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An immersive educational tool for dental implant placement: A study on user acceptance

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ABSTRACT

Background: Tools for training and education of dental students can improve their ability to perform technical procedures such as dental implant placement. Shortage of training can negatively affect dental implantologists' performance during intraoperative procedures, resulting in lack of surgical precision and, consequently, inadequate implant placement, which may lead to unsuccessful implant supported restorations or other complications.
Objective: We designed and developed IMMPLANT a virtual reality educational tool to assist implant placement learning, which allows users to freely manipulate 3D dental models (e.g., a simulated patient's mandible and implant) with their dominant hand while operating a touchscreen device to assist 3D manipulation.
Methods: The proposed virtual reality tool combines an immersive head-mounted display, a small hand tracking device and a smartphone that are all connected to a laptop. The operator's dominant hand is tracked to quickly and coarsely manipulate either the 3D dental model or the virtual implant, while the non-dominant hand holds a smartphone converted into a controller to assist button activation and a greater input precision for 3D implant positioning and inclination. We evaluated IMMPLANT's usability and acceptance during training sessions with 16 dental professionals.
Results: The conducted user acceptance study revealed that IMMPLANT constitutes a versatile, portable, and complementary tool to assist implant placement learning, as it promotes immersive visualization and spatial manipulation of 3D dental anatomy.
Conclusions: IMMPLANT is a promising virtual reality tool to assist student learning and 3D dental visualization for implant placement education. IMMPLANT may also be easily incorporated into training programs for dental students.

1. Introduction

Preoperative dental implant placement is essential to ensure successful oral surgery outcomes, which positively influences subsequent prosthetic stages. Due to the anatomical complexity of both the maxilla and mandible, as well as the risk of damaging existing vital structures (e.g., maxillary sinus, arteries, submandibular glands and nerves), precise 3D perception of these anatomical risks and their spatial relationships is of great importance in order to carry out proper alveolar bone diagnosis and, more importantly, to guarantee precise implant positioning and inclination [1,2].

Computed tomography (CT) is the standard imaging modality for dental diagnosis and oral implant procedures. From CT data, 3D views and volume rendering images of the mandible and maxilla are generated [3]. However, the available dental image workstations are composed of 2D screens, mouse and keyboard input devices, which users operate to interact with the digital content through Windows-Icons-Menus-Pointers (WIMP) interfaces. Such interfaces often fail to be effective in the execution of tasks related to 3D content visualization and manipulation [4].

Computer-aided implant placement tools allow users to position and rotate virtual implants using patient-specific CT data as image references [3]. Conventional WIMP systems enable implantologists to plan where should an implant be placed, as well as to visualize neighboring

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anatomical structures. Such tasks are hindered by WIMP interfaces. On one hand, WIMP interfaces are crowded with menus and icons. On the other hand, CT images and volume rendering images are displayed on flat media that do not offer a proper 3D perception of patient-specific anatomy.

Besides hampering 3D visual insight, performing virtual implant placement and inclination based on 2D images has the drawback of being an iterative process: when the user properly positions and/or inclines the implant in one anatomical plane, their is the risk of mispositioning or misaligning the implant on the remaining axes or angles. Therefore, planning implant placement may benefit from immersive technologies that combine Virtual Reality (VR) with handheld devices, as they promote more natural interfaces for 3D camera control and 3D perception. Moreover, according to [5], VR is an excellent medium for mentoring while the student/trainee carries out a series of precise movements.

Several studies have specifically explored new forms of interaction to improve implant planning by combining Augmented Reality (AR) or VR stereoscopic headsets, input controllers, and interactive surfaces [6–10, 4,11].

Regarding education, several undergraduate and postgraduate programs [12–14] do integrate VR technologies to support implantology dental courses [15], as VR scenarios do not carry clinical consequences as users perform procedures on virtual dental patients [16]. Moreover, VR scenarios allow countless repetitions, which is an essential feature for learning dental practices. VR also proves to be useful when it comes to training, as VR allows the simulation of the placement of dental implants regarding position, dimensions and proximity to vital structures [17], hence, stimulating the student's adaptive capacity and versatility by allowing alteration of implant placement, and avoiding anatomical accidents [17], in order to meet the treatment aesthetic and functional demands, as well as avoiding injury to anatomically important structures in the virtual environment.

