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CLINICAL REPORT

Dental implant placement with immersive technologies: A preliminary clinical report of augmented and mixed reality applications

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ABSTRACT

A preliminary clinical report of implant placements with 2 immersive reality technologies is described: augmented reality with head mounted display and mixed reality with a tablet PC. Both immersive realities are promising and could facilitate innovative dental applications. However, mixed reality requires further development for clinical optimization. (J Prosthet Dent xxxx;xxx:xxx-xxx)

Artificial intelligence (AI) and immersive technologies have been applied in several dental fields offering novel clinical applications.[1–3] AI development has been facilitated by the exponential increase in data collection, high performance computing, and data extraction.[4,5] In dentistry, AI has been applied in disease identification, image segmentation, image correction and enhancement, implant identification, finish line mapping, automation of tooth restoration and prostheses designs, color analysis and shade guide optimization, and restoration failure prediction.[4–10]

Immersive realities include virtual reality (VR), augmented reality (AR), and mixed reality (MR).[11–14] These technologies modify the real environment by blending the virtual and real world (AR and MR) or by creating a fully virtual experience (VR).[11–14] In VR, the user is completely immersed in an artificial environment to create visual, aural, or other stimuli. VR development has been driven by the gaming industry, and dental applications include preoperative planning, education and training, and patient specific simulation.[14] AR uses elements of a virtual environment and superimposes them onto the real environment to augment sensory perception.[7,8,14] AR has been used in different dental applications with either 2-dimensional (2D) or 3-dimensional (3D) overlay projection of the virtual elements in the surgical field of view, including implant surgery, smile design, maxillofacial surgery, restorative dentistry, endodontics, orthodontics, and dental education.[1,7–10,15–24] MR is the recent development of immersive technology and allows projections and interactions with digital elements. MR surpasses the limitation in AR in its lack of alignment to the real environment.[12–14]

The use of AI and immersive technologies has been reported in dental applications.[1,15–24] This preliminary clinical report describes the applications of AI, AR, and MR in dental implant placement.

CLINICAL REPORT

Two patients requiring implant placements were selected to demonstrate 2 immersive technologies: AR with a head mounted display (HMD) and MR with a tablet PC (iPad; Apple Inc) as a see-through display.

