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Virtual Reality in Preoperative Planning of Adolescent Idiopathic Scoliosis Surgery Using Google Cardboard

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Objective: Preoperative planning in spine surgery is a fundamental step of the surgical workup and is often assisted by direct visualization of anatomical 2-dimensional images. This process is time-consuming and may excessively approximate the 3-dimensional (3D) nature of spinal anatomy. Virtual reality (VR) is an emerging technology capable of reconstructing an interactive 3D anatomical model that can be freely explored and manipulated.
Methods: Sixty patients with adolescent idiopathic scoliosis underwent correction of the scoliotic curve by posterior arthrodesis after preoperative planning using traditional on-screen visualization of computed tomography scans (control group, n = 30) or exploration of a 3D anatomical model in VR using Google Cardboard (Google Inc.) (VR group, n = 30). Mean operative time, blood loss, length of hospital stay, and surgeon's satisfaction were assessed after surgery.
Results: The use of VR led to a significant decrease in operative time and bleeding while increasing the surgeon's satisfaction compared to the control group.
Conclusion: Preoperative planning with VR turned out to be effective in terms of operative time and blood loss reduction. Moreover, such technology proved to be reproducible, cost-effective, and more satisfactory compared to conventional planning.

Keywords: Virtual reality, Spine surgery, Scoliosis, Minimally invasive, Preoperative planning

INTRODUCTION

Surgical planning for particularly complex cases has been performed since computed tomography (CT) has been introduced in 1970. Initially, it was carried out based on sequential 2-dimensional (2D) images, assembled in a single dataset, and visualized by the surgeon. The surgeon then needed to mentally build a 3-dimensional (3D) model of the patient's specific anatomy. Obviously over time, the process becomes quick and easy for an expert practitioner. Despite imaging technologies have evolved, the method of visualization has remained almost identical. In the era of ultra-high-definition displays, smartphones,

clouds, and virtual reality (VR), preoperative planning remained bidimensional, through personal computer displays and in standard definition. Although this is the accepted paradigm for surgical planning, the use of new technologies in various areas may potentially lead to significant improvements in spine surgery as well.

3D visualization through the interactive nature of VR gives the opportunity to more clearly visualize the anatomy of the patient, hence making this technology particularly suitable for the preoperative planning of complex cases. The use of 3D models in preoperative evaluation is not a new procedure,[1] but virtually assisted technologies are generally very expensive and

require high-end computers and specific devices.

Spine surgery is characterized by a high risk of complications due to the close relationships with important neurovascular structures that may lead to neurological and vascular deficits but also infections and instrumentation failure. In particular, the rate of neurological deficits is higher in patients with neuromuscular scoliosis, spondylolisthesis, and adult spinal deformities.[2] Likewise, massive bleeding is more common in patients with scoliosis and spinal deformities.[3] Therefore, it is mandatory to find innovative methods to reduce the complication rate. Appropriate preoperative planning may help increase precision of the procedure and speed up operative time (OR). 3D models have found wide application in this field, allowing the surgeon to be familiar with the unique anatomy of complex cases through visualization and tactile manipulation of their replicated anatomy.[4] This process has been shown to improve the surgeon's knowledge of the altered anatomical relationships of patients with vertebral deformities, facilitating the identification of anatomical abnormalities not easily detectable with conventional radiology. In a few cases, these models have been employed preoperatively to determine the feasibility of the surgery and plan the best surgical approach.[4-6]

In this study, we tested a novel method to create a 3D model for VR using Google Cardboard (Google Inc., Mountain View, CA, USA) for the preoperative planning of adolescent idiopathic scoliosis (AIS) correction surgery, comparing this technology to classic 2D visualization.

MATERIALS AND METHODS

A total of 65 consecutive patients affected by AIS (Lenke type 1-3) were treated at the Orthopedic Unit of Bambino Gesù Children's Hospital between March 2019 to April 2020. Patients underwent correction of the scoliotic curve by posterior arthrodesis using a free-hand technique. Inclusion and exclusion criteria

are summarized in Table 1. Five patients were excluded from the study due to the lack of adequate 3D images. Sixty patients were randomly divided. The patients were allocated into an intervention group (named VR group; VR) of 30 people whose preoperative planning was made using VR and a control group of 30 (named control group; CG) whose preoperative planning was performed with standard CT scan visualized on a computer screen. All the procedures were performed by 2 experienced spine surgeons who have completed >1,000 AIS cases. All the patients had a minimum follow-up of 6 months. Baseline characterizes were collected for both groups, including age, sex, number of levels treated, and major curve preoperative Cobb angle (Table 2). It was analyzed the OR (minute), the blood loss (BL; calculated both in mL and as estimated blood volume loss related to patients' weight; %EBV), the hospital stay (night of stays), and the satisfaction of the surgeon. To assess the satisfaction of the surgeon for the preoperative planning we created a scale ranging from 0 (not satisfied) to 5 (fully satisfied).