In this paper, we present IMMPLANT (IMMersive Implant PLANning using a Mobile Touchscreen) an interactive VR educational tool for preoperative planning of dental implant placement. We explore the versatility of handheld device combined with hand tracking to improve object manipulation and visualization of 3D dental content i.e., subject-specific 3D mandible and virtual implant. Our goal is to verify if IMMPLANT can positively assist teaching and learning experiences for planning implant placement procedures, namely, if IMMPLANT can enhance 3D visualization and manipulation of anatomical content in implantology education. In order to evaluate the usefulness, usability, and user acceptance of IMMPLANT's interactive and immersion features, we conducted a user-study with professional dentists.

2. Materials and methods

2.1. Interactive system overview

IMMPLANT consists of a tech probe that combines a VR head-mounted display, a small hand tracking device placed in the front side of the VR headset and a smartphone, all connected to a laptop (Fig. 1). User interaction follows a bi-manual approach [18] where the free (dominant) hand directly manipulates all 6 or 5 degrees-of-freedom of either the mandible or implant, respectively, while the other (non-dominant) hand operates a smartphone for more fine-tuned manipulation.

2.2. 3D image data

A single dental Cone-Beam Computer Tomography (CBCT) dataset was used, provided by our clinical partners from Centro de Investigação Interdisciplinar Egas Moniz (Egas Moniz University Institute – Almada, Portugal). The acquired stack of 2D medical images was converted from DICOM (*.dcm) to bitmap (*.bmp) so that the image data could be imported into Unity environment. A patient-specific model of the mandible (Fig. 3(a)) was 3D reconstructed from the 2D cross-sectional CBCT images following an image-based geometric modeling pipeline relying on free and open-source tools [19,20].

2.3. Spatial user interface

The virtual scene consists of a minimalist black background (to avoid distractions) populated with the following 3D graphical elements: a floating 3D white mandible mesh, a virtual implant, a green cylinder attached to the implant placement site, the inferior alveolar nerve colored red, virtual hands and a virtual smartphone. During free hand manipulation the virtual smartphone interface presents a 1×1 layout displaying a *Free Manipulation* message (Fig. 2). Once the implant is attached, the virtual smartphone's interface splits in a 2×1 layout with the top and lower sections for selecting translation or inclination input modes, respectively. After selecting either mode, the user has access to directional pads to perform finer adjustments upon implant's position and inclination. To apply constrained manipulations, a translation or rotation widget with color coded guides (x – red, z – blue, y – green) appear attached to the implant's spatial reference system.

For precise implant placement and inclination, a set of directional arrows are made available on the smartphone's screen. The touchscreen is divided into top and bottom sections to support precision tasks for translation and rotation movements using thumbs (Fig. 2). Haptic feedback is provided to the user in the form of a smartphone vibration, confirming the implant was placed successfully.

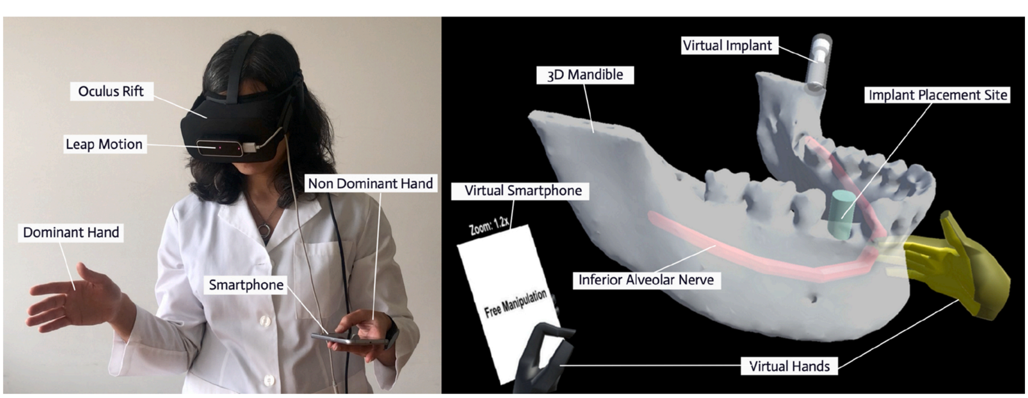

Fig. 1. User interacting with IMMPLANT, an immersive prototype that combines a VR headset, a small hand tracking device and a smartphone. Gross implant position and orientation are performed with the user's free (dominant) hand while finer adjustments are inputted via the smartphone's touchscreen. Once immersed, the user interacts with a patient-specific 3D model, a virtual implant and manipulation widgets (lower right corner).