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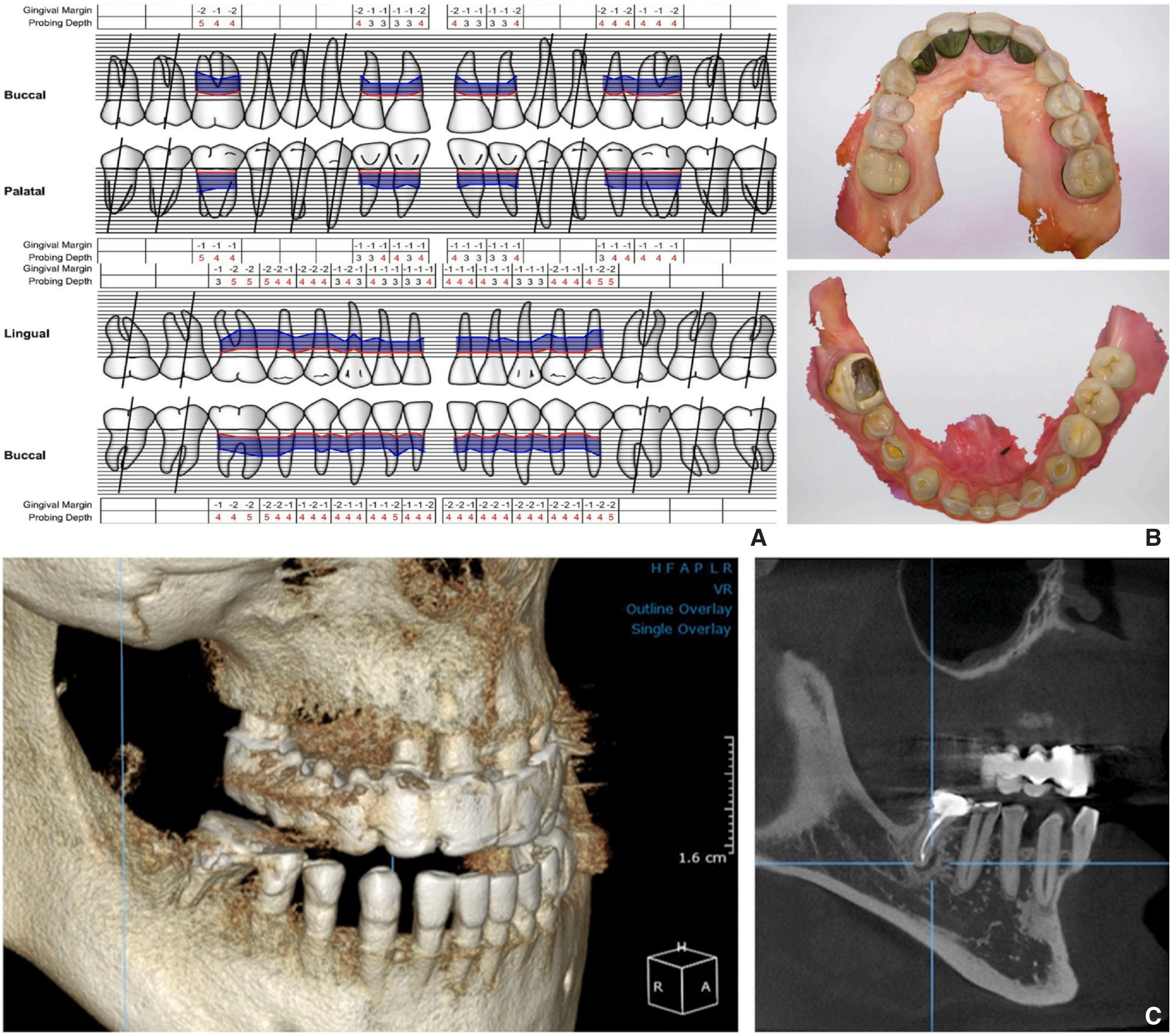

Figure 1. Preoperative assessment for augmented reality workflow. A, Periodontal charting. B, Preliminary maxillary and mandibular intraoral scanning. C, Cone beam computed tomography scan.

A 53-year-old man complaining of pain from the mandibular right quadrant was referred to the clinics of the University Medical Center Hamburg-Eppendorf. His medical history was noncontributory, and he was selected for the AR with HMD workflow. The mandibular right first molar was tender to percussion with grade II mobility. Examination showed a metal-ceramic crown with poor marginal fit that had been previously treated endodontically. A periapical radiograph showed apical radiolucency and increased periodontal ligament width. He was diagnosed with previously treated symptomatic apical periodontitis and with generalized periodontitis (Stage II, grade A). His periodontal charting is presented in Figure 1A. He consented to extraction of the mandibular right first molar and immediate implant placement. Diagnostic digital arch scans were made with an intraoral scanner (IOS) (TRIOS 3; 3Shape A/S) and stored in standard tessellation language (STL) format (Fig. 1B). A cone beam computed tomography (CBCT) scan was obtained in digital imaging and communication in medicine (DICOM) format with field of view (FoV) of ⌀10×8 cm (R2Studio; RayEurope) (Fig. 1C).