1. 3D Model Creation

Google Cardboard is an affordable VR platform consisting of a cardboard head mount for a smartphone.[7] It was released for the first time in 2014 and to date, different models have been

Table 2. Demographic data and preoperative Cobb angle

Variable	VR (n=30)	CG (n=30)	p-value
Age (yr), mean (range)	13.9 (12-17)	14.2 (12-16)	0.272
Sex			0.341
Male	6	9	
Female	24	21	
No. of levels treated per patient, mean	12.3	12.5	
Preoperative Cobb angle, mean (range)	57.3 (48-75)	60.2 (46-80)	0.223

VR, virtual reality; CG, control group.

Table 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Age 10-18 years	Early onset scoliosis
Major curve Cobb angle >45°	Neurological diseases: paraplegia, tetraplegia
Preoperative CT scan	Genetic defects: Prader-Willi syndrome, Neurofibromatosis type 1, Marfan syndrome
Levels between T2 and L4	Other comorbidities: cardiac defects, coagulation disease
	Previous surgery
	Levels between C1–7 and L5–S1
	Not adequate 3-dimensional images

released on the market. It works with all the new smartphones using Android or iOS, allowing the user to experience VR by inserting a smartphone into the visor and directly visualizing virtual contents through the lenses. Google Cardboard has already been used in several clinical fields.[8] For our purpose, we acquired the CT-scans of the patients affected by AIS before surgery to create a 3D model of their spines. We used the open-source software InVesalius 3 (Centro de Tecnologia da Informação Renato Archer, Campinas, Brazil) to create a 3D model from the CT scan acquired data. Using the software, we enlightened the regions of interest (ROI) for our study (column and aorta) and then created a mask (Fig. 1A-D). Subsequently, we exported the 3D model as a .stl file and cleaned and resampled the model with MeshLab (Visual Computing Lab, ISTI-CNR, Pisa, Italy) to obtain a lighter file, exported in .ply format. It was also possible to choose different layers to display (bone, vessels, and other soft tissues). The first DICOM file of the CT scan was about 250 MB and the final one less than 50 MB which was an appropriate size for the upload and fast visualization on mobile phones. The entire procedure lasted about 30 minutes and was made using a personal computer equipped with the following hardware: Intel Core i7-4710MQ CPU @ 2.50 GHz; 16 Gb ram; Nvidia 880M. Once the model was created, it was uploaded on our personal webpage created on Sketchfab (New York, NY, USA) and freely visualized utilizing either a personal computer or a mobile phone (Fig. 2).

2. Preoperative Planning

The surgeons explored the 3D model of the spine of 30 patients using the Chrome application in VR mode with different
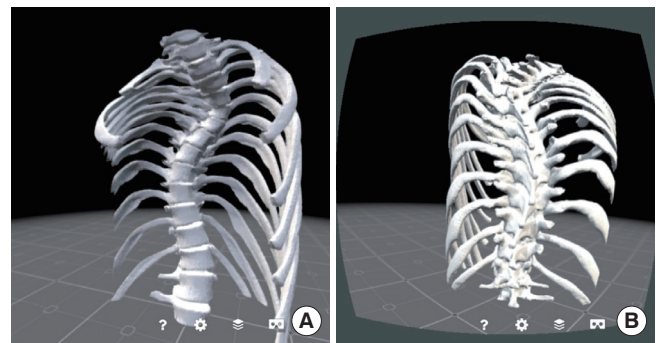