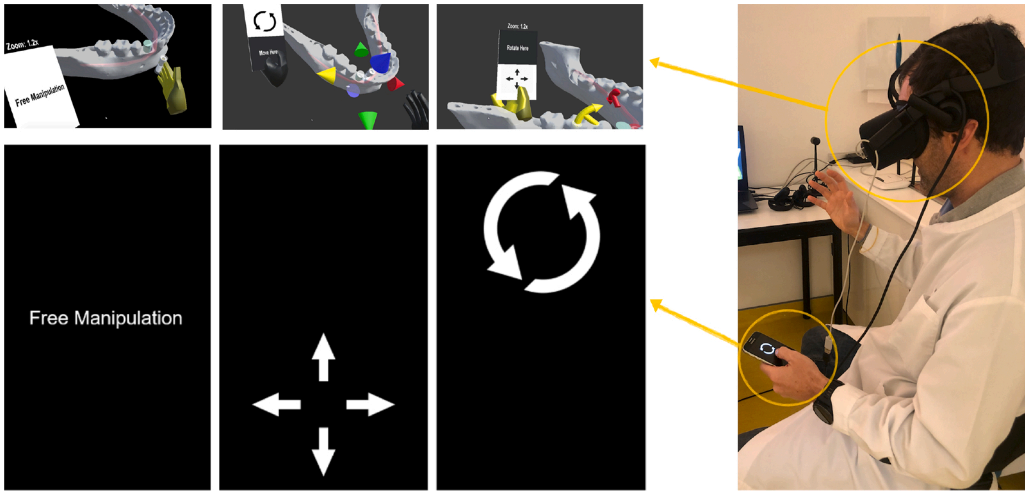

Fig. 2. Smartphone interface: free manipulation screen (left), translation screen (center), rotation screen (right).