The files were uploaded to a planning software program (R2Gate; MegaGen), and preoperative procedures included manual digital and radiographic data set alignment, virtual diagnostic waxing, implant selection and alignment, and surgical guide design for single implant placement (Fig. 2). The design of the surgical guide was stored in STL format and was exported to a vat polymerization printer (Form 3B+; Formlabs), and a

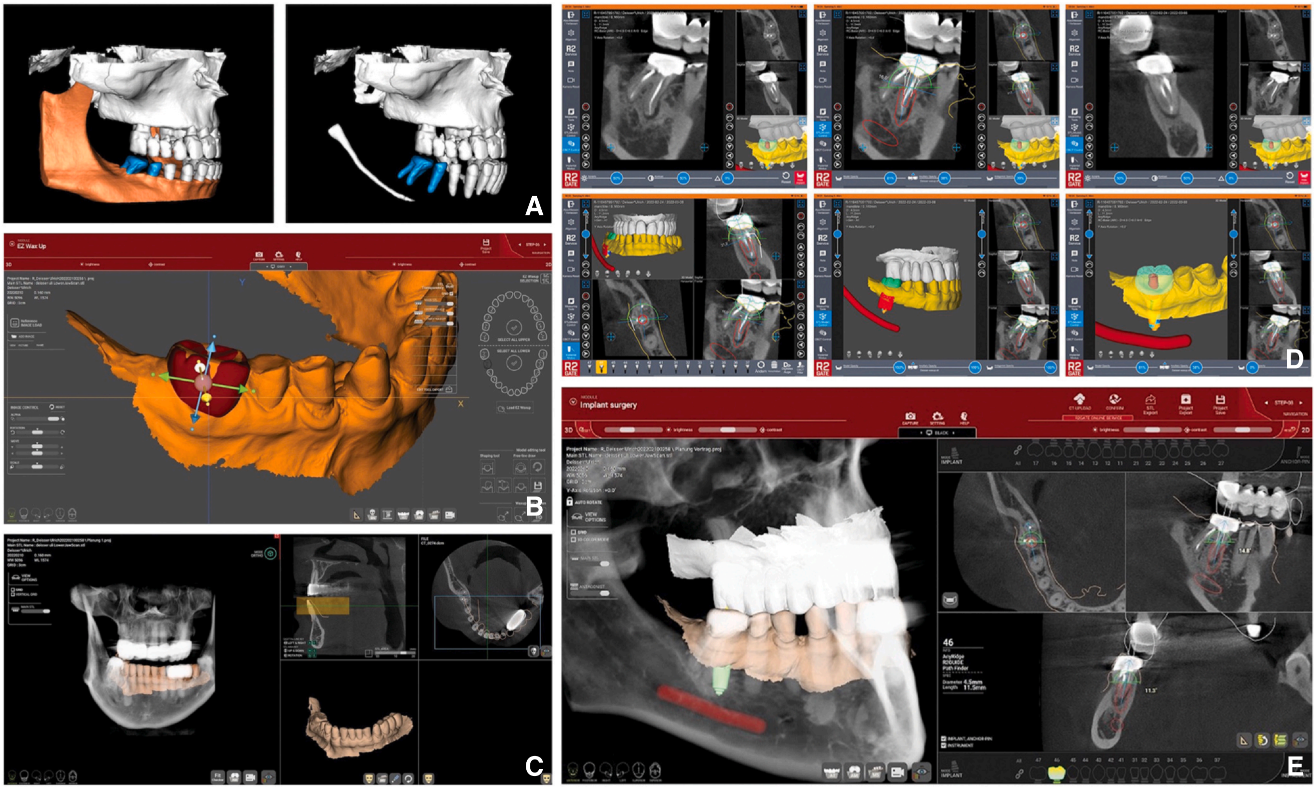

Figure 2. Preoperative implant planning with artificial intelligence. A, Data segmentation. B, Tooth design. C, Digital scan and radiographic dataset alignment. D, Implant planning and selection. E, Complete dataset.

