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

2 **Short title** VR in craniofacial trauma education

3

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19 **34 Conflict of interest**
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21 35 Mohamed El Beheiry and Jean-Baptiste Masson are cofounders, shareholders and scientific
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26 37 Jean-Baptiste Masson is one of the scientific advisors of the Robeauté startup.
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38 **Author's role and participation on the manuscript**

39 All authors have participated to the conception and design, acquisition of data, or analysis and
40 interpretation of data;

41 All authors have participated to the drafting the article or revising it critically for important
42 intellectual content;

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44 All authors have participated to the agreement to be accountable for all aspects of the work in
45 ensuring that questions related to the accuracy or integrity of any part of the work are
46 appropriately investigated and resolved

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49 This study was approved by Institutional review board and performed in accordance with the
50 Helsinki declaration. Collection of data and analysis were in accordance with guidelines of
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53 **Abstract**

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

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

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

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

72 **Keywords:**

73 virtual reality; data visualization; image processing; craniofacial; traumatology; education

74 **Introduction**

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

81 The benefits of VR in craniofacial surgery have been assessed in previous studies [3]. Almost
82 all studies reported the use of VR for pre-operative planning [4] and intra-operative assistance
83 [5], notably in implantology, orthognathic surgery and maxillofacial reconstruction [3]. Few
84 studies have reported the benefits of VR in surgical education. Within the educational
85 literature, radiology [6] and implantology [7] applications have been evaluated but no study
86 has been dedicated to craniofacial trauma to date.

87 DIVA (Data Integration and Visualization in Augmented and Virtual Environments, Pasteur
88 Institute, Paris) is a software allowing a fast and user-friendly visualization of raw CT-scan
89 data with immediate immersion [8,9]. DIVA allows users to intuitively navigate in a flexible
90 3D environment with virtual handheld tools that can be used to interact with 3D images in
91 real-time including landmarking, clipping and highlighting tools.

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

95 **Materials and Methods**

96

97 **1. VR in craniofacial trauma education: benefits and tolerance**

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

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

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

112 **2. Anatomical precision of VR**

113 4 postgraduate students were requested to explore these cases and to place 6 anatomical
114 landmarks on two types of 3D renderings: (1) 3D reconstructions from CT-scan using Avizo
115 (ThermoFisher Scientific, Waltham, MA, USA) and (2) 3D renderings of the same DICOM
116 data using the DIVA VR interface.

117 The landmarks selected were: (1) anterior nasal spine, (2) posterior nasal spine, (3) distal
118 palatal cusp of tooth 17 (right second maxillary molar), (4) distal palatal cusp of tooth 27 (left
119 second maxillary second molar), (5) apex of the crista galli process and (6) apex of the

120 odontoid process of C2. Landmarks on both rendering were positioned 3 successive times (3
1 trials) by the 4 subjects and 3D coordinates were extracted. Geometric morphometrics was
2 121 performed using *MorphoJ* (Apache License, Version 2.0) [10]. After screening for outliers
3 122 and Procrustes superimposition, canonical variate analysis on Procrustes coordinates using
4 123 both trials and subjects as classifier variables allowed to compute Procrustes distances
5 124 between groups (trials and subjects) [11]. Permutation test for pairwise distances with 10000
6 125 iterations allowed obtaining p-values accounting for the significance of Procrustes distances
7 126 between trials 1-3 and subjects 1-4.
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9 128 We furthermore evaluated the variability in landmark positioning by assessing inter- and
10 129 intra-individual error rates, defined as the variance of the position divided by N-1, with N
11 130 being the number of points.
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131 **Results**

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133 **1. VR in craniofacial trauma education: benefits and tolerance**

134 Almost all undergraduate medical students (92%) reported a high degree of satisfaction
135 (question 1, responses defined as “very satisfied” and “more than satisfied”) when using
136 DIVA to explore and analyze craniofacial trauma cases (Table 1). The use of DIVA was
137 deemed easy, intuitive (88%) and well tolerated (86%) (questions 2 and 3, Table 1).
138 Furthermore, DIVA allowed students to visualize some lesions not seen on the usual 2D and
139 3D renderings (82%), such as skull base and pterygoid process fractures (questions 4 and 5,
140 Table 1). Almost all students strongly recommended the use of DIVA for educational
141 purposes in traumatology (questions 6-8, Table 1).

