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Immersive VR training system for clipping intracranial aneurysms

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Abstract: Training clipping of intracranial aneurysms is challenging due to less frequent interventions because of minimal-invasive methods, ethical aspects regarding cadaver training and consumption of resources when using 3D printed models. By proposing an immersive virtual reality training system, we make use of increased motivation, engagement and realism when using a virtual operating room. In this simulation, a selected microsurgical clip can be applied at the aneurysm neck. Before closing the clip and deforming the vessels, the affected area is visualized to assess the clip position. Our qualitative evaluation with two neurosurgeons with different levels of experience indicates benefits such as increased motivation, presence, and the possibility to try out different strategies. However, some surgical steps can be refined to increase realism and learning effect, and interactions can be further improved. The proposed training system benefits from training by trial and error in an engaging environment leading to an improved training experience.

Keywords: Virtual Reality, Surgical Training, Intracranial Aneurysms, Clipping.

1 Introduction

Immersive virtual training (VR) is an easily available and cost-effective method to train specific surgical procedures, especially procedures that are seldom and require anatomical understanding. Such a procedure is microsurgical clipping of intracranial aneurysms (IAs), which are pathological dilatations of blood vessels in the brain. A clip has to be applied carefully at the aneurysm neck to seal it off the blood flow without affecting other arteries and thus retaining the normal blood flow. Depending on the access, possible clipping strategies are limited. To train the correlation between access and clipping, virtual training is a good way to explore different strategies without harming someone or having ethical conflicts.

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In our proposed immersive VR clipping training, we make use of the motivational benefits of immersive VR. Hereby, the user is surrounded by a virtual environment imitating the real scenario. Furthermore, immersive VR provides intuitive and realistic interactions with 3D anatomical models. In virtual systems it is also possible to undo single steps, save results, explore anatomical structures without physical limitations, and to easily compare different strategies and results.

2 Related Work

Because of the relevance of additional training for IA clipping, there are several commercial and non-commercial virtual systems. An easy-available but non-immersive system proposed by Allgaier et al [3] provides additional visualizations highlighting the vessel deformation during clipping.

The commercial *Immersive Touch*® system (Chicago, IL) was evaluated by 17 experts [1]. The study was conducted with a semi-immersive stereoscopic monitor-mirror system and a haptic stylus, the *Geomagic Touch* (3D Systems, Rock Hill, SC). The procedure includes the drawing of a craniotomy outline and placing the clip. Exposing the aneurysm by opening the Dura and Sylvian Fissure was not included. Their results show that the majority of participants believes that the simulation is helpful regarding anatomy, education, preparing for a surgery and finding an appropriate approach. However, nine participants had difficulties with grasping and interacting with the clip because of an unfamiliar depth perception. Furthermore, only 12% rated the haptic feedback as realistic.

Similar to Alaraj et al. [1], Gmeiner et al. [5] evaluated a semi-immersive clipping system developed at *RISC Software* (Hagenberg, Austria) using a stereoscopic display and the *Geomagic Touch*. However, Gmeiner et al. [5] applied the real medical instrument such as a forceps to the haptic device and included blood flow to evaluate the clipping. Their study with 18 experts also revealed similar results. For anatomical education it is highly appreciated, whereas only one third mentioned that the haptic interaction was truly satisfactory.

Another commercial system is the *Dextroscope*® (Volume Interactions Pte Ltd, Singapore). Three neurosurgical departments used this system with either a monitor-mirror system or a stereoscopic display [9]. However, this system could only be used to plan the intervention by placing an already

closed clip at the desired location. The clip could not be opened and closed and no vessel deformation was simulated.

In contrast to the previously mentioned approaches, Shono et al. [11] proposed a virtual simulation that comprises dissecting the arachnoid membrane and trabecula, and retracting the brain. In the clipping phase, clips can be applied at a deformable aneurysm. For the deformation, they use NVIDIA's PhysX engine, which is integrated in the game engine Unity. Like the previous approaches they use a stereoscopic display. For interactions they employ the motion capture device *Leap Motion*® (Leap Motion, San Francisco, CA) with a 3D-printed forceps. Additionally, they include usual sounds of an operating room to increase the sensation.

Besides virtual simulations, there are also hybrid simulations combining realistic physical cases with VR. Theodorovite et al. [12] use a physical workstation with a patient skull and Mayfield clamp in combination with a VR simulation using a VR headset to explore and clip an aneurysm. The user can interact with the virtual instruments with the help of the *Geomagic Touch*.

In contrast to the above-mentioned approaches, we want to provide an immersive training experience. To achieve this, we use a VR headset in combination with a pen-like device to imitate a real surgical instrument. Furthermore, the experience is improved by using a virtual operating room including virtual staff. During clipping, a real-time deformation is used to deform the vessels according to the applied clip. Finally, additional visual support to increase the usability and training is included.

