

# Can virtual reality improve traditional anatomical education?: A randomized controlled trial on use of 3D skull model

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# Abstract

## Background

Anatomy teaching is trending towards a mixture of lectures, cadaveric models, 2D atlas and computer simulations. This paper presents a study which compare the educational effectiveness of virtual reality (VR) skull model with that of cadaveric skulls and atlas.

## Methods

A randomized controlled study with 73 medical students was carried out with three different groups: VR skull (N = 25), cadaveric skull (N = 25) and atlas (N = 23). Anatomical structures were taught through an introductory lecture and a model-based learning. All students completed the pre- and post-intervention test, which is composed of a theory test and an identification test.

## Results

Participants in all three groups gained significantly higher total scores at post-intervention test than at pre-intervention test; the post-identification test score of VR group was non-statistically higher than the other group (VR 30 [22-33.5], cadaver 26 [20-31.5], atlas 28[20-33]). Participants in VR and cadaver group provided more positive feedbacks on their learning models (VR 26 [19-30] vs. 25 [19.5-29.5] vs. 12 [9-20],  $p < 0.05$ ).

## Conclusions

VR skull model showed equivalent efficiency in teaching anatomy structure as cadaver skull and atlas. In addition, VR can assist participants in understanding complex anatomy structures with higher motivation and tolerable adverse effects.

# Background

Anatomy is one of the most critical and complicated courses of medical education, requiring knowledge memorization, spatial imagination and plenty of cadaveric practice<sup>1</sup>. Traditional anatomy curriculums rely largely on cadaveric dissection, lectures and two-dimensional (2D) atlas to illustrate the anatomy structures while cadavers are becoming more and more limited driven by the ethical concerns, donation shortage, difficulties and potential risks of preservation and prohibitive costs<sup>1,2</sup>.

Anatomy teaching is now trending towards a mixture of lectures, cadaveric models, 2D atlas and computer simulations<sup>3</sup>. The miniaturization and improvement of the processing capacity of computers has caused VR to become a feasible technology in our society<sup>4,5</sup>. VR provides participants with an interactive experience within an immersive environment in which faithful representation of almost any objects. In addition, its ability to make the skin, organs and muscles semitransparent as well as to repeat the operative process will facilitate in the understanding of complex anatomical structure<sup>6</sup>. Theoretical

lecture and cadaveric dissection are often conducted in a centralized setting due to time and space constraints. Students can use the selected 3D model for self-learning through VR technology at their free time, which will be a strong supplementary in medical education. Previous studies evaluating VR teaching models in anatomical education have yielded mixed results. 3D models of carpal bones<sup>7-9</sup>, shoulder<sup>10</sup> and brain<sup>11</sup> didn't show superiority over textbook in theoretical test. While studies in temporal bone<sup>12</sup>, biliary system<sup>13</sup> and bronchus<sup>14</sup> showed a clear benefit of VR teaching. As education is moving towards evidence-based practice<sup>15</sup>, randomized controlled trials are required to provide evidence from different aspects.

Structure of skull is always one of the most complicated areas of anatomy. In order to take advantage of the VR, we constructed a colored and detachable skull model in a simulated classroom. In this randomized controlled trial, we combined the VR simulation learning with theoretical lecture, and compare the educational effectiveness of virtual reality (VR) skull model with that of cadaveric skulls and atlas. Efficacy in terms of anatomical knowledge memorization, structure identification and subjective evaluation by the participants were recorded.

## Material And Method

### Skull model based on VR technology

We reconstructed a VR model of skull anatomy based on the previous cadaver skull information<sup>16</sup> that contained normal skull structures (Fig. 1). The STL (STereoLithography) file were converted into a MAX file and several defective structures (ethmoid plate, crista galli, anterior clinoid process and inferior orbital fissure) were modified, using the 3D Studio Max 2016. In addition, each bone was isolated from the whole skull and painted in different color (Fig. 2c & d). The model was then placed into a simulated classroom (Fig. 2a)) using the HTC VIVE Software Development Kit and Unreal Engine 4.15, which is compatible with the HTC VIVE (resolution: 2160·1200), a VR head-mounted display (HMD) developed by HTC (Taiwan, China, 2016). Users can zoom in/out the isolated skull bone and the remaining part at the same time through the handheld controllers. When the isolated structure is placed back to its original position, it will reset. To make up for the inability to view the printout in simulated classroom, a projector was created to project the print-out teaching materials on the screen in the front of the simulation classroom (Fig. 2b).

## Participants

We recruited 74 third-year medical students of the PUMC, who finished their pre-medical program in Tsinghua University but had not yet began anatomy course. All participants signed the informed consents. Each student got a random number generated by SPSS and were ranked number size. No.1–25 were assigned to VR skull group (VR group), No.26–50 were assigned to cadaveric skull group (cadaver group), No.51–74 were assigned to the 2D atlas group (atlas group). 73 the participants completed the trial, 1 student in the atlas group quitted for personal reason before the pre-intervention test.