142

143 **2. Anatomical precision of VR**

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

150 **Discussion**

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5 152 Craniofacial anatomy is challenging to teach to undergraduate medical students and common
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7 153 misunderstandings lead to pitfalls in diagnosis and treating head and neck trauma. While the
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9 154 teaching of traditional anatomy usually involves books and cadaveric dissection, which
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11 155 requires significant amounts of time and effort, other teaching methods can be beneficial [12–
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17 157 VR has been recently re-introduced in medical schools as an easy-to-access technology due to
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19 158 the availability of low-cost VR headsets. Through the integration of stereoscopy, motion
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21 159 tracking technologies and total 3D immersion, VR aims at providing a more natural means to
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23 160 visualize 3D structures. VR headsets are bundled with 3D controllers (that act as 3D computer
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25 161 mice) allowing manipulation and interaction with data within the virtual environment.
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27 162 Interactions with the VR controller are rather intuitive as they are performed as if the data
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29 163 were physically present in front of the user.
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34 164 DIVA is a software that automatically generates detailed 3D reconstructions of tomographic
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36 165 medical images such as CT-scans. The avatar generated by DIVA based on raw DICOM CT-
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38 166 scan images is generated through volumetric reconstruction without pretreatment (e.g.
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40 167 segmentation). DIVA is optimized to ensure high refresh rate (at least 60 Hz) and a high
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42 168 quality of volume rendering and thus provides a fluid experience. Users are free from latency
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44 169 issues that induce negative experience within VR environments [9].
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51 171 Here we showed that using DIVA to explore and analyze 3D CT-scans[8] improved the
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53 172 understanding craniofacial trauma. Furthermore, we found a high degree of interobserver
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55 173 reproducibility reflecting the precision and accuracy of this tool to explore head and neck 3D
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57 174 anatomy and landmarking.
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175 As outlined by Alsabbagh et al., craniofacial fractures may be better interpreted using VR
176 compare to usual CT-scan renderings[15]. We furthermore found that 82% of students
177 reported spotting lesions using VR that they had missed on usual 3D renderings, thus
178 confirming that VR is beneficial for exploring complex 3D objects [16].

179

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

184

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

190

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272 **Figures legends**

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

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

282

283 **Figure 3.** Low error values when positioning 3D landmarks using DIVA: all mean 3D errors
284 were lower than an arbitrary threshold of 1 millimeter. mm: millimeter; 3D: tridimensional;
285 ANS: anterior nasal spine; PNS: posterior nasal spine; Cusp_17: distal palatal cuspid of tooth
286 17; Cusp_27: distal palatal cuspid of tooth 17; Apex_C2: apex of the odontoid process of C2;
287 Apex_galli: apex of the *crista galli* process.

288 **Table legends**

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

292 **Supplemental Digital Contents**

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294 ***Supplemental Digital Content 1.*** Pre-operative and post-operative virtual avatars (case №3)

295 on DIVA.

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297 ***Supplemental Digital Content 2.*** Pre-operative virtual avatar (case №3) on DIVA with

298 implementation of 2D sections and the cutting tool.

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300 ***Supplemental Digital Content 3.*** Post-operative virtual avatar (case №3) on DIVA with

301 implementation of 2D sections and the cutting tool.

302

303 ***Supplemental Digital Content 4.*** 3D distribution of anatomical landmarks placed by the 4

304 evaluators on a post-operative virtual avatar (case №3).