3 Material and Methods

The immersive VR simulation was implemented with the game engine *Unity* (Unity Technologies: <https://unity.com>, San Francisco U.S.). For the implementation and evaluation an *HTC Vive Pro Eye* (HTC Corporation, Taiwan) was used. As input device, the *VR Ink* (Logitech, Switzerland) was chosen because a pen-like device is more similar to the medical instrument than a device held in power-grip, such as a VR controller, and thus more appropriate [4]. The same clip and middle cerebral artery aneurysm models as in previous work were used [3].

In the following the simulation workflow is described. After one of the predefined aneurysms is selected, the user enters a virtual operating room (see Fig. 1) adapted from Huber et al. [7]. According to the use case, the patient's head is approximated by a skull, since skin incision is not included in the workflow. The positioning of the head, craniotomy and brain retraction are described in [2]. Afterwards, the user has

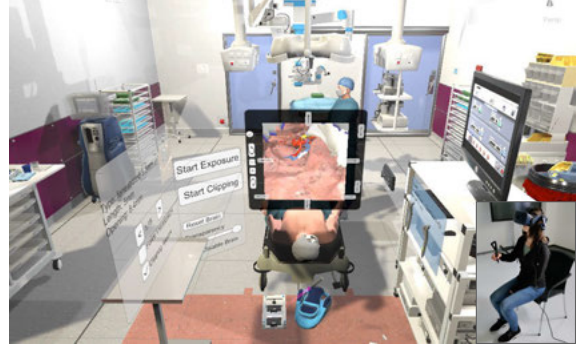


Fig. 1: Virtual operating room.

Tab. 1: Parameters used for NVIDIA Flex soft container for vessel deformation.

Simulation Parameters		Common Parameters	
Substep Count	9	Static Friction	3
Iteration Count	15	Dynamic Friction	2
Gravity	(0,0,0)	Particle Friction	1
Radius	0.002	Max Speed	340282.3
Solid Rest	0.0005	Max Acceleration	340282.3
Fluid Rest	0.0002	Damping	50
		Collision Distance	0.0002

to choose a clip from an inventory menu where the clip properties such as opening angle and length can be seen. The chosen clip can then be applied to the aneurysm. Since the navigation is difficult due to a lack of depth cues because of missing surrounding structures, rays indicating distances between the clip and vessels are included [3] (see Fig. 2 1b). Once the clip is placed, closing is visualized by highlighting the area the clip would hit (see Fig. 2 2b). By this, the user can assess whether the clip is placed in the desired way and which parts of the vessels and aneurysm are affected. Finally, the clip can be closed leading to a deformation of the vessels. For this, an NVIDIA Flex softbody surface representation with the physical parameters summarized in Tab 1 is applied to the vessels.

4 Evaluation

The virtual clipping was qualitatively assessed by two neurosurgeons: One male senior neurosurgeon (S) with 13 years of neurosurgical experience who often used VR, and one female novice neurosurgeon (N) with one year of neurosurgical experience who has used VR a few times. The evaluation started with a short description of the tasks and interactions. Before using the application, they were asked to complete the Simulator Sickness Questionnaire (SSQ-pre) [8]. Subsequently, they had to go through the application. Thereby, they were verbally

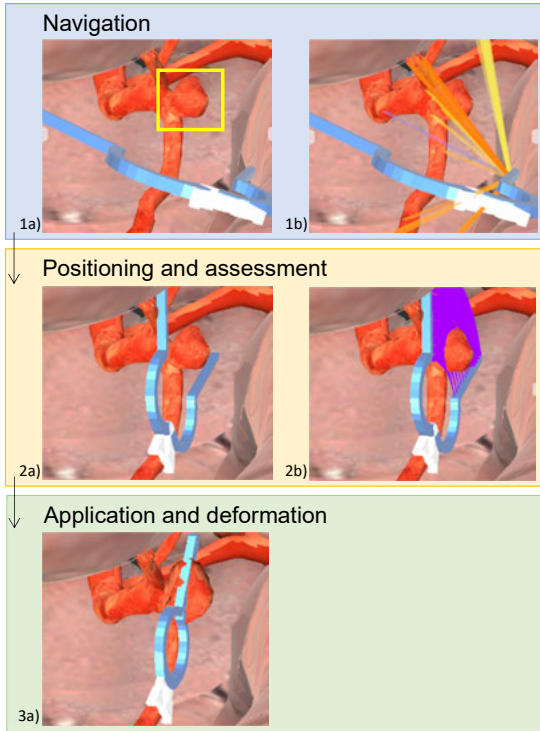


Fig. 2: Virtual clipping of an aneurysm (marked with the yellow rectangle in 1a).

assisted and reminded which buttons they have to use. After they completed the workflow, they were asked to fill out a questionnaire comprising the following parts:

1. Simulator Sickness Questionnaire (SSQ-post) [8]
2. NASA Task Load Index (NASA-TLX) to assess mental and physical demand [6]
3. Questions referring to clipping
4. Questions referring to further improvements
5. Igroup Presence Questionnaire [10] and additional questions to assess presence and immersion

5 Results

In the *SSQ* one participant (S) mentioned an increase from 'none' to 'slight' regarding the symptoms 'general discomfort' and 'eye strain' after using the VR system.

