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Original Article

DIVA, a 3D virtual reality platform, improves undergraduate craniofacial trauma education

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ABSTRACT

Craniofacial fractures management is challenging to teach due to the complex anatomy of the head, even when using three-dimensional CT-scan images. DIVA is a software allowing the straightforward visualization of CT-scans in a user-friendly three-dimensional virtual reality environment. Here, we assess DIVA as an educational tool for craniofacial trauma for undergraduate medical students.

Three craniofacial trauma cases (jaw fracture, naso-orbital-ethmoid complex fracture and Le Fort 3 fracture) were submitted to 50 undergraduate medical students, who had to provide diagnoses and treatment plans. Each student then filled an 8-item questionnaire assessing satisfaction, potential benefit, ease of use and tolerance. Additionally, 4 postgraduate students were requested to explore these cases and to place 6 anatomical landmarks on both virtual reality renderings and usual slice-based three-dimensional CT-scan visualizations.

High degrees of satisfaction (98%) without specific tolerance issues (86%) were reported. The potential benefit in a better understanding of craniofacial trauma using virtual reality was reported by almost all students (98%). Virtual reality allowed a reliable localization of key anatomical landmarks when compared with standard three-dimensional CT-scan visualization.

Virtual reality interfaces such DIVA are beneficial to medical students for a better understanding of craniofacial trauma and allow a reliable rendering of craniofacial anatomy.

1. Introduction

Craniofacial trauma is difficult to teach due to the complex anatomy of the skull [1]. Three-dimensional (3D) CT-scans help in visualizing fracture lines based on exploration of the 3D objects on 2D screens. Virtual reality (VR) is a technology that uses real-world visual perception within entirely artificial computer-generated environments. VR allows users to efficiently explore 3D environments in an entirely immersive manner, providing a natural and spatially realistic experience [2].

The benefits of VR in craniofacial surgery have been assessed in previous studies [3]. Almost all studies reported the use of VR for pre-operative planning [4] and intra-operative assistance [5], notably in implantology, orthognathic surgery and maxillofacial reconstruction [3]. Few studies have reported the benefits of VR in surgical education. Within the educational literature, radiology [6] and implantology [7] applications have been evaluated but no study has been dedicated to craniofacial trauma to date.

DIVA (Data Integration and Visualization in Augmented and Virtual Environments, Pasteur Institute, Paris) is a software allowing a fast and user-friendly visualization of raw CT-scan data with immediate immersion [8,9]. DIVA allows users to intuitively navigate in a flexible 3D environment with virtual handheld tools that can be used to interact with 3D images in real-time including landmarking, clipping and highlighting tools.

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Here we assess DIVA as an educational tool for teaching craniofacial trauma using a dedicated questionnaire. We furthermore assess the anatomical precision of this tool using anatomical landmark placement.

2. Materials and methods

2.1. VR in craniofacial trauma education: benefits and tolerance

Three craniofacial trauma cases (jaw fracture, naso-orbital-ethmoid complex fracture and Le Fort 3 fracture) were submitted to 50 fourth-year undergraduate medical students from the University of Paris, who had to provide a diagnosis and a treatment plan. For each student, pre- and post-operative CT-scans were assessed using both a freeware DICOM viewer (RadiAnt, Medixant, Poznan, Poland) and DIVA (Fig. 1).

The DIVA interface offers two visualization tools: (1) a desktop tool for standard 3D visualization and (2) the VR environment. The desktop tool was used to reconstruct the skull in 3D based on pre-defined transfer functions. This same visualization is seamlessly switched to the VR viewing context where it can be physically interacted with (Fig. 2 and Supplemental Digital Contents 1–3).

After using the DICOM viewer and DIVA, each undergraduate medical student filled a questionnaire based on 8 items assessing satisfaction, potential benefit, comfort of use and tolerance.