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19 313 **Conflict of interest**

20
21 314 Mohamed El Beheiry and Jean-Baptiste Masson are cofounders, shareholders and scientific
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24 315 advisors of Avatar Medical.

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26 316 Jean-Baptiste Masson is one of the scientific advisors of the Robeauté startup.
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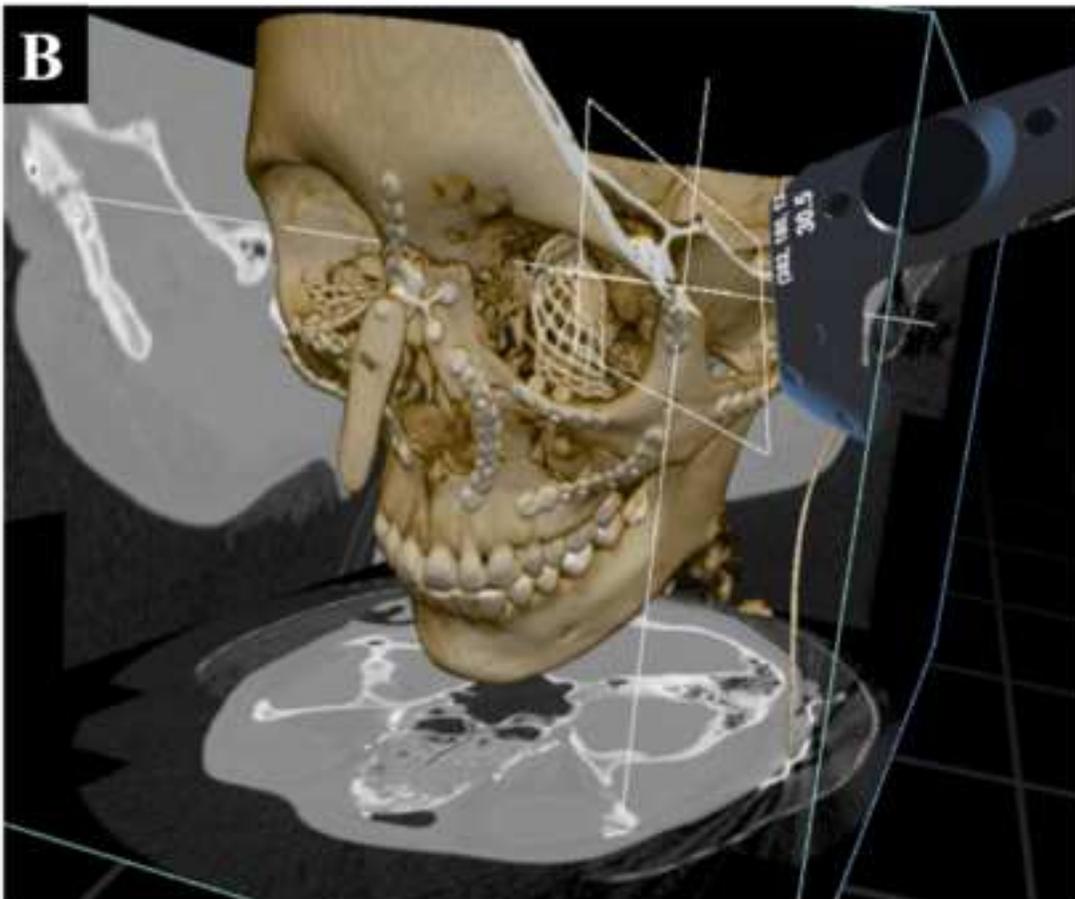
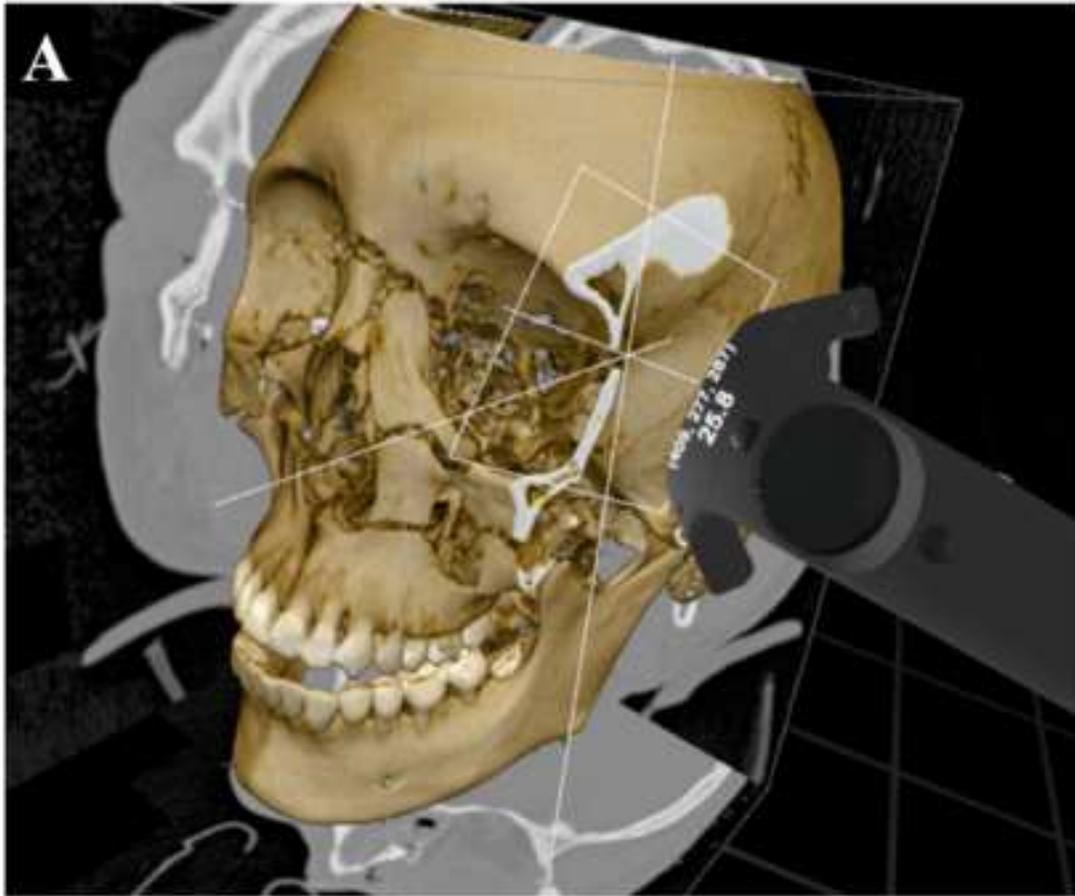