The results of the *NASA-TLX*, where usually a 20-point Likert scale is used, show that for one participant the task was more mentally demanding (N: 15/20, S: 15/20) than physically demanding (N: 11/20, S: 18/20). Both of them had to work hard to accomplish their level of performance (N: 14/20, S: 19/20). The question of how frustrated they were (N: 2/20, S: 14/20) and following up questions indicate that the novice surgeon did not have more difficulties placing the clip compared

to real microsurgical procedures. However, the senior neurosurgeon emphasized that the virtual clipping is much more difficult due to jittering, leading to a higher frustration. The reason for this is probably because of a missing physical skull with which they usually stable their hands.

Regarding *clipping*, both participants liked the deformation and rated it as realistic enough. They also emphasized that it is a crucial part of a training system. However, it would be good to have the possibility to modulate the speed of the clip application. Usually surgeons do not just apply the clip but close it carefully, observing the deformation and open it again to replace it if necessary. Showing the area affected by the clip helped the surgeons to discern the clip location in the 3D space. Furthermore, it should be possible to apply multiple clips.

Regarding *clip assessment*, different possibilities were discussed. The first possibility would be to include visual exploration of the clipped aneurysm. Both rated this approach as very useful, as this would be similar to an angiography with which one can check whether the aneurysm is sealed off completely. Furthermore, they would appreciate an additional numeric output indicating how much (e.g. percentage) of the aneurysm ostium is closed. The third possibility was rated a bit less helpful than the others. Here, it was proposed to fill the vessels with blood. One participant mentioned that with this one can see whether the parent artery is still open. However, it is currently not possible to simulate realistic blood flow during runtime of a real-time application. It can only be approximated by a fluid simulation e.g using NVIDIA Flex. Further aspects that can be used to evaluate and compare the clipping results are time and how strong the brain is retracted.

Furthermore, general *improvements* were discussed. First, we proposed collaborative VR, where two or more users can use the simulation at the same time. They can either work together and discuss different approaches, or work in a competitive mode where the users compete against each other. Both participants think that both modes would lead to an increased motivation and learning effect. However, the feedback and reactions of the senior neurosurgeon show that he would prefer the competitive mode.

Moreover, the brain retraction should be limited as such large deformations are not possible in reality. The novice neurosurgeon stated the consistence and volume of the brain as a challenge of the access during clipping surgery. A further aspect that could be included is pulssynchronous clipping. In this context, the novice neurosurgeon also mentioned that including EKG sound would make the experience more realistic.

The last part of the questionnaire was about *immersion*. Both participants agreed that they felt present in the virtual space and they were captivated by the virtual world. However, they were aware of the real world and paid attention to it.

Additionally, three questions were added to get an impression whether the participants think that immersion can improve the training experience. The statement 'Due to immersion I can concentrate better on the exercise' was rated with 4 (S) and 5 (N) (1=fully disagree, 5=completely agree). Whether they take the exercise more seriously was rated with 3 (S) and 5 (N) and 'Due to immersion I'm more motivated to solve the exercise well' was rated with 4 (S) and 5 (N).

6 Discussion and Conclusion

Our proposed training system differs from previous approaches on the basis of providing an immersive environment using a virtual operating room for aneurysm clipping training. Consequently, we provide a motivating and engaging experience, which is essential for an effective training. With the presented prototype we combine the immersive environment with the clipping of aneurysms using a soft body deformation. Thus, users can try out different strategies in a more realistic scenario. Although the device is no medical instrument, we put emphasis on providing a similar device regarding the hand position. However, having a completely virtual system without grounded haptic devices has the drawback of having no supportive surface which is available in a real clipping procedure. To solve this, a 3D printed skull with a large craniotomy hole can be used. This physical model has to be adjusted according to the virtual head placement or the virtual head has to be registered with the physical skull after placement. If the virtual instrument still jitters more than a real instrument, it is likely due to tracking inaccuracy.

Our evaluation focused on qualitative feedback, which also provides important feedback for further developments. However, having more participants would lead to statistical results. The main challenge in this case is to get that many participants, as the target group is limited to neurosurgeons.

In conclusion, we have presented an immersive VR training system for the clipping of intracranial aneurysms. Our system benefits from an immersive virtual operating room, realistic interactions with a pen-like device and real-time deformation of the vessels.

Author Statement

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tions, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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