2.2. Anatomical precision of VR

4 postgraduate students were requested to explore these cases and to place 6 anatomical landmarks on two types of 3D

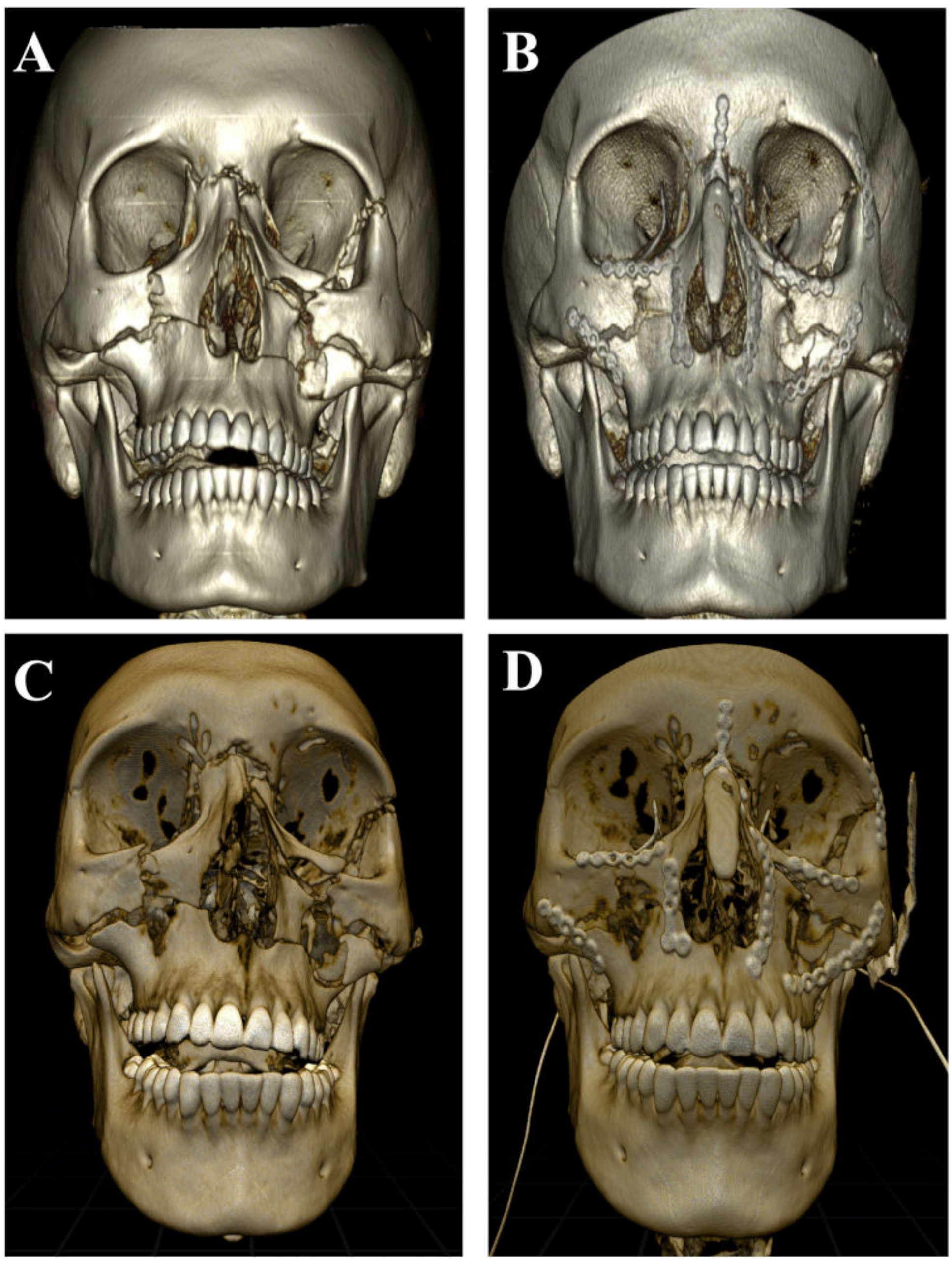

Fig. 1. 3D renderings provided by a freeware (RadiAnt, Medixant, Poznan, Poland) (**A**, **B**) and DIVA (**C**, **D**) for the per- and post-operative aspects of a Le Fort III fracture trauma case (case №3).