# Design

The study protocol and design were approved by the Institutional Review Board of the Institute of Peking Union Medical College Hospital (PUMCH) (Project No: ZS-1724). The flowchart of the study is displayed in Fig. 3. All participants finished pre-intervention tests. Then they attended a 30-min PowerPoint-based introductory lecture on cranial anatomy by a teacher from PUMC. During the lecture, each participant received a single printout of teaching materials for note-taking. After that, three groups were led to three separate rooms for a 30-min self-directed learning session using VR skulls, cadaveric skulls, 2D atlas. There was a 2-min instruction about the manipulation of VR equipment for VR group before learning. Study mentors were assigned to each room to prevent intra-group communication, and they were forbidden to answer questions related to anatomy. Each participant had 7.5 min to manipulate and observe the model in the first perspective by turns, while others observed the 3D model on the computer screen in the remaining 22.5 min. Participants in the cadaver group or atlas group also have equal time to hold the cadaver skull or atlas, while others could only observe without manipulation. Post-intervention test was conducted right after learning session to evaluate the educational efficacy of each model. Finally, each participant finished a subjective evaluation questionnaire.

Pre- and post-intervention tests composed of the same set of theory test and identification test. The theory test consisted of 18 multiple-choice questions which mainly covered basic knowledge of skull. Each correct answer could score 1 point and examination time is 15 minutes. The identification test consisted of 25 fill-in-the-blank questions on labeled anatomical structures about skull. All structures were labeled on cadaveric skulls. Participants have 45 seconds to observe each structure and write down its name. Each correct answer could score 1 point. The content was based on the syllabus from PUMC anatomy course and all the test questions are available as Supplementary file 1.

The subjective questionnaire aimed to assess participant's motivation and engagement (Table 1). The questionnaire consisted of five parts, including enjoyment, learning efficiency, authenticity, attitude and intention to use, and used standard five-point Likert-scale to quantify responses (1-strongly disagree, 5-strongly agree with the statement).

Table 1

Between groups values for demographic information, preintervention and postintervention tests

	<b>VR skulls (N = 25)</b>	<b>Cadaveric skulls (N = 25)</b>	<b>Atlas (N = 23)</b>	<b>p-value</b>
Gender [n (%)]				
Male	9 (36%)	13 (52%)	12 (52.17%)	0.425 <sup>a</sup>
Female	16 (64%)	12 (48%)	11 (47.83%)	
Age (Median [IQR])	21.22 ± 0.69	21.15 ± 0.54	21.19 ± 0.78	0.948 <sup>c</sup>
Previous GPA (Median [IQR])	3.28 [3.14–3.43]	3.30 [3.06–3.47]	3.23 [3.21–3.40]	0.780 <sup>b</sup>
Self-reported VR headset experience [n (%)]				
	9 (36%)	7 (28%)	7 (30.43%)	0.823 <sup>a</sup>
Video game experience [n (%)]				
Always	2 (8%)	0 (0%)	1 (4.35%)	0.600 <sup>a</sup>
Occasionally	4 (16%)	4 (16%)	2 (8.70%)	
Rarely	19 (76%)	21 (84%)	20 (86.95%)	
Pre-intervention score (Median [IQR])				
Total	9 [6.5–13]	8 [7–11]	10 [7–14]	0.634 <sup>b</sup>
Theory test	7 [5–9]	7 [5–9]	7 [6–10]	0.667 <sup>b</sup>
Identification test	3 [1.5–4.5]	2 [0.5-3]	2 [1–5]	0.176 <sup>b</sup>
Post-intervention score (Median [IQR])				
Total	30 [22-33.5]	26 [20-31.5]	28 [20–33]	0.571 <sup>b</sup>
Theory test	15 [12.5–16]	14 [12.5–15.5]	14 [11–16]	0.824 <sup>b</sup>
Identification test	15 [10–18]	12 [8-15.5]	13 [8–18]	0.511 <sup>b</sup>

Full scores of theory test, identification test, and total score were 18, 25, and 43 points, respectively.

<sup>a</sup>Chi-square test.

<sup>b</sup>Kruskal-Wallis H.

<sup>c</sup>ANOVA

	VR skulls (N = 25)	Cadaveric skulls (N = 25)	Atlas (N = 23)	p-value
Change in score (Median [IQR])				
Total	18 [14.5–21.5]	18 [12.5–21.5]	16 [10–20]	0.317 <sup>b</sup>
Theory	7 [5–9]	7 [4.5–10]	6 [3–8]	0.524 <sup>b</sup>
Identification test	12 [8–12]	9 [7.5–13.5]	9 [7–13]	0.278 <sup>b</sup>
Full scores of theory test, identification test, and total score were 18, 25, and 43 points, respectively.				
<sup>a</sup> Chi-square test.				
<sup>b</sup> Kruskal-Walis H.				
<sup>c</sup> ANOVA				

## Data collection and marking

Demographic information including age, gender, self-reported VR headset experience and video game experience was collected during the trial. Participants gain their group and within group individual numbers on the sign-in sheet. The previous grade point average (GPA) of each participant was obtained from the grade counselor. The demographic and grouping information were sealed to the test mentor, study mentor and study staff until the trial was completed. The study staff scored each answer sheet and the resulted was reviewed by investigators (Zhu J and Cheng C) twice.