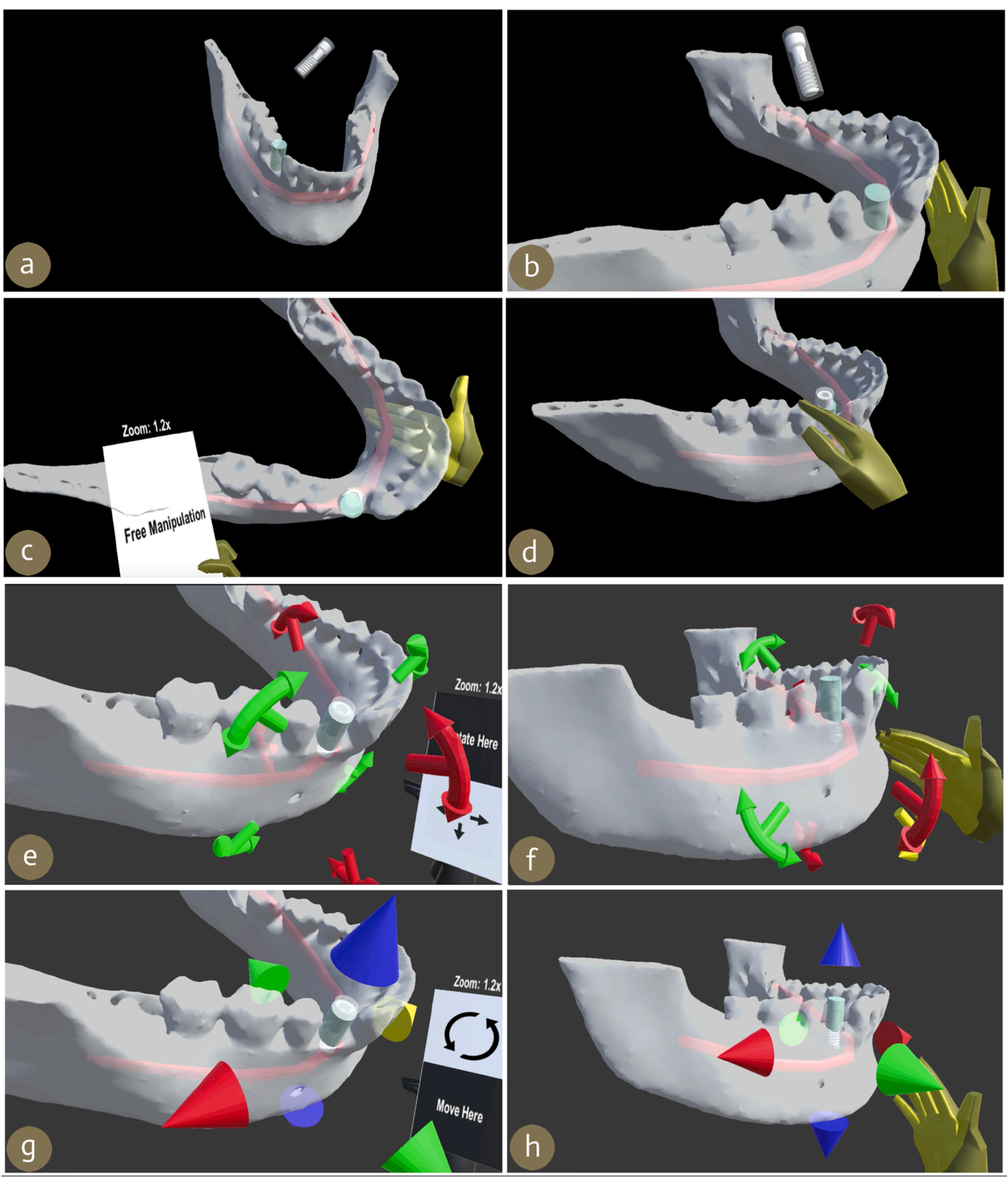

Fig. 3. Example of a sequence of IMMPLANT expedite, free hand interaction steps: (a) a 3D model of a mandible and a virtual implant are made available to the user and are placed “floating” in the 3D virtual scene; (b–d) users can directly manipulate (translate and rotate) either the 3D mandible or virtual implant using their (dominant) free hand controlling all 6 degrees-of-freedom; (e–h) users can apply more constrained manipulations in position and rotation by interacting with 3D rotation (e–f) and 3D translation (g–h) widgets that give access to 1 degree-of-freedom at a time.

Visual aids were added to promote precise adjustments of the implant with directional pads (Fig. 3(e–h)). For successful implant planning and to prevent further postoperative complications, it is crucial to visualize the spatial relations between anatomical structures and to be aware of relative distances between the implant and vital structures (e.g., inferior alveolar nerve and surrounding teeth). Therefore, visual feedback on implant collision with such structures is a necessary feature. To this end, the implant is embedded within a safety cylinder with a radius equal to the implant's radius plus 1.5 mm and a height of 2.0 mm. These values are normative and ensure safety distances from the inferior alveolar nerve and neighbouring teeth. If the implant collides with a vital structure, then the safety cylinder turns red.

2.4. Free hand and handheld device interaction

With their free (dominant) hand, users can directly manipulates all 6 degrees-of-freedom of either the mandible or implant. The 6 degrees-of-freedom of the users hand are mapped to the mandible or implant local reference system. Free manipulation is performed with an opened hand while pressing and holding their thumb on the touchscreen. Once the virtual hand collides with the 3D object the user wants to manipulate (i.e., mandible or virtual implant), the virtual hand turns yellow as a confirmation that the object is locked and the selected 3D object will start following the user's dominant hand movement (Fig. 3(b–d)) according to the hand's spatial reference, which is mapped directly to the object. To let go of the object, the user must lift the thumb of the smartphone's screen and move the hand away from the 3D object.

With their other (non-dominant) hand, users operate a smartphone for activating different selection modes and to apply more fine-tuned manipulations. More specifically, through the smartphone's touchscreen, users can define manipulation modes (free and constrained manipulation), selection modes (i.e., select between mandible or implant and select single translation axis or single rotation axis rotation). To apply minute translations or rotations to the virtual implant, user's select with their free hand one of the color coded widgets axes and, through the touchscreen, input minute translations or rotations to the virtual implant in relation to the virtual mandible.