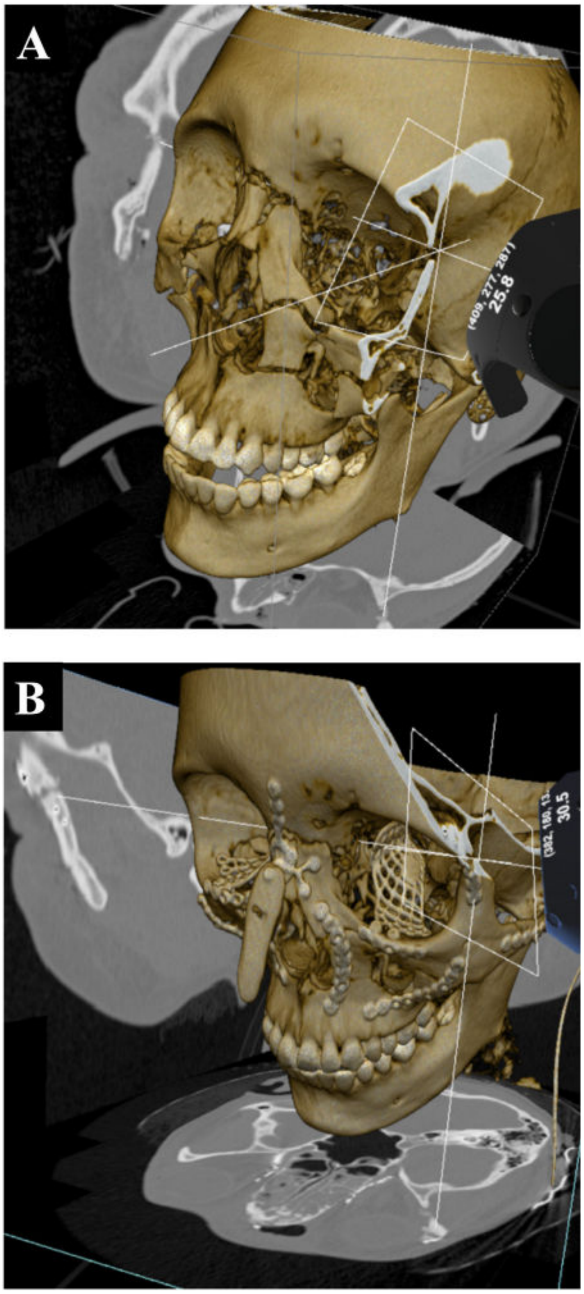

Fig. 2. Exploring a pre-operative (**A**) and post-operative (**B**) Le Fort III trauma case (case №3) using DIVA. 2D sections can be visualized on a box surrounding the 3D rendering, and the used can interact with the 3D avatar using cutting tools, in order to better understand the internal skull anatomy.

renderings: (1) 3D reconstructions from CT-scan using Avizo (ThermoFisher Scientific, Waltham, MA, USA) and (2) 3D renderings of the same DICOM data using the DIVA VR interface.

The landmarks selected were: (1) anterior nasal spine, (2) posterior nasal spine, (3) distal palatal cusp of tooth 17 (right second maxillary molar), (4) distal palatal cusp of tooth 27 (left second maxillary second molar), (5) apex of the crista galli process and (6) apex of the odontoid process of C2. Landmarks on both rendering were positioned 3 successive times (3 trials) by the 4 subjects and 3D coordinates were extracted. Geometric morphometrics was performed using *MorphoJ* (Apache License, Version 2.0) [10]. After screening for outliers and Procrustes superimposition, canonical variate analysis on Procrustes coordinates using both trials and subjects as classifier variables allowed to compute Procrustes distances between groups (trials and subjects) [11]. Permutation test for pairwise distances with 10,000 iterations allowed obtaining p-values accounting for the significance of Procrustes distances between trials 1–3 and subjects 1–4.