We compared the difference between male and female in each group and in the whole group. Besides, we categorized the identification questions into 4 subgroups based on the types of labeled structures, including single bone, superior view, inferior view and lateral view.

## Statistical analysis

Previous GPA, test scores and subjective evaluation scores were expressed as median (interquartile range, [IQR]), and categorical variables as number (%). Participants' ages were expressed as mean [ $\pm$ SD]. A p-value of < 0.05 represented significance. Statistical analysis was performed using IBM SPSS statistical package, version 23 (IBM Corp, Armonk, NY).

Between-group differences in pre- and post-intervention test scores, change in score, subgroup analysis and subjective evaluation scores were tested using Kruskal-Walis H test. If there was a significant difference with Kruskal-Walis H test, Mann-Whitney U was employed for pairwise comparison. Comparisons between between male and female participants were performed with Mann-Whitney U test. Participants' age was compared with ANOVA. Categorical variables were compared with chi-square test.

## Result

### Participant demographics

A total of 73 third-year medical students (39 females, 53.42%) attended the study. Most participants were between the ages of 20 and 21 years old. There were no statistically significant differences between the 3 groups in terms of gender, age, previous Grade Point Average (GPA) in pre-med study at Tsinghua University Beijing, VR experience or video game experience ( $p = 0.425, 0.981, 0.500, 0.823, 0.600$ , respectively).

### Comparison test scores between groups

Table 1 displays the results on the pre- and post-intervention tests. The total score is the sum of the theoretical test score and the identification test score. Within-subject analysis showed overall improvement in pre- and post-intervention test scores, which was statistically significant different for participants in all the three groups ( $p < 0.001$ ).

There were no statistically significant differences between the three groups on the scores of pre-intervention test ( $p = 0.634, 0.667, 0.176$  in total score, theory test, and identification test, respectively), the post-intervention test ( $p = 0.571, 0.824, 0.511$  in total score, theory test, and identification test, respectively), and score changes between preintervention and postintervention tests ( $p = 0.317, 0.524, 0.278$  in total score, theory test, and identification test, respectively), as shown in Fig. 4. Since the theory score of each participant wasn't directly associated with the identification score, the median and quartiles in the total score are not equal to the sum of the theory score and the identification score.

### Comparison of scores between subgroups

In all participants, Mann-Whitney U test revealed statistically significant differences in post-intervention total scores (male: 30.5 [24–34], female: 26 [20–30],  $p = 0.023$ ), post-intervention identification scores (male: 15.5 [10–19], female: 12 [8–15],  $p = 0.008$ ) and identification score changes (male: 12 [8–13.25], female: 9 [6–12],  $p = 0.043$ ). Similar differences between males and females were observed in VR group in terms of post-intervention total scores (male: 33 [30.5–34.5], female: 26.5 [23.25–31.5],  $p = 0.025$ ), post-intervention identification scores (male: 18 [15–19.5], female: 13 [9.25–15],  $p = 0.01$ ), and identification score changes (male: 12 [12–13], female: 11 [7–12],  $p = 0.036$ ), as shown in Supplementary file 2. There were no statistically significant differences between male and female in cadaver group. While in atlas group, male had greater improvement in theory score and total score.

There were no statistically significant differences between post-intervention scores of VR group on inferior view, lateral view and single bone compared with the other two groups, as shown in Supplementary file 3.

### Response to subjective evaluations

Subjective evaluation questionnaire is shown in Supplementary file 1. The results of the responses in the three groups are compared in Table 2. Overall, participants of VR group and cadaver group found their assigned learning models to be more enjoyable, more interesting, more authentic and more efficient for learning than those of atlas group and rated a higher likelihood of promoting the study material to standard anatomy education (total score: 26 [19–30] vs. 25 [19.5–29.5] vs. 12 [9–20],  $p < 0.001$ ). It is noteworthy that participants evaluated VR models as a more efficient learning tool in the understanding of single cranial bones and adjacent structures than cadaver skulls and atlas.