Note that the virtual implant just has 5 degrees-of-freedom (3 translations and 2 rotational axes to define its inclination) as the rotation along the implant's longitudinal axis was discarded as the implant is a helically symmetric object.

2.5. Apparatus

Our setup resorted on a laptop computer (Asus ROG G752VS, Intel Core i7-6820HK Processor, 64 GB RAM, NVIDIA GeForce GTX1070) running Windows 10, along with a smartphone (Samsung Galaxy S7 32 GB RAM) running Android 9.0 Pie, an Oculus Rift and a Leap Motion controller mounted onto the frontal panel of the VR headset (Fig. 4). In addition, we used a router (Router TP-Link model TL-WR841N) to enable communications between the smartphone and laptop. Code development was performed using Unity 2017.2.0f3 and C# scripting.


Fig. 4. Equipment set for running IMMPLANT.

2.6. Participants

A total of 16 participants (12 male, 4 female) with ages ranging from 23 to 64 (Median = 32, SD = 10.23) were invited for our assessment study. All participants were medical dentists, 4 specializing in oral rehabilitation, 2 in prosthodontics, 1 in implantology, 1 in endodontics, 1 in periodontics, 3 in oral surgery, and 4 in general dentistry, ranging from 1 to 20 years of experience. All participants referred that they were right-handed. Every participant dealt with touch screens on a daily basis and 8 participants never dealt with virtual or augmented reality applications. Implantologists and Oral Surgeons frequently use 3D visualization software for dental implant placement, while the remaining participants do not use this type of software. Fig. 5 shows the alluvial diagram that highlights important user characteristics emphasized by color and node clustering.

2.7. Tasks

Participants were asked to place a virtual implant at a specific bone-loss area location within a subject-specific 3D model of a lower jaw (Fig. 7). In particular, participants were requested to perform the implant placement tasks by, firstly, placing the implant as close as possible to the predetermined location and, secondly, by adjusting the position and inclination with finer input through thumb gestures (Fig. 6). Participant feedback regarding IMMPLANT's limitations and benefits, as well as the adequacy of IMMPLANT to support implant placement, was then gathered via questionnaires and guided interviews, Furthermore, we aim to include a System Usability Scale (SUS) [21] questionnaire for the purpose of measuring usability, and a NASA Task Load Index (NASA-TLX) [22] questionnaire for perceived workload rates to assess prototype effectiveness. Each task could take at most 20 min, after which the task was interrupted.

2.8. Procedure

All tests were conducted in an office at the Centro de Investigação Interdisciplinar Egas Moniz's Clinic. The expected duration of a test session was about 20–30 min and was divided in six phases: (i) informed consent and demographics, (ii) introduction, (iii) free experimentation, (iv) task execution, (v) questionnaires, and (vi) guided interview. At the beginning of each session, we asked participants to sit through the test session and to fill in an informed consent form agreeing to the study conditions and terms, followed by a demographic questionnaire. Afterwards, participants were given a short demonstration of IMMPLANT's interface and interaction features. Then, users were prompted to freely explore the interface while performing a habituation task for up to 5 min. This phase was followed by task execution were we asked participants to complete implant placement tasks. This phase was followed by participants filling in preference and satisfaction questionnaires regarding the interface and the tasks undertaken. Finally, a guided interview was conducted to capture the participants' impressions about the interface and interaction techniques, as well as their potential application in dental implant placement, both in surgery and dental implant education (through preoperative simulation). Participants were invited to elaborate as much as possible on the issues they found to be the most relevant from their experience. We also requested their thoughts and opinions regarding improvements to the system. In addition to questionnaire answers and interview transcripts, data gathered also included observational notes taken during test sessions.

