the top 1% of podiatry students [7].

Based on the above data, we observe that students obtain good results when they are motivated by the best understanding of what is explained to them. Students recreate a more accurate three-dimensional image of reality by coming to understand, and at the same time, visualize much faster the muscular movements and the disposition of the structures with respect to other structures. We can conclude the current study in the same manner that other studies [13] on spatial skills have done, i.e., by statistically showing the improvement of the performance of students when they use augmented reality.

Similar results have been obtained in previous studies [14–16], thereby leading to the conclusion that augmented reality books such as ours provide a familiar, intuitive, and accessible interface for interacting with content in a three-dimensional manner and create innovative and engaging experiences for the user, such that students value more positively levels of training that offer didactic material with AR.

If we consider the results of the survey as well as the informal student opinions about the use of the didactic material with AR, we can say that AR effectively helps to improve the process of learning the contents of minimal incision surgery by using three-dimensional vision and interactivity [17, 18].

This statement is not true as much in regard to conceptual results but rather in regard to two key elements that are necessary for a formative process such as the master's degree discussed in this study, i.e., the use of AR material improves both the quality of the learning process and the acquisition of skills, as well as the visualization of complex three-dimensional structures[17, 19].

Learning, in the context of appropriate and realistic simulations, increases the level of the acquisition of students’ skills by simulating and allowing interaction in explanatory situations and allowing the more effective visualization of all surgical movements, thereby reducing stress and anxiety when performing real procedures[20].

AR technology also has a positive impact on students' attention levels; in fact, an increase in attention levels is one of the educational effects that is expected from the new technologies stemming from both

the 3D virtual worlds and AR [7, 8, 21–23]

Conclusion

The current study shows that using augmented reality for the study of minimally invasive surgery of the foot increases the attention, the motivation and therefore the learning of the students, in addition to providing three-dimensional images of the surgical movements that are more accurate to reality.

Abbreviations

AR
Augmented Reality
CAT
Computed Axial Tomography

Declarations

Ethics approval and consent to participate.

The study was approved by the Ethics Committee of Valencia Catholic University, Project Code UCV2017-2018-114. All participants signed informed consent forms.

Consent for publication

Written informed consent for publication of images and video was obtained. A copy of the consent form is available for review by the Editor of this journal.

Availability of data and materials

All the data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests

Funding

The authors declare that they have no financial relationships relevant to this article to disclose.

Authors' Contributions

J.F. and M.J. were responsible for the project design. J.F., L.M., N.F., and R.L. were responsible for the data analysis, and the writing and preparation of the manuscript. J.F., M.J., N.F., L. M and R.L. edited and revised the paper. All authors have approved the final submitted manuscript.

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Tables

Table 1. Frequencies and descriptive analysis Component 1:

COMPONENT 1 Training, attention and motivation. The didactic material used for this topic.

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
1.- It helps me to fix my attention.	AR	F	0,00	15,00	40,00	25,00	3,13	0,70	0,08
		%	0,00%	18,75%	50,00%	31,25%			
	Traditional	F	0,00	37,00	43,00	0,00	2,54	0,50	0,06
		%	0,00%	46,25%	53,75%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
2.- It helps me to retain the contents.	AR	F	3,00	9,00	41,00	27,00	3,15	0,76	0,09
		%	3,75%	11,25%	51,25%	33,75%			
	Traditional	F	1,00	37,00	42,00	0,00	2,51	0,53	0,06
		%	1,25%	46,25%	52,50%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
3.- Motivates me to learn.	AR	F	3,00	13,00	23,00	41,00	3,28	0,87	0,10
		%	3,75%	16,25%	28,75%	51,25%			
	Traditional	F	0,00	40,00	40,00	0,00	2,50	0,50	0,06
		%	0,00%	50,00%	50,00%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
4.- It makes it possible to study in different ways thus avoiding the feeling of frustration.	AR	F	1,00	14,00	36,00	29,00	3,16	0,75	0,08
		%	1,25%	17,50%	45,00%	36,25%			
	Traditional	F	0,00	33,00	47,00	0,00	2,59	0,50	0,06
		%	0,00%	41,25%	58,75%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
5.- It helps me to see/imagine very clearly what they are explaining to me.	AR	F	0,00	4,00	38,00	38,00	3,43	0,59	0,07
		%	0,00%	5,00%	47,50%	47,50%			
	Traditional	F	22,00	37,00	21,00	0,00	1,99	0,74	0,08
		%	27,50%	46,25%	26,25%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
6.- It helps me to understand the biomechanics of the foot.	AR	F	0,00	18,00	44,00	18,00	3,00	0,68	0,08
		%	0,00%	22,50%	55,00%	22,50%			
	Traditional	F	1,00	43,00	36,00	0,00	2,44	0,52	0,06
		%	1,25%	53,75%	45,00%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
7.- It helps me to understand the subject without excessive explanations of the professor.	AR	F	1,00	17,00	39,00	23,00	3,05	0,74	0,08
		%	1,25%	21,25%	48,75%	28,75%			
	Traditional	F	1,00	36,00	43,00	0,00	2,53	0,53	0,06
		%	1,25%	45,00%	53,75%	0,00%			