Table 2  
Between groups values for subjective evaluation

		VR skulls (N = 25)	Cadaveric skulls (N = 25)	Atlas (N = 23)	p-value
Enjoyment	Enjoyable	4 [3–5]	4 [3–5]	2 [1–3]	$< 0.001^{b,*}$
	Interest	4 [3–5]	3 [3-4.5]	2 [1–3]	$< 0.001^{b,*}$
Authenticity		3 [2.5-4]	3 [3–4]	2 [1–3]	$0.001^{b,*}$
Learning Efficiency	Memorize	3 [2–4]	3 [3–4]	2 [1–4]	$0.029^{b,*}$
	Spatial	4 [4–5]	4 [3-4.5]	1 [1–3]	$< 0.001^{b,*}$
Attitude		3 [2–3]	3 [2–4]	1 [1–2]	$< 0.001^{b,*}$
Intention to use		3 [2–4]	4 [2.5-4]	1 [1–2]	$< 0.001^{b,*}$
Total		26 [19–30]	25 [19.5–29.5]	12 [9–20]	$< 0.001^{b,*}$
Full score of subjective evaluation is 35.					
<sup>b</sup> Kruskal-Walis H.					
* $p < 0.05$ .					

## Discomforts during learning section

During learning session, discomforts such as headache, blurred vision and nausea, were reported in the three groups. Although more participants in the VR group exhibited adverse effects (VR group: 24%, cadaver group: 12%, atlas group: 8.7%,  $p = 0.357$ ), as shown in Supplementary file 4, there were no statistically significant differences. The total scores of participants with discomforts and those without discomforts were almost the same in VR group (30 [IQR: 19.25–32.5] vs. 30 [IQR: 22–34],  $p = 0.726$ ).

## Discussion

Previous studies focused on the comparison between VR models and 2D atlas or lacked the assessment of spatial ability<sup>11-13,17-21</sup>, while little attempt has been made to compare the VR models with cadaver models and 2D atlas in the same trial. Our study is the first randomized controlled trial that compare these three methods at the same time through both objective assessments and subjective assessments, which is designated as “various question types”<sup>16</sup>. The objective assessments comprised a theory test and an identification test. The latter is a crucial part to assess participants’ spatial ability since structure identification outweighs theoretical knowledge in the study of anatomy, and it is a predictor of improved learning outcomes following 3D learning<sup>16,22</sup>.

The results of the objective assessment demonstrated that VR simulation learning had equivalent efficiency in anatomical learning as cadaver skull and atlas, despite the relative simplicity of the 3D VR model used in this study, lacking texture and haptic feedback. The stereoscopic three-dimensionality of 3D VR model directly incorporates the intrinsic spatial relationships of the anatomical sites studied, and thus may confer a spatial knowledge advantage<sup>21</sup>, which is consistent with the insignificant higher post-identification score of VR group than the other two groups. Subjective evaluation of VR group and cadaver group also showed a more positive attitude towards learning model than 2D atlas group. Responses indicated that the two groups unanimously agreed with the enjoyment, teaching efficacy and authenticity of their skull models. Novel interventions usually arouse participants’ curiosity and lead to better results and all participants were willing to promote the use of VR model in anatomy education. Similarly, previous studies comparing 3D VR model with traditional 2D teaching method also reported that VR was evaluated as a more enjoyable and useful educational tool<sup>11,21,23</sup>.

Cadavers offer high realism, haptic feedback, and the opportunity to use real instruments and tools, which is thought to be the gold standard in anatomical learning<sup>24-26</sup>, particularly in surgery<sup>27</sup>. However, they are expensive, limited resource and offer no objective feedback of skill. 3D VR models, which are able for rapid and feedback-based modification, offer an opportunity for repetitive practice<sup>23</sup>. Another advantage of VR is that students are able to observe and receive instant visual feedback based on pre-defined practical tasks<sup>28</sup>. Critiques argued that this approach lacked the expert guidance during the learning process which play an important role in forming the basic framework<sup>29</sup>. In fact, teachers could also assess students’ learning progress and mistakes through digital reports to further strengthen students’ skills. What’s more, participants in our trial conducted a self-learning in the absence of guidance and gain substantial progress in anatomical knowledge, which is consistent with previous study<sup>30</sup>. It suggested that individuals’ self-learning at their private places is a feasible way to implement VR simulation learning without constrains of places or time<sup>30</sup>. In addition, 3D models are likely to enhance rather than replace lecture-based teaching by experts<sup>23</sup>. We could move the initial part of the learning curve from practice on cadavers to VR simulation, allowing the participants to practice the procedure and acquire basic skills before using expensive lab facilities<sup>30</sup>.

In our trial, the scores of cadaver skull group showed no statistically significant differences from those of VR group and atlas group in this trial. This discrepancy might partially result from structural variation and

damaged structures in the cadaveric skulls, and the negative psychological reaction in participants triggered by the cadaveric skulls<sup>31,32</sup>. Besides, we combined lecture and model learning together to simulate the real learning process. The lecture allowed participants to get hints about the correct answers and narrow the differences between the three groups. What's more, all these participants practiced and took the examination together introducing competitive element.