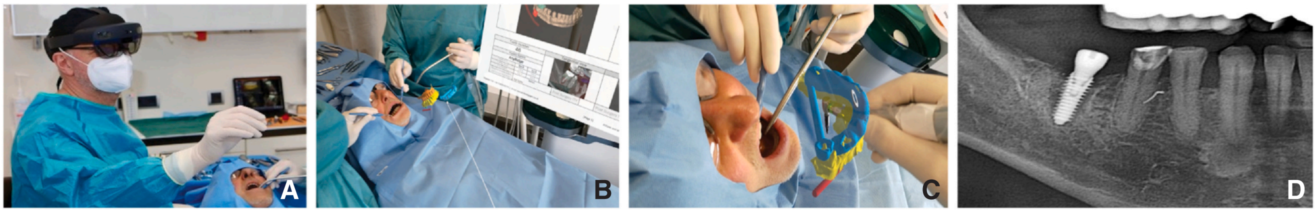

Figure 3. Augmented reality arrangement. A, Operator with mounted headset performing hand gestures for data navigation. B, Operator view through mounted headset including 2D surgical protocol files, 3D bimaxillary arches and anatomic structures files, and 3D virtual surgical guide. C, Seated virtual guide (*blue*) on mandibular arch (*yellow*) and inferior dental nerve (*red*) for extraoral simulation. D, Radiograph 3 months after treatment.

static surgical guide was manufactured with class IIa light-polymerized resin (Surgical Guide Resin; Formlabs). The files were exported to an AI software program (Diagnocat; DGNCT LLC) for image segmentations. All files were exported in STL file format to an immersive reality platform (Holodentist; fifthengenium) and used with an untethered HMD (HoloLens 2; Microsoft Microvision Inc). The HMD allowed the preoperative planning data to be readily available in the FoV of the operator, including the surgical protocol and patient information 2D files, and the virtual 3D seated guide for simulation (Fig. 3A-C; Supplementary Video 1, available online).

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The mandibular right first molar was extracted, and a single Ø5.0×11.5-mm implant was immediately placed (AnyRidge; MegaGen) with static surgical guide navigation. Surgical procedures included raising a flap, bone augmentation with xenografts (TheGraft; Regedent) and a resorbable membrane (SmartBrane; Regedent), flap repositioning without tension, and suturing with nonresorbable suture. Amoxicillin (500 mg) was prescribed 2 days before surgery for 1 week, and postoperative instructions were provided according to standard protocols (Fig. 3D).

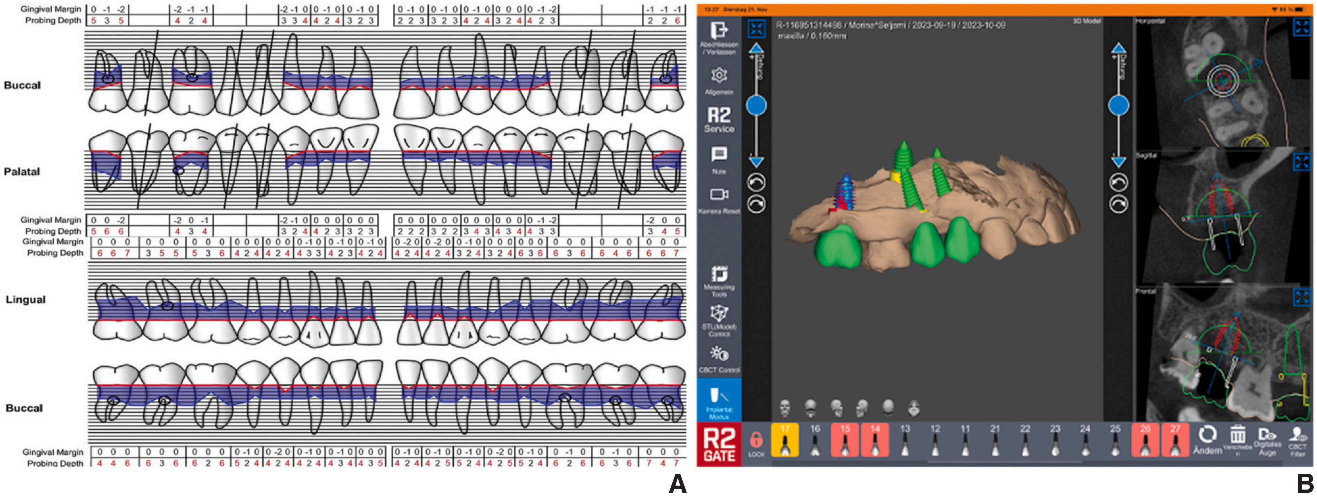

Figure 4. Preoperative assessment for mixed reality workflow. A, Periodontal charting. B, Complete preoperative dataset planning including artificial intelligence segmentation, data alignment, tooth design, implant planning and selection.