Table 2. Test of related samples Component 1:

COMPONENT 1 Training, attention and motivation. The didactic material used for this topic.

	Related differences					
	Average	Typical deviation	Typical error	t	gl	Sig. (bilateral)
1.- It helps me to fix my attention.	,58750	,86703	,09694	6,061	79	,000
2.- It helps me to retain the contents.	,63750	,93109	,10410	6,124	79	,000
3.- Motivates me to learn.	,77500	1,00599	,11247	6,891	79	,000
4.- It makes it possible to study in different ways thus avoiding the feeling of frustration.	,57500	,93829	,10490	5,481	79	,000
5.- It helps me to see/imagine very clearly what they are explaining to me.	1,43750	,96579	,10798	13,313	79	,000
6.- It helps me to understand the biomechanics of the foot.	,56250	,89787	,10038	5,603	79	,000
7.- It helps me to understand the subject without excessive explanations of the professor.	,52500	,89972	,10059	5,219	79	,000

Table 3 Frequencies and descriptive analysis Component 2:

COMPONENT 2 Regarding self-study: The didactic material used for this topic.

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
8.- It helps me to go over in my house.	AR	F	0,00	8,00	32,00	40,00	3,40	0,67	0,07
		%	0,00%	10,00%	40,00%	50,00%			
	Traditional	F	0,00	34,00	46,00	0,00	2,58	0,50	0,06
		%	0,00%	42,50%	57,50%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
9.- Stimulates active learning.	AR	F	1,00	10,00	35,00	34,00	3,28	0,73	0,08
		%	1,25%	1,25%	43,75%	42,50%			
	Traditional	F	27,00	24,00	29,00	0,00	2,03	0,84	0,09
		%	33,75%	30,00%	36,25%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
10.- Power my self-study.	AR	F	0,00	11,00	36,00	33,00	3,28	0,69	0,08
		%	0,00%	13,75%	45,00%	41,25%			
	Traditional	F	0,00	41,00	39,00	0,00	2,49	0,50	0,06
		%	0,00%	51,25%	48,75%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
11.- It would allow me to repeat on my own, outside the university, activities carried out in class.	AR	F	3,00	14,00	29,00	34,00	3,18	0,85	0,10
		%	3,75%	17,50%	36,25%	42,50%			
	Traditional	F	1,00	48,00	31,00	0,00	2,38	0,51	0,06
		%	1,25%	60,00%	38,75%	0,00%			

Table 4 Test of related samples Component 2

COMPONENT 2 Regarding self-study: The didactic material used for this topic

	Related differences					
	Average	Typical deviation	Typical error	t	gl	Sig. (bilateral)
8.- It helps me to go over in my house.	,82500	,86822	,09707	8,499	79	,000
9.- Stimulates active learning.	1,25000	1,21697	,13606	9,187	79	,000
10.- Power my self-study.	,78750	,82207	,09191	8,568	79	,000
11.- It would allow me to repeat on my own, outside the university, activities carried out in class.	,80000	,95996	,10733	7,454	79	,000

Table 5 Frequencies and descriptive analysis Component 3

COMPONENT 3 Comparative with cadaveric material. The didactic material used for this topic