Our study incorporated a room-scale HMD unit, which is available for individuals. Many more manipulations can be achieved easily, such as rotating to a suitable view, isolating a single cranial bone and zooming in/out the model, making it a better tool in understanding of difficult anatomical structures. Participants in the VR group only received a 2-min instruction about the VR equipment, which suggested that the operation of our equipment and software can be quickly adapted to. This HMD unit provides a completely immersive experience with a high display resolution, a high refresh rate, and a more precise, low-latency constellation head tracking capability. Previous study reported a high adverse rate in VR group (headaches 25%; blurred vision 35%)<sup>20</sup>, while the adverse rate was lower in our trial (headaches 20%, blurred vision 4%). It can be inferred that the discomforts caused by the activities in the virtual environment was relieved with increased resolution and lower latency. Large amount of knowledge to memorize, compact exam arrangement and unfamiliarity with learning material might bring too much burden to the brain, causing headache, blurred vision and other discomforts in all groups.

The results suggest two minor findings. First, male participants scored higher than female participants in post-intervention identification test. Previous studies have shown that individual spatial ability is associated with improved learning outcomes following small-group 3D learning<sup>22,33</sup>, which is consistent with our finding. One possible explanation is that males have stronger mental rotation, which is closely associated spatial imagination<sup>34</sup>. Similar results between genders were observed in VR group, indicating VR model learning relies on good spatial imagination partially. Second, 2D atlas tended to improve participants' understanding of structures at superior view. A possible explanation may be that the structures at superior seems to be at the same plane when observing from the top of the skull and they can be well painted on atlas.

Our study had several limitations. First, the single-institution sample was small as we only recruited 73 students at their third year from PUMC, who just finished their pre-medical course. Further studies should be performed to investigate a multi-institution sample and broader participants at different levels, such as resident physicians, nursing students, and related educators. Second, our study is limited to a 30-min self-directed learning and failed to let the participants get used to the virtual world without learning model in advance. Third, we failed to disclosure the aim of our study in advance as participant required access to the different interventions. The study design does not represent a single- or double-blinded trial. Knowledge of the grouping and interventions affected students' performance to some extent.

## Conclusion

VR skull model showed equivalent efficiency in teaching anatomy structure as cadaver skull and atlas. It can assist participants in understanding complex anatomy structures with higher motivation and tolerable adverse effects. VR simulation learning will be powerful supplement to traditional anatomy teaching and facilitate the learning process. With the increase of free 3D anatomical models, the widespread implementation of individual VR simulation learning is possible.

## **Abbreviations**

VR: Virtual Reality; 2D: Two-dimensional; 3D: Three-dimensional; HMD: Head-mounted Display; GPA: Grade Point Average.

## **Declarations**

### **Ethics approval and consent to participate**

Ethical approval was obtained from the Institutional Review Board of the Institute of Peking Union Medical College Hospital (PUMCH) (Project No: ZS-1724). All participants completed written informed consent. Study methods were performed in accordance with approved guidelines.

### **Consent for publication**

Not applicable, no individual person's data in any form.

### **Availability of data and materials**

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

### **Competing Interests**

The authors declare that they have no competing interests.

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### **Author's contributors**

S.C. and J.Z. wrote the paper. Z.P., C.C., L.L., J.D. and X.S. conducted the experiment and analyzed and interpreted the results. J.L. and Z.S. constructed the model. H.Y. collected data. H.Z. and C.M. reviewed the paper. H.P. designed the trial. All authors reviewed the manuscript.