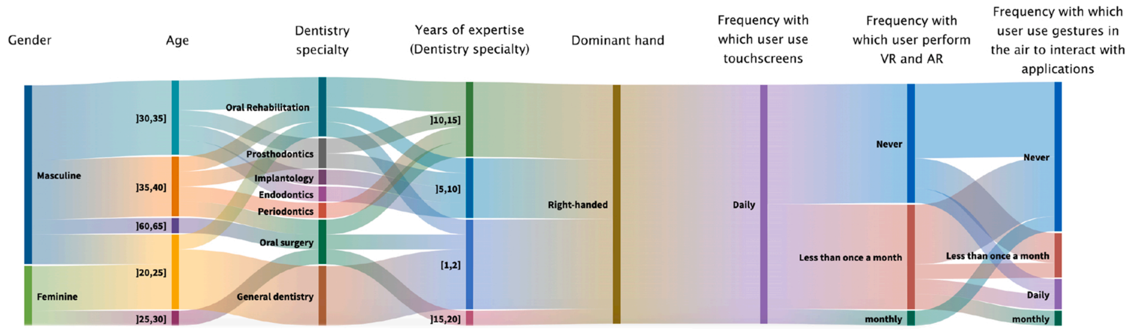

Fig. 5. Alluvial diagram summarizing the demographic data from profiles included in the assessment study. In this diagram, demographic data is categorized in each column and the ratios of the categories are presented. Colored edges between columns indicate direct relations between demographic attributes. The sizes of edges and flows are therefore linked to the values containing the same couple of nodes.

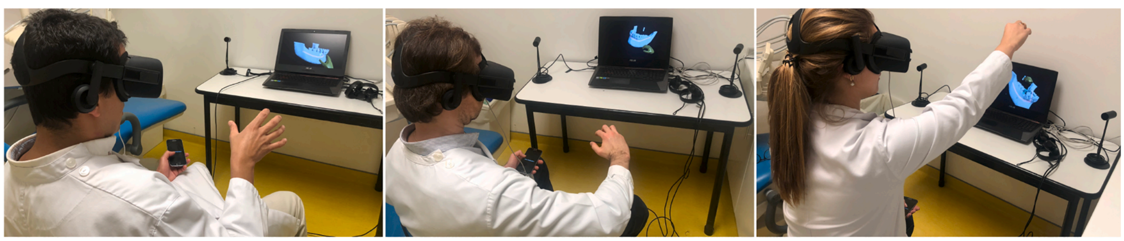

Fig. 6. Participants during an assessment evaluation session.

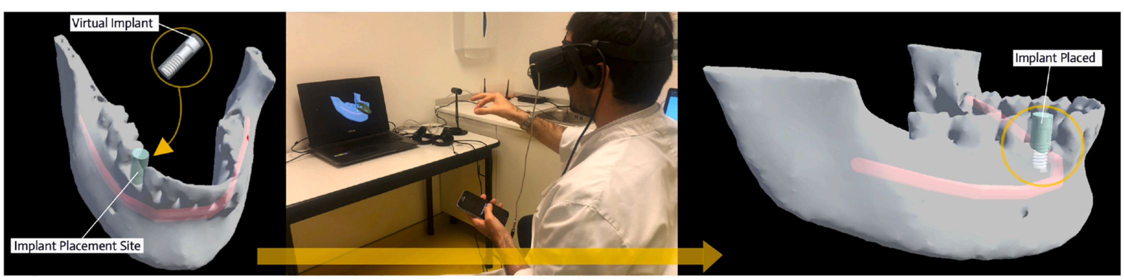

Fig. 7. Participants were asked to place a virtual implant at a specific bone-loss area location within a subject-specific 3D model of a lower jaw.

3. Results and discussion

During all the task performances, users revealed an interesting pattern: they all started by freely manipulating the mandible to visually explore the 3D nature of its anatomy, to then orient and place it in an appropriate point of view; afterwards user's freely manipulated the virtual implant placing it near the target site, to then perform finer translation and inclination adjustments via touchscreen. Whenever they were not satisfied with the result, user's would remove the implant and try another placement and inclination in free manipulation mode followed by constrained adjustments.