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty.error
12.- It could replace the cadaveric material to understand the location of structures.	AR	F	36,00	22,00	12,00	10,00	1,95	1,05	0,12
		%	45,00%	27,50%	15,00%	1,25%			
	Traditional	F	28,00	26,00	26,00	0,00	1,98	0,83	0,09
		%	35,00%	32,50%	32,50%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty.error
13.- It could replace the cadaveric material to understand the movement of each muscle.	AR	F	27,00	16,00	29,00	8,00	2,23	1,03	0,12
		%	33,75%	20,00%	36,25%	10,00%			
	Traditional	F	1,00	44,00	35,00	0,00	2,43	0,52	0,06
		%	1,25%	55,00%	43,75%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty.error
14.- It could replace the cadaveric material to understand the function of each muscle.	AR	F	25,00	20,00	21,00	14,00	2,30	1,10	0,12
		%	31,25%	25,00%	26,25%	17,50%			
	Traditional	F	1,00	37,00	42,00	0,00	2,51	0,53	0,06
		%	1,25%	46,25%	52,50%	0,00%			

Table 6 Test of related samples Component 3

COMPONENTE 3 Comparative with cadaveric material The didactic material used for this topic

	Related differences					
	Average	Typical deviation	Typical error	t	Average	Typical deviation
12.- It could replace the cadaveric material to understand the location of structures.	-,02500	1,40501	,15708	-,159	79	,874
13.- It could replace the cadaveric material to understand the movement of each muscle.	-,20000	1,21593	,13594	-1,471	79	,145
14.- It could replace the cadaveric material to understand the function of each muscle.	-,21250	1,18742	,13276	-1,601	79	,113

Table 7 Frequencies and descriptive analysis Component 4

COMPONENT 4 3D Comprehension. Thanks to the didactic material used for this topic.

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
15.- Get me to understand every move perfectly.	AR	F	2,00	23,00	36,00	19,00	2,90	0,79	0,09
		%	25,00%	28,75%	45,00%	23,75%			
	Traditional	F	0,00	44,00	36,00	0,00	2,45	0,50	0,06
		%	0,00%	55,00%	45,00%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
16.- It has allowed me to know the parts of the anatomy of the foot but not its overall functioning.	AR	F	2,00	28,00	37,00	13,00	2,76	0,75	0,08
		%	25,00%	35,00%	46,25%	16,25%			
	Traditional	F	1,00	41,00	38,00	0,00	2,46	0,53	0,06
		%	1,25%	51,25%	47,50%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
17.- I have managed to understand the anatomy.	AR	F	3,00	15,00	45,00	17,00	2,95	0,74	0,08
		%	3,75%	18,75%	56,25%	21,25%			
	Traditional	F	1,00	32,00	47,00	0,00	2,58	0,52	0,06
		%	1%	40%	59%	0%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
18.- I have managed to understand the movements of each muscle studied.	AR	F	4,00	18,00	40,00	18,00	2,90	0,81	0,09
		%	5%	23%	50%	23%			
	Traditional	F	0,00	41,00	39,00	0,00	2,49	0,50	0,06
		%	0%	51%	49%	0%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
19.- I have managed to visualize the movements of each studied muscle.	AR	F	5,00	16,00	37,00	22,00	2,95	0,86	0,10
		%	6%	20%	46%	28%			
	Traditional	F	0,00	42,00	38,00	0,00	2,48	0,50	0,06
		%	0,00%	52,50%	47,50%	0,00%			

			Never	Rarely	Frequently	Always	Average	Deviation Típica	Ty. error
20.- I have managed to relate the different anatomical structures between them.	AR	F	5,00	13,00	38,00	24,00	3,01	0,85	0,10
		%	6,25%	16,25%	47,50%	30,00%			
	Traditional	F	0,00	41,00	39,00	0,00	2,49	0,50	0,06
		%	0,00%	51,25%	48,75%	0,00%			

Table 8 Test of related samples Component 4

COMPONENT 4 3D Comprehension. Thanks to the didactic material used for this topic.