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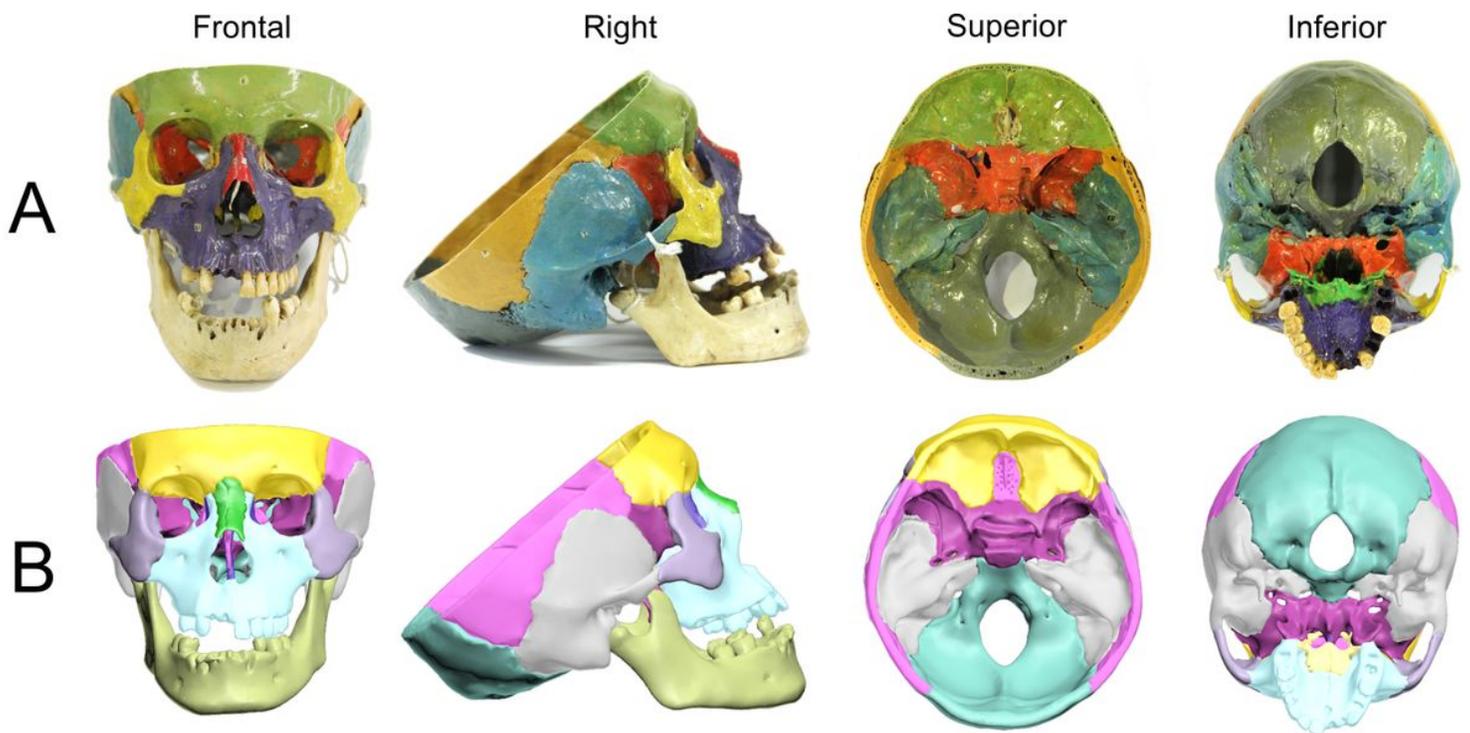
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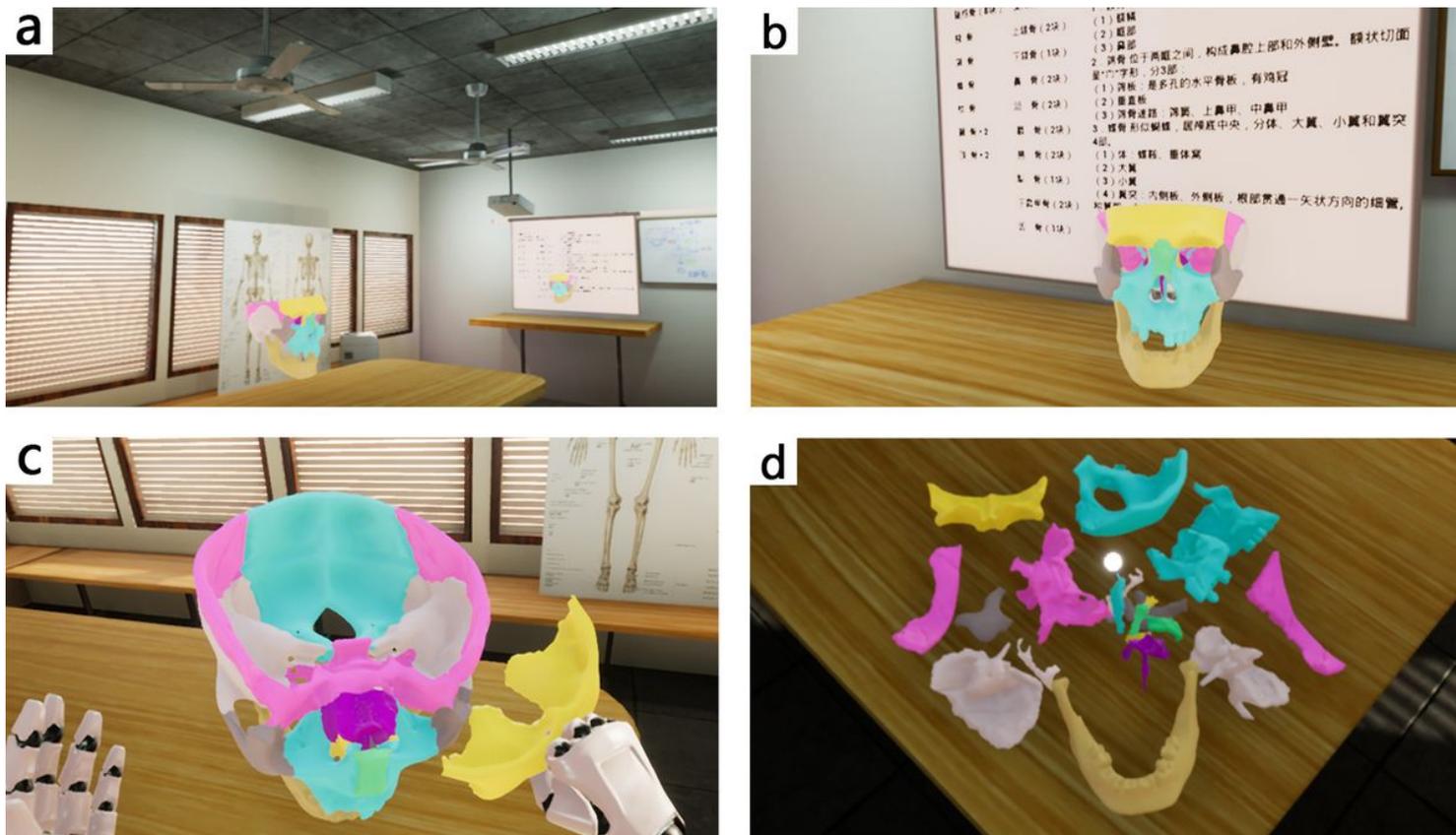
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## Figures