Figure 3

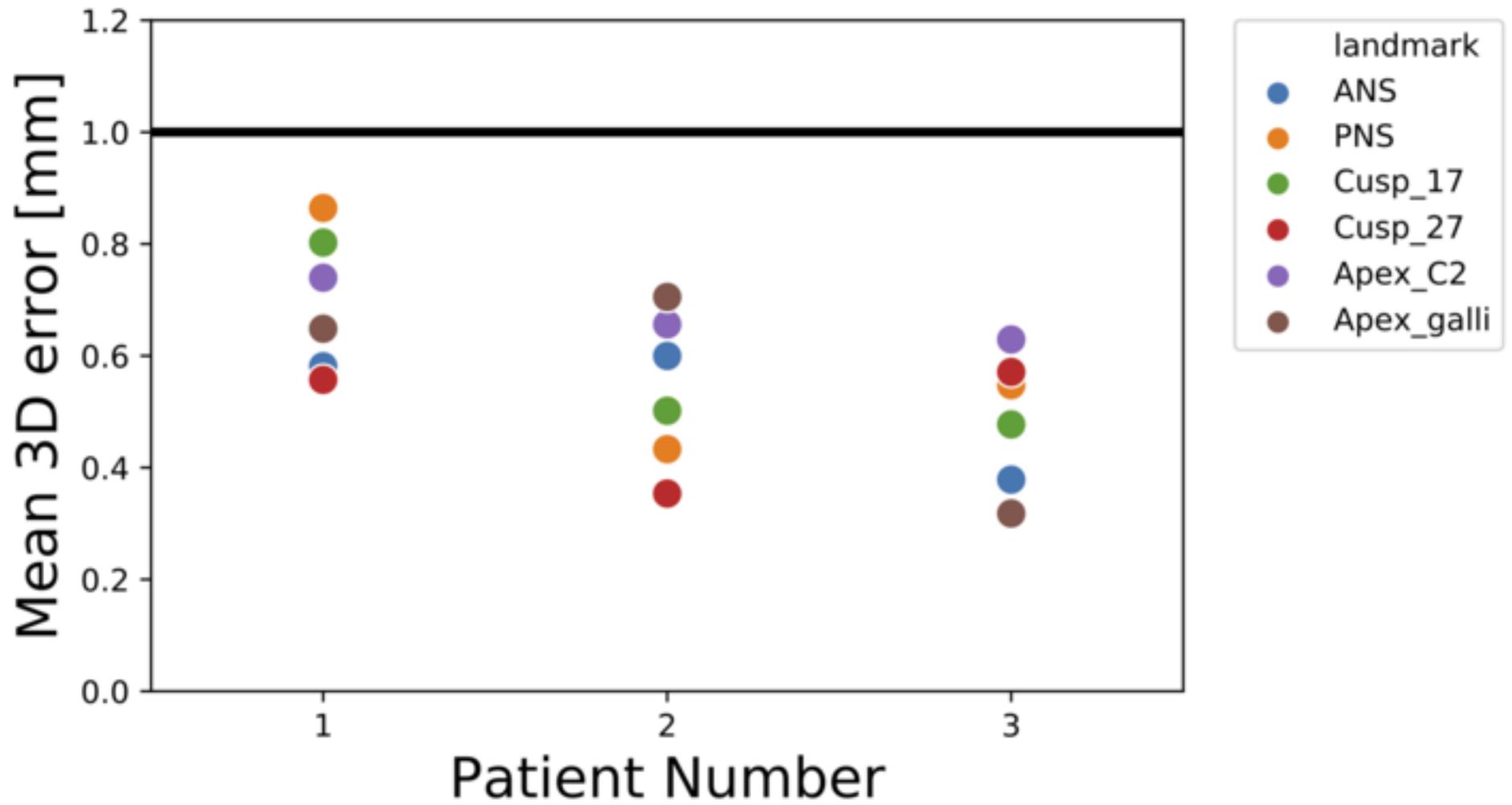


Table 1

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 4: more than satisfied 3: satisfied 2: partly satisfied 1: not at all satisfied	5: n=27 4: n=19 3: n=4 2: n=0 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 4: more than easy and intuitive 3: easy and intuitive 2: partly intuitive 1: not at all intuitive	5: n=22 4: n=22 3: n=4 2: n=2 1: n=0
3. Have you experienced any difficulties in tolerating the use of DIVA?	Yes n=7 No n =43	<input type="checkbox"/> visual fatigue <input type="checkbox"/> headaches <input type="checkbox"/> dizziness <input type="checkbox"/> nausea <input type="checkbox"/> other (precise)	n=0 n=0 n=0 n=0 n=0
4. Does the use of DIVA allow you to visualize some lesions <u>not suspected</u> 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 4: more than profitable 3: profitable 2: partly profitable 1: not at all profitable	5: n=27 4: n=19 3: n=4 2: n=0 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 4: more than recommended 3: recommended 2: partly recommended 1: not at all recommended	5: n=25 4: n=22 3: n=2 2: n=0 1: n=1