Fig. 2. Three-dimensional model of a patient with adolescent idiopathic scoliosis uploaded in Sketchfab (New York, NY, USA).
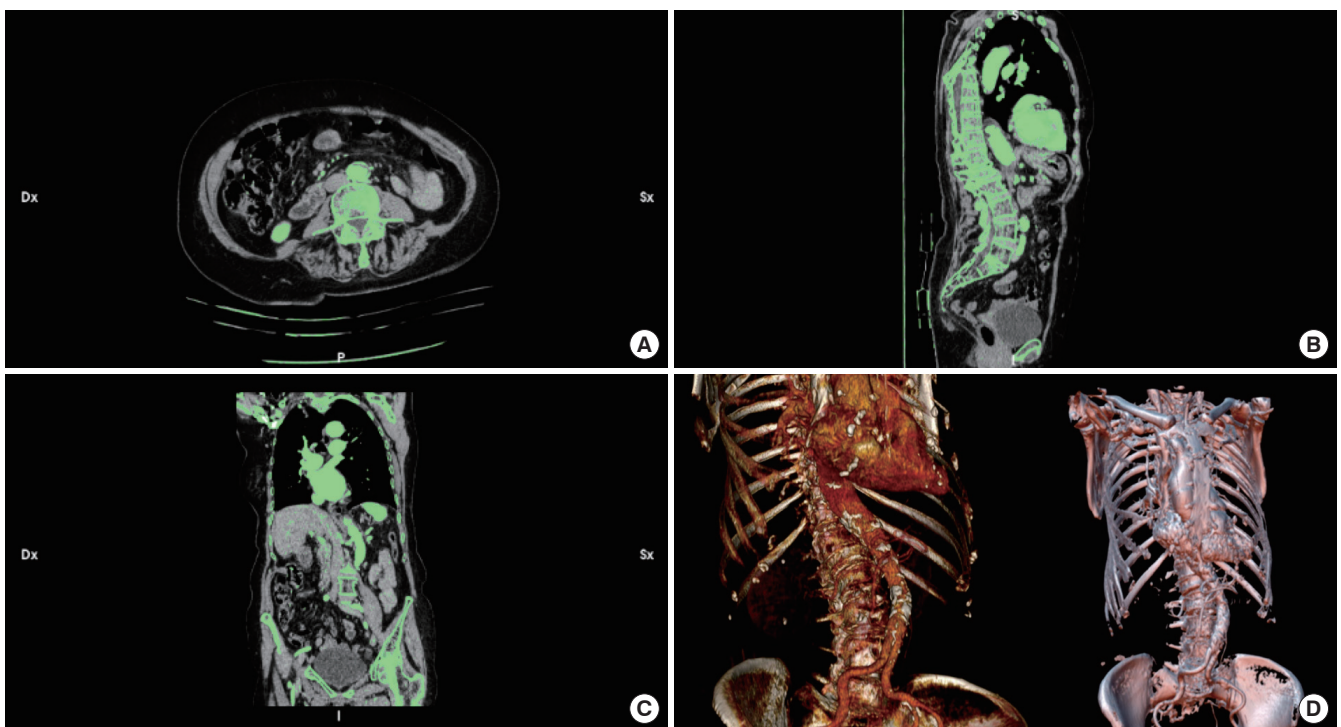

Fig. 1. Three-dimensional (3D) model creation. The regions of interest (ROI) considered for the reconstruction of the virtual model included the spine, the pelvis, the aorta, and the heart. ROI were highlighted on preoperative computed tomography on transverse (A), sagittal (B), and coronal planes (C). (D) Subsequently, a 3D mask was obtained.
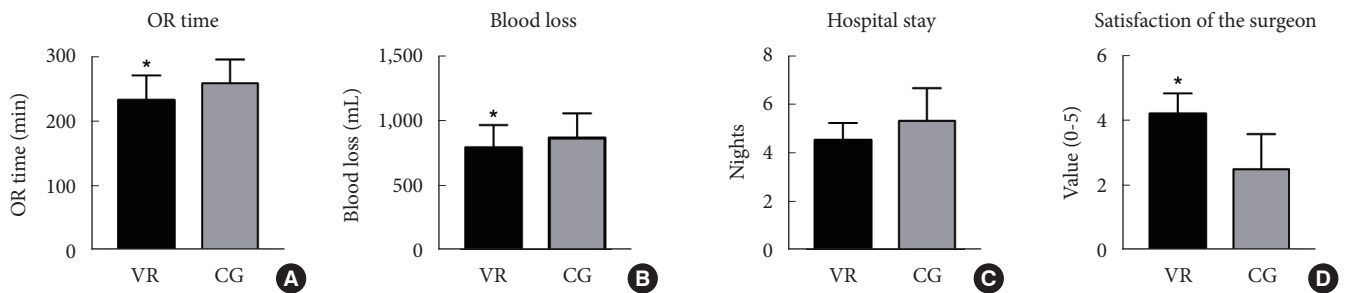
Fig. 3. Comparison of major outcome measures analyzed in the study. The use of virtual reality (VR) in the preoperative planning resulted in significantly reduced operative (OR) times (A) and blood loss (B). (C) Although with a descending trend, no significant difference was noted between the groups regarding hospital stay. (D) Overall, preoperative planning with VR resulted in a significantly higher degree of satisfaction in the surgeon compared to conventional methods. CG, control group. *p < 0.05.