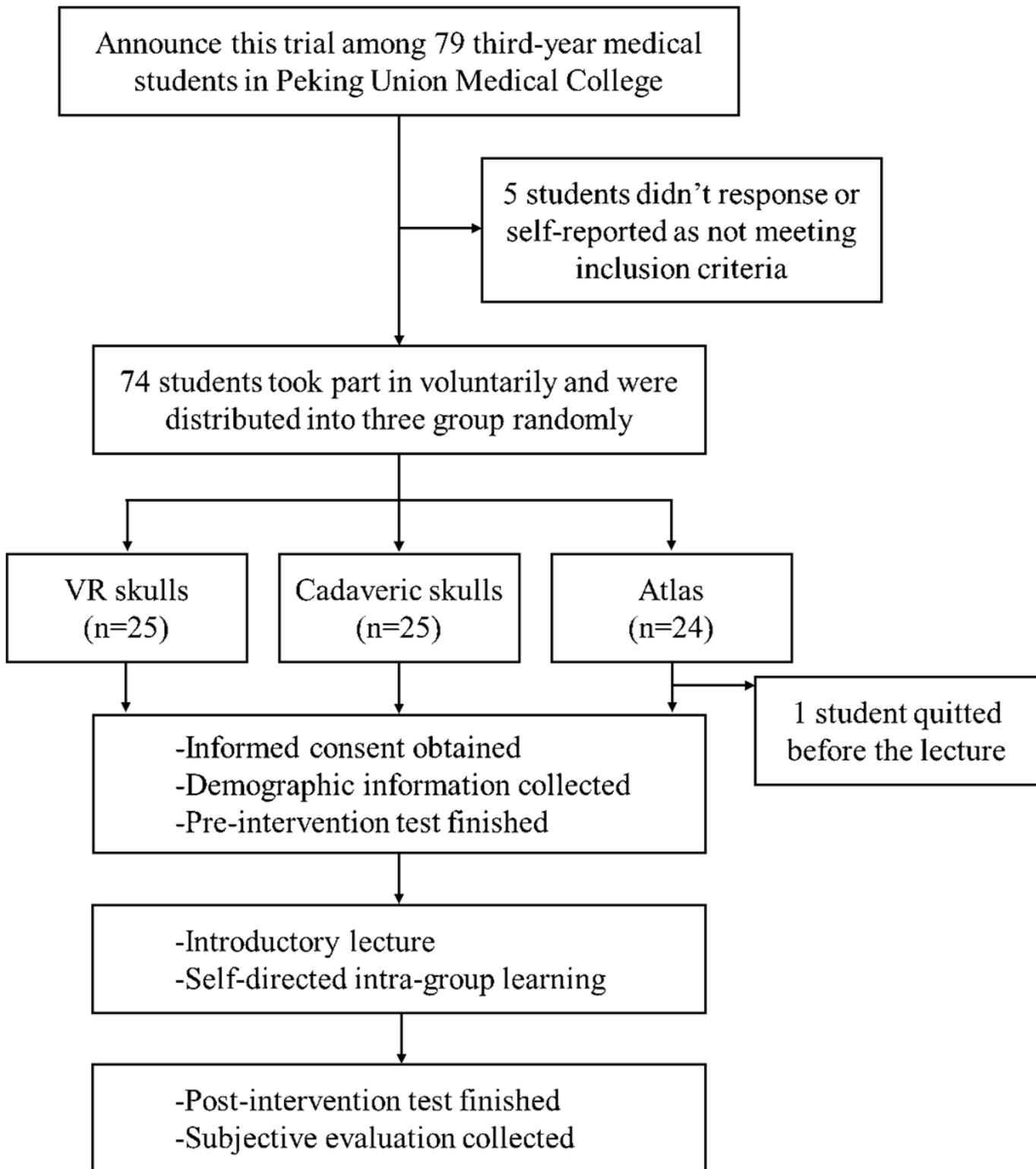
**Figure 1**

Photos of cadaveric skull and VR skull. (A) Cadaveric skull is showed in frontal, right, superior and inferior views, respectively. (B) VR skull is showed in frontal, right, superior and inferior views, respectively.