	Related differences					
	Average	Typical deviation	Typical error	t	gl	Sig. (bilateral)
15.- Get me to understand every move perfectly.	,45000	,97954	,10952	4,109	79	,000
16.- It has allowed me to know the parts of the anatomy of the foot but not its overall functioning	,30000	,93321	,10434	2,875	79	,005
17.- I have managed to understand the anatomy.	,37500	,93287	,10430	3,595	79	,001
18.- I have managed to understand the movements of each muscle studied.	,41250	,95060	,10628	3,881	79	,000
19.- I have managed to visualize the movements of each studied muscle.	,47500	1,09052	,12192	3,896	79	,000
20.- I have managed to relate the different anatomical structures between them.	,52500	,96751	,10817	4,853	79	,000

Figures

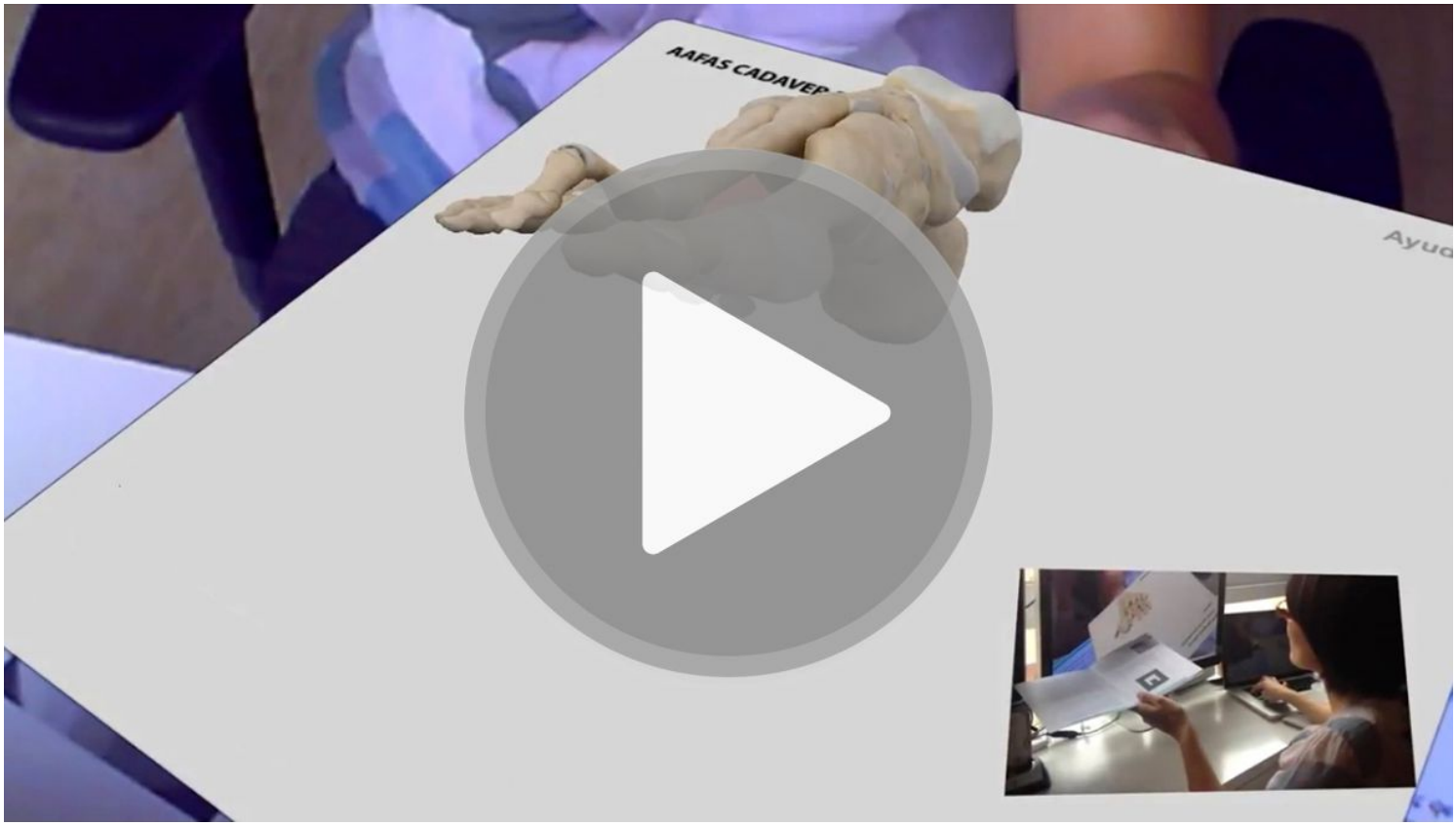

Figure 1

3D models displayed on the computer

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- videos.mp4
- videos.mp4