Regarding user and satisfaction questionnaires, results indicate that our VR system is easy to use and promotes greater spatial awareness of the 3D dental model. As for the results from usability tests they reveal that participants considered the system easy to learn. However, while participants were relatively quick to identify the structures of interest (bone-loss, bone height, bone width and nerve position) via 3D camera control, they acknowledged some difficulty selecting the predetermined implant position and inclination, thus adding to the time necessary to complete the task. Furthermore, participants in our evaluation suggested that the user experience and interaction methods were adequate. Despite the lack of familiarity with VR, results are highly encouraging as most professionals considered that IMMPLANT complements conventional WIMP interfaces since it provides greater camera control for 3D anatomical visualization. All senior participants mentioned the possibility of adopting IMMPLANT as a surgical training and/or medical educational tool in everyday practice.

In addition, we evaluated participants perception of usability through a SUS questionnaire with a usability score of 83.91, revealing that IMMPLANT has good usability and high learnability (Table 2). We also studied the subjective workload experienced by users during the prototype evaluation. For this purpose, we conducted a workload analysis study using NASA-TLX. Fig. 8 shows the subscale summary of workload analysis. Thus, NASA-TLX provides support for the proposed system designs as being effective solutions for reducing the ergonomics gaps in terms of mental workload and, to a lesser extent, the physical workload, imposed by the system [23]. The findings suggest that this approach shows a low rating for the entire workload-dimension. The results regarding the workload are similar in general terms, implying that this systematic task process with IMMPLANT was not considered difficult.

Moreover, users felt confident using the system, which provided the medical dentists a feeling of control, in fact, participant 4 stated "the system complements conventional practice because it allows for several repetitions, as well as recurring practice", while participant 6 stated "[IMMPLANT] allows a better orientation in the placement of implants when compared to traditional implant planning software" and participant 8 mentioned "the biggest benefit of this VR system is its

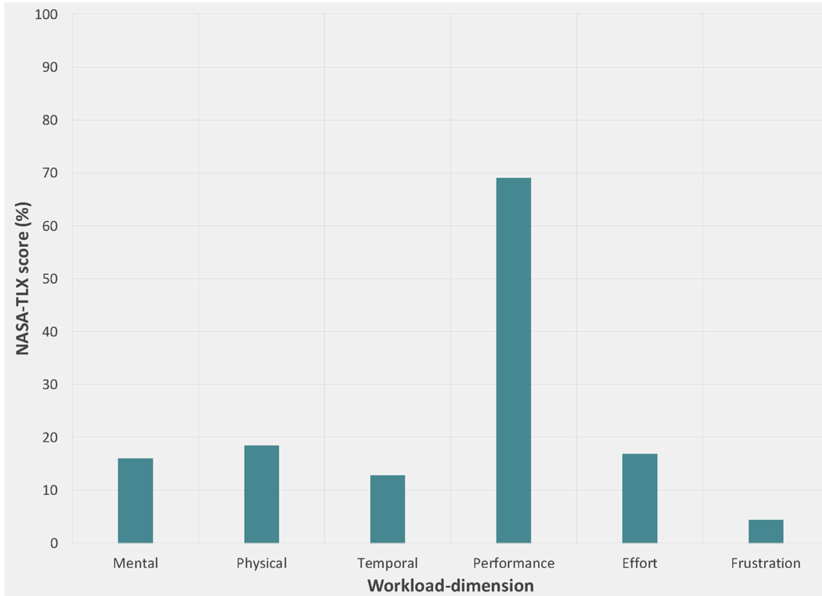

Fig. 8. NASA-TLX workload analysis results.

interactivity and ease to visualize anatomical structures”. Table 1 shows the participants’ feedback to the prototype’s features, revealing all were well received.

Despite the positive results, our study has several limitations. For instance, wearing a VR headset can force the wearers to modify their posture and potentially affect their performance when attempting to manipulate a 3D object with their bare hand [24]. Other metrics such as fatigue, stress tests and cognitive load are important variables to understand the limitations of the proposed tool, yet they were not considered in this paper. The greatest limitation of our study consist in the lack of a comparative study between IMMPLANT and standard implant software that could include a quantitative analysis of user performance, with dozens of dental medicine students as participants, that would not only assess but validate IMMPLANT as a user-friendly VR tool for learning implant placement. Despite these limitations, while our study is exploratory, we see it as the precursor to a new generation of user-friendly educational tools for planning implant placement. Finally, the application of immersive VR education tools in both undergraduate and postgraduate dentistry programs, although allowing for immediate evaluation and instantaneous feedback, is far from being universal and

Table 1
Results from the user preferences questionnaires (median, (interquartile range – IQR)).