We furthermore evaluated the variability in landmark positioning by assessing inter- and intra-individual error rates, defined as the variance of the position divided by N-1, with N being the number of points.

3. Results

3.1. VR in craniofacial trauma education: benefits and tolerance

Almost all undergraduate medical students (92%) reported a high degree of satisfaction (question 1, responses defined as "very satisfied" and "more than satisfied") when using DIVA to explore and analyze craniofacial trauma cases (Table 1). The use of DIVA was deemed easy, intuitive (88%) and well tolerated (86%) (questions 2 and 3, Table 1). Furthermore, DIVA allowed students to visualize some lesions not seen on the usual 2D and 3D renderings (82%), such as skull base and pterygoid process fractures (questions 4 and 5, Table 1). Almost all students strongly recommended the use of DIVA for educational purposes in traumatology (questions 6–8, Table 1).

3.2. Anatomical precision of VR

Geometric morphometrics analyses showed that all p-values accounting for the significance of Procrustes distances between trials 1–3 and subjects 1–4 were > 0.05: landmarking using standard 3D CT-scan visualization and landmarking using DIVA provided a similar 3D display of landmarks, without significant distortion. All mean 3D errors, exploring the variability in landmark positioning, were lower than 1 mm, ranging from 0.37 to 0.84 mm (Fig. 3 and Supplemental Digital Contents 4).

4. Discussion

Craniofacial anatomy is challenging to teach to undergraduate medical students and common misunderstandings lead to pitfalls in diagnosis and treating head and neck trauma. While the teaching of traditional anatomy usually involves books and cadaveric dissection, which requires significant amounts of time and effort, other teaching methods can be beneficial [12–14].

VR has been recently re-introduced in medical schools as an easy-to-access technology due to the availability of low-cost VR headsets. Through the integration of stereoscopy, motion tracking technologies and total 3D immersion, VR aims at providing a more natural means to visualize 3D structures. VR headsets are bundled with 3D controllers (that act as 3D computer mice) allowing manipulation and interaction with data within the virtual environment. Interactions with the VR controller are rather intuitive as they are performed as if the data were physically present in front of the user.

DIVA is a software that automatically generates detailed 3D reconstructions of tomographic medical images such as CT-scans. The avatar generated by DIVA based on raw DICOM CT-scan images is generated through volumetric reconstruction without pretreatment (e.g. segmentation). DIVA is optimized to ensure high refresh rate (at least 60 Hz) and a high quality of volume rendering and thus provides a fluid experience. Users are free from latency issues that induce negative experience within VR environments [9].

Table 1
Assessment of the use of VR in craniofacial trauma education by 50 undergraduate medical students from the University of Paris.