mobile phones mounted on Google Cardboard. In the CG, standard preoperative planning through CT scan and 2D visualization on a screen were used. The following items were systematically discussed:

- Number of levels (selective vs. nonselective fusion)
- Direction of screws
- Potential structural abnormalities (vascular and nervous pathologic modifications)
- Potential bone abnormalities (hemispondylous, spondylolisthesis, and spondylolysis)
- Type of approach (anterior vs. posterior)
- Number of osteotomies required

3. Data Analysis

A *post hoc* power analysis was performed comparing the mean OR between VR and CG. A large effect size was used (Cohen d = 0.824). The sample was calculated to have a large effect size (Cohen d = 0.824 and alpha level = 0.05. A sample of 60 patients was required with a power of 0.93. We compared baseline characteristics between preoperative planning performed in VR and CG with and without and VR. Student t-test was performed to compare VR and CG using Prism 7 (Graph-Pad Software Inc., La Jolla, CA, USA). Significance was at the 0.05 level. Data are presented as mean ± standard deviation.

4. Ethics Approval

This research study was conducted retrospectively from data obtained for clinical purposes. Written informed consent to publish this information was obtained from the patient. Internal Ethics Committee of our Pediatric Hospital approved this study. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Table 3. Secondary outcomes: length of stay (nights) and surgeon satisfaction grade

Variable	VR (n = 30)	CG (n = 30)	p-value
Nights of stay, mean ± SD	4.5 ± 0.22	5.3 ± 0.42	0.049
Satisfaction of the surgeon (0-5), mean	4.2	2.5	0.052

VR, virtual reality; CG, control group; SD, standard devitaion.

RESULTS

There were no differences in baseline characteristics of the patients between groups. Patients treated after VR-assisted preoperative planning had significantly lower OR time (231.8 ± 32.2 minutes vs. 258.1 ± 31.6 minutes, p = 0.017; Fig. 3A) and BL (790 ± 55.68 mL vs. 865 ± 60.12 mL, p = 0.047; 21.9 ± 1.54 %EBV vs. 23.52 ± 1.63 %EBV, p = 0.039; Fig. 3B) compared to the CG. Moreover, patients treated without preoperative VR planning were more likely to stay longer in the hospital (5.3 ± 0.42 days) compared to patients treated after preoperative VR planning (4.5 ± 0.22 days, p = 0.07) (Table 3, Fig. 3C). The satisfaction of the surgeon was higher in the VR group (4.2 ± 0.2 with VR planning vs. 2.5 ± 0.8 with standard planning, p = 0.006) (Fig. 3D).

DISCUSSION

In this study, we have described a novel method to build a 3D VR model using Google Cardboard for the preoperative planning of AIS correction and compared our results to standard preoperative planning using 2D images.

Nowadays, medical technology has reached important milestones. Beyond the technological progress of surgical instrumentation, it is necessary to find new solutions for the preoperative planning of complex clinical cases to decrease the rate of

complications. The treatment of bone deformities, and specifically the correction of AIS is a challenging field due to the complex 3D deformities, thus representing an interesting field of application.

Using VR, it is possible to reconstruct and simulate a full 3D model of the spine of the patient fostering a more intuitive and effective preoperative planning. The standard planning through CT scan allows to visualize 2D images, hence representing a suitable method for experienced surgeons. However, a complete image of the patient, enlarged by VR, provides the possibility to explore and visualize every anatomical layer by simply turning one's head, thence allowing surgeons to have a better 3D comprehension of the specific case.