Features	Statement	Median (IQR)
General impressions	The anatomy is realistic.	5 (2)
	It is useful to be able to see the internal anatomy (anatomical structures potentially damaged by implant osteotomy).	5.5 (1)
	It is useful to see the depth of implant insertion.	6 (1)
	Colors and graphic elements represented the location of the implant osteotomy and insertion.	5.5 (1)
	It is easy to use.	5 (2)
	It is fast learning.	5 (2)
	It is useful for teaching implant insertion.	5.5 (1)
	Interactivity promotes focus and learning.	6 (0)
In comparison with conventional teaching for implant placement	It allowed you to identify anatomical landmarks more easily.	6 (1)
	It is easier to use.	5 (1.25)
	It is faster to learn.	5 (2)
	It is useful for teaching.	6 (0)
	It is easier to memorize the correct implant placement.	6 (1)

Table 2
Descriptive statistics of the SUS questionnaire: average, median, minimum value – Min, largest value – Max, standard deviation – SD, interquartile range – IQR.

SUS item	Average	Median	Min	Max	SD	IQR
I think that I would like to use this system.	4.50	5.00	3.00	5.00	0.73	1.00
I found the system unnecessarily complex.	1.38	1.00	1.00	3.00	0.62	1.00
I thought the system was easy to use.	4.44	4.50	3.00	5.00	0.63	1.00
I think I would need technical support to be able to use this system.	2.19	2.00	1.00	4.00	1.17	2.00
I found the various functions in the system were well integrated.	4.19	4.00	3.00	5.00	0.75	1.00
I thought there was too much inconsistency in this system.	2.06	2.00	1.00	4.00	1.12	1.25
I would imagine that most users would learn to use this system very quickly.	4.38	4.50	3.00	5.00	0.72	1.00
I found the system very cumbersome to use.	1.38	1.00	1.00	5.00	1.02	0.00
I felt very confident using the system.	4.56	5.00	3.00	5.00	0.63	1.00
I needed to learn a lot of things before I could get going with this system.	1.50	1.00	1.00	4.00	1.03	0.25
Total SUS score	**83.91**	**87.50**	**65.00**	**97.50**	**10.33**	**18.13**

the equipment cost is one of the most frequently pointed out factors [25].

4. Conclusion

Learning where to place and how to incline a dental implant is crucial to guarantee optimal surgical outcomes and reduced intra-operative risks. In this study, we designed and developed IMMPLANT, an immersive educational tool to assist 3D dental implant placement learning. We evaluated our VR system that complements conventional implant planning interfaces by improving user interactions via the use of a smartphone. Participant feedback from the conducted usability and user tests clearly indicate that IMMPLANT enhances 3D visualization and manipulation of 3D dental content (in this case, lower jaw and virtual implant) as VR provides users with an immersive experience, with enhanced camera control and 3D perception, while hand interaction provided manipulation freedom and valuable geometrical information. In our evaluation, we found that users were receptive to the innovations brought forth by our work. The ability to preoperatively repeat the procedure and self-assess the work done on a VR system could help users gauge the quality of their work and determine skills to improve.

Regarding future improvements to the system, participants in our evaluation suggested that the smartphone interface can be improved, in particular, that the directional pad interface should explicitly indicate which geometric transformation is being applied, and also that measuring tools need to be implemented given that distance and angle measurements are essential for successful implant planning and surgical outcome.

Summary points

What is already known on the topic?

- Tools for improving the training and learning of dentistry students are required.
- Lack of training can negatively affect implantologists' performance during intraoperative procedures.
- Virtual environments could help to enhance 3D visualization and manipulation of anatomical content.
- Works focused on VR and AR in implant placement learning are scarce.

What does this study add to our knowledge?

- A Virtual Reality system to assist implant placement learning.
- Implants can be virtually placed into their ideal positions according to reversely planned implant-based rehabilitations.
- Free-hand interaction provides additional degrees of freedom and valuable geometrical information.
- A study on user acceptance with dentistry professionals.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ijmedinf.2020.104342.

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