Questions	Responses	Evaluation scale and more detailed student responses	
1. Are you satisfied of DIVA when exploring craniofacial trauma cases?	Yes n = 49 No n = 1	5: very satisfied	5: n=27
		4: more than satisfied	4: n = 19
		3: satisfied	3: n=4
		2: partly satisfied	2: n = 0
		1: not at all satisfied	1: n = 0
2. Do you think that DIVA was easy and intuitive to use?	Yes n = 50 No n = 0	5: very easy and intuitive	5: n = 22
		4: more than easy and intuitive	4: n = 22
		3: easy and intuitive	3: n=4
		2: partly intuitive	2: n=2
		1: not at all intuitive	1: n = 0
3. Have you experienced any difficulties in tolerating the use of DIVA?	Yes n = 7 No n = 43	visual fatigue	n = 0
		headaches	n = 0
		dizziness	n = 0
		nausea	n = 0
		other (precise)	n = 0
4. Does the use of DIVA allow you to visualize some lesions not suspected on usual 2D and 3D renderings?	Yes n = 41 No n = 9	Fracture of the pterygoid processes were especially well apprehended and visualized using DIVA.	
5. Does the use of DIVA allow you to better visualize some lesions seen on usual 2D and 3D renderings?	Yes n = 49 No n = 1	Fractures lines were better visualized and understood using DIVA.	
6. Do you think that DIVA was beneficial to understand maxillofacial trauma?	Yes n = 50 No n = 0	5: very profitable	5: n=27
		4: more than profitable	4: n = 19
		3: profitable	3: n=4
		2: partly profitable	2: n = 0
		1: not at all profitable	1: n = 0
7. Do you VR is of interest for the better understanding of maxillofacial anatomy? Please precise	Yes n = 48 No n = 1	It provides a better visualization of the maxillofacial anatomy, which helps the comprehension of the traumatology.	
8. Would you advise using DIVA as a standard educational tool in traumatology?	Yes n = 49 No n = 1	5: highly recommended	5: n=25
		4: more than recommended	4: n = 22
		3: recommended	3: n=2
		2: partly recommended	2: n = 0
		1: not at all recommended	1: n = 1

Here we showed that using DIVA to explore and analyze 3D CT-scans [8] improved the understanding craniofacial trauma. Furthermore, we found a high degree of interobserver reproducibility reflecting the precision and accuracy of this tool to explore head and neck 3D anatomy and landmarking.

As outlined by Alsabbagh et al., craniofacial fractures may be better interpreted using VR compare to usual CT-scan renderings [15]. We furthermore found that 82% of students reported spotting lesions using VR that they had missed on usual 3D renderings, thus confirming that VR is beneficial for exploring complex 3D objects [16].

The value of VR in understanding fractures has recently been reported in orthopedics [17] and in pre-surgical planification of maxillofacial cases [18], as well as in dental education [19]. Roessel et al. have recently reported a systematic literature review supporting the using of VR in surgical education and training [20].

In brief, VR solutions such as DIVA can complement conventional teaching methods (2D sketches, 3D renderings, cadaveric dissections) when complex 3D structures such as the skull are involved [21–24]. High satisfaction and tolerance degrees could be obtained using VR tools such as DIVA. Beyond traumatology, similar tools may be used to explore craniofacial malformations and head and neck cancers, by combining CT-scan and MRI data.

Approval and confirming statements

This study was approved by Institutional review board and performed in accordance with the Helsinki declaration. Collection of data and analysis were in accordance with guidelines of the French National Committee for the Protection of Personal Data (Commission Nationale Informatique et Libertés, CNIL, declaration number 2218907v0).

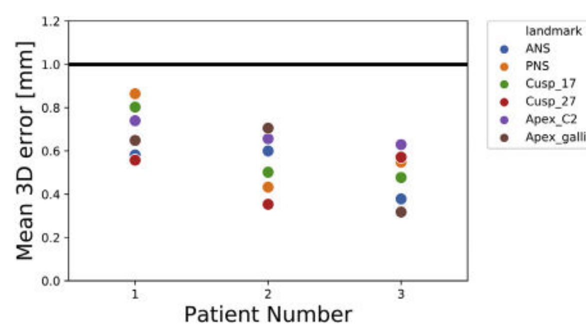

Fig. 3. Low error values when positioning 3D landmarks using DIVA: all mean 3D errors were lower than an arbitrary threshold of 1 mm. mm: millimeter; 3D: tridimensional; ANS: anterior nasal spine; PNS: posterior nasal spine; Cusp_17: distal palatal cuspid of tooth 17; Cusp_27: distal palatal cuspid of tooth 17; Apex_C2: apex of the odontoid process of C2; Apex_galli: apex of the *crista galli* process.

Conflict of interest

Mohamed El Beheiry and Jean-Baptiste Masson are cofounders, shareholders and scientific advisors of Avatar Medical.
Jean-Baptiste Masson is one of the scientific advisors of the Robeauté startup.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jormas.2020.09.009.

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