Similar technology has already been applied in other fields,[9] such as general surgery,[10,11] cardiac surgery,[12,13] and others.[14] Zawy et al.[15] performed preoperative planning using VR for the treatment of unilateral cervical stenosis. A CG underwent traditional preoperative planning using standard imaging procedures only (CT and x-ray). The study showed that the use of VR allowed to visualize anatomical structures that could not be easily detected with normal imaging, permitting the surgeon to decide on the most appropriate surgical approach before surgery.

In our 60 consecutive cases experience, we reported better outcomes in terms of OR time, BL, and hospital stay in VR group, which may be related to a more accurate preoperative planning with a better consciousness of the 3D image of the case. Google Cardboard and VR in fact, allow the surgeon to have a broader view of the anatomy and a 3D comprehension of the delicate structures in the operative field, thence avoiding major risks. If compared to the CG, we found greater satisfaction among the surgeons for planning using VR. Moreover, our procedure is fast to develop and affordable, with a high-fidelity reproduction of the anatomy of the patient. The model allows multiple users to access the reconstructions by simply using a smartphone and an internet connection, which are, nowadays, as much indispensable as ubiquitous, making such technology cost-effective and widely accessible. Moreover, the 3D model created may also be printed by a 3D-printer, allowing surgeons to make a preoperative planning with a real model of the spine.

The model developed has the potential to be used in the teaching field.[16] VR has been established as a learning tool which allows both surgeons and residents to improve surgical techniques avoiding real complications.[17] Several studies have demonstrated the effectiveness of VR training in the positioning of lumbar pedicle screws.[18] The results were attributed to sequential learning, which was enhanced by depth perception and improved understanding of anatomy.[19] Shi et al.[20] have also demonstrated that VR-trained residents achieved better results in screw positioning compared to a CG that was trained with conventional methods. Gottschalk et al.[21] conducted a similar trial on the insertion of screws into the cervical lateral masses of cadavers and sawbones. The results of residents trained with VR were better than those of the CG.

Indeed, through this technology, it is possible to show the anatomy in a completely different way, with a magnification of bones and tissues.[22]

Therefore, VR could represent a turning point in modern surgery. With the continuing development of different technologies, such as robotic surgery, augmented reality, or telemedicine, VR will increase its importance in the next few years. VR planning could be applied in different settings. New biotechnologies[23] involving the regenerative treatment of intervertebral disc degeneration may particularly benefit from this approach.[24,25] With an accurate pre-procedural evaluation, it would be possible to decide the best approach to carry mesenchymal stem cells into the disc.[26] It could be also useful for the evaluation of tumours, infections,[27] and postoperative assessment of suspected pedicular screw or instrumentation failure. Therefore, it is crucial to invest in this technology and our method allows everyone to try the possibilities of VR. The satisfaction of the surgeon is also an important parameter. In VR group surgeons were more satisfied compared to CG. This was probably due to the virtual training performed by VR that allows the surgeon to avoid complications (as anatomical anomalies) during the surgery. Using Google Cardboard guarantees access to VR from everywhere, without significant costs.

However, this study has some limitations. First of all, our technique has been only tested for the preoperatory planning of patients affected by AIS, therefore the possible advantage of Google Cardboard in the intraoperative setting has not been assessed. Moreover, clinical and functional outcomes should be further evaluated in order to assess the effectiveness of the procedure. Therefore, further randomized clinical studies are mandatory to assess the advantages of this technique in the clinical setting. Moreover, the risk to lose important 3D details when the ROI of the model is not accurate. In addition, the Sketchfab website allows the upload of the model which are smaller than 250 MB which however did not represent a problem in our study. Nevertheless, these issues can be easily solved. High-end smartphones are increasingly present and an operator with a good knowledge of the software can easily highlight the right ROI, generating an accurate 3D model in a few minutes. Lastly,

with VR is possible to fully inform patients of their diseases, showing the anatomy in a more comprehensive method.[28]

CONCLUSION

3D VR models for preoperative planning significantly improved key parameters that can impact the outcomes of patients undergoing complex spine surgery as correction of AIS. Further studies should be performed to improve this technology and enlarge its adoption in other complex cases, also by performing larger randomized controlled trials.

CONFLICT OF INTEREST

The authors have nothing to disclose.

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