For the MR workflow with the tablet PC display, a 35-year-old man complaining of several missing maxillary teeth was selected (Fig. 4A). His medical history was noncontributory. Preoperative procedures were similar to those of the AR workflow (Fig. 4B). All files were exported in STL format to a custom developed immersive reality platform with C++ programming language (Test flight beta version; Arreye). A tablet computer (iPad; Apple Inc) was used for a see-through display. The developed platform allowed visualization and interaction with digital elements by regulating their 6 degrees of freedom, position, and transparency. The digital preoperative planning files were aligned to the real environment by using a markerless procedure with a visual-inertial odometry (VIO) algorithm(Fig. 5A-C).[22,25,26] Also, all files were uploaded to the immersive reality platform (Holodentist; fifthengenium), which allowed a team member to join and interact from a remote location by sharing the view of the HMD (HoloLens 2; Microsoft Microvision Inc), (Fig. 5D, E; Supplementary Video 1, available online).[22] Two implants (AnyRidge; MegaGen; Ø3.5×11.5-mm) were placed in the maxillary right first and second premolar areas, 2 implants (AnyRidge; MegaGen; Ø4.5×7-mm) were placed in the maxillary left first and second molar areas, and 1 implant (AnyRidge; MegaGen; Ø5×8.5-mm) was placed in the maxillary right second molar area (Fig. 5F). Also, the 2 maxillary third molars were extracted.

This clinical report only included the treatment protocols with regard to the implant placement. Further

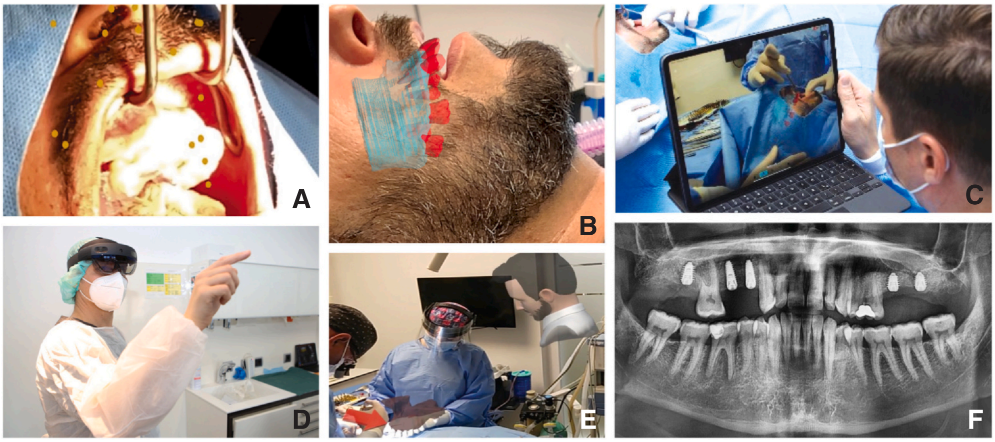

Figure 5. Mixed reality arrangement. A, Point of interest registration. B, Maxillary virtual preoperative planning model aligned to real environment with visual-inertial odometry algorithm software. C, Tablet PC see-through screen. D, Team member with head mounted display joining from remote relocation. E, Operator view (through tablet PC screen) of avatar representing team member joining from remote location. F, Radiograph 3 months after treatment.

comprehensive dental treatment was conducted by the referring dentists.