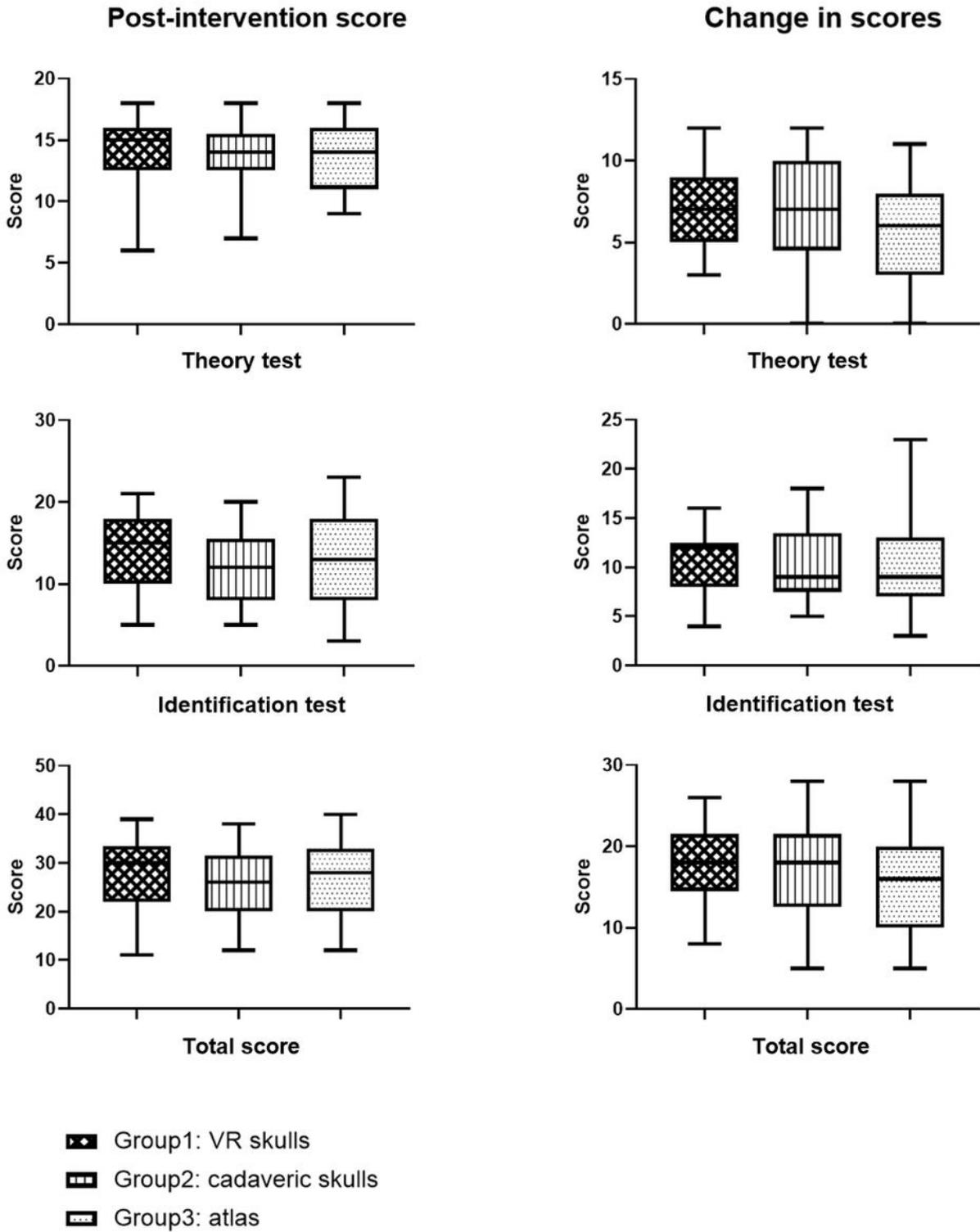
**Figure 2**

Photos of the simulation classroom and the VR skull model. (a) The whole scene of the classroom: one skull is placed on a table in the front of the classroom, the other is placed on a table in the middle of the classroom and pictures of human skeleton is placed in front of the window. (b) The VR skull and the projection screen. (c) Isolating frontal bone from the whole skull. (d) Each bone is isolated and the light ball represent the center of the original skull.



**Figure 3**

Flowchart of study design.



**Figure 4**

Comparison between genders of three groups in post-intervention test score and change in score. (a) Group A: significant differences were found in post-intervention total score, identification test score and change in identification test score. (b) Group B: no significant differences were found. (c) Group C: significant differences were found in change in total score and change in identification test score.

## Supplementary Files

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