DISCUSSION

The implementation of AI and 2 immersive realities in the preoperative and intraoperative implant placement procedures with 2 workflows is described. The AI components included data segmentation, virtual implant position proposal, and radiographic diagnostics. The selection of AR and MR workflows and the method of display was not specific to the patient; the MR workflow necessitated the use of a registration software program for digital element alignment. This software program was optimized for use with the tablet PC and not with the HMD. In the AR with HMD workflow, the digital 2D and 3D data were visualized in the FoV of the operator, providing convenience and simulation and allowing access to patient data in a sterile environment (Supplementary Video 1, available online). Therefore, this arrangement represented AR technology.[11–14] In the MR workflow with the tablet PC display, the preoperative digital elements were registered with the VIO software program, which would qualify this arrangement as MR technology.[11–14] The egomotion of the registration was calculated through a Kalman filter with the support of the LiDAR scanner and dual camera of the tablet computer.[22] This arrangement created a 3D reference environment acting as a visual marker using the precise positioning of point of interests (POI) on the anatomic view and the background scene in real time. Although this markerless registration was promising, the registration was not stable and needed continuous re-registration, possibly because of the partial coverage of the face during surgery which reduced the areas for POI creation and because of patient head movement (Fig. 5A; Supplementary Video 1, available online). Also, the software performance was partly overwhelmed by the light during surgery, as this affected the tracking of the infrared (POI) dots. These issues require development for clinical use optimization.

The HMD is an untethered device that contains the computer processing on board. Its convenient arrangement avoids operator distraction when alternating between the FoV and a visual aid screen. However, it could disconnect the operator from the real environment. The see-through tablet PC display acts like the half-silvered mirror screen concept, avoiding the alternate view distraction issue, and also does not disconnect the operator from the real environment, avoiding spatial discordance (cybersickness). However, it requires the installation of mounting equipment between the operator and the FoV (Fig. 5C).[17–19] Both the AR and MR workflows allow team member participation from a remote location if desired (demonstrated in the second workflow). This was performed with the immersive platform (Holodentist; fifthengenium) that allowed avatar creation and HMD view sharing. Alternatively, an HMD with internet surfing capability could allow a team member to join with any AR glasses by using the view sharing of a video conferencing software program (such as Microsoft Teams; Microsoft Corp, or Zoom; Zoom Inc), albeit with no avatar.

Advantages of using immersive technologies include less invasive surgery, avoidance of iatrogenic damage, and the potential for higher accuracy. However, most of these advantages are still unclear because of concerns about accuracy, expense, and the need for training.[7,12–14] One study[22] with a similar arrangement to the MR workflow in this report investigated the use of a digital guide for endodontic access and reported promising results with 0.51-mm-coronal and 0.77-mm-apical entry deviations. However, angular deviation of 8.5 degrees was reported, which was higher than those reported by other methods.[22] Other reports used immersive technologies for implant navigation with registration procedures that included point to point registration with manual, stereo camera, or point cloud.[1,15–19] These studies had an in vitro design and used either static surgical guides or reference tracking system. In this clinical report, navigation was obtained with static surgical guides. Hence, the accuracy was not investigated, and the aim was only to investigate the feasibility of using these technologies without the intention of using them as standalone navigation guides.

The descriptions of immersive realities in the dental literature appear to be fragmented and inconsistent,[14] a testament to the newness of these technologies. A review of immersive reality taxonomy in the dental literature is suggested.

SUMMARY

This clinical report describes implant placements with 2 immersive technologies by using AR with an HMD display and MR with a tablet PC see-through display. Immersive realities are promising technologies and offer novel applications. However, MR requires further development for clinical optimization.

PATIENT CONSENT

Written informed consents were obtained prior to conducting the procedures described in this clinical report.

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Marcus Engelschalk: Conceptualization, Methodology, Resources. **Khaled Q. Al Hamad:** Methodology, Writing- original draft, Writing-reviewing and editing. **Roberto Mangano:** Software, Validation. **Ralf Smeets:** Project administration, Validation. **Tamás F Molnar:** Project administration, Validation.

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