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Introducing OMFA3D — A Novel Open-Access Mixed Reality Resource for Dental Education

Dental and medical students have had difficulty accessing cadaveric specimens and physical anatomy models outside their scheduled lab hours even prior to COVID-19, so it's not surprising that the availability of these educational tools has become extremely limited during the pandemic. The value of virtual teaching aids has become increasingly relevant, especially for digital resources that are representative of the anatomical variation seen clinically. In this article, the authors present a digital alternative to cadaveric and physical models, developed at the Schulich School of Medicine & Dentistry, Western University.

Background

Mixed reality (MR) is the fusion of the real world and a computer generated virtual world to produce a hybrid environment. Augmented reality (AR) is a type of MR in which virtual graphics are superimposed on top of video input from the real world. AR is most commonly displayed on the screen of a mobile device such as a smartphone or tablet. In contrast, immersive virtual reality (VR) is a technology that fully surrounds the viewer in a virtual world, using strap-on headsets or multi-projection environments (1). The term extended reality (XR) describes all immersive technologies in the field of spatial computing, including both AR and VR. A key difference between the two XR technologies is the use of binocular displays to simulate the perception of depth (termed stereoscopic depth.) Unlike AR, VR makes use of lenses to deliver two different images to the eye, allowing for true perception of depth and three-dimensional structure (stereopsis). Parallax, in contrast, is a two-dimensional representation of an object's depth and does not require separate input from both eyes (termed monoscopic depth.) While both AR and VR make use of parallax, only VR provides the benefits of stereopsis — significant given recent literature indicates that stereopsis plays an important role in improving student performance when using XR for education, especially when learning osseous anatomy (2).

The application of XR technology to anatomical education is well documented. Virtual 3D models provide many benefits when presented through AR or VR. Numerous studies have shown equal or improved student performance on post-study assessment scores when the study period involved XR models as opposed to traditional, non-physical pedagogical resources (i.e. video tutorial, slide deck, textbook) (3-8). Qualitatively, students view XR models to be more immersive and engaging than traditional media, which are thought to be more passive (5,7-11). Furthermore, virtual models reduce the demand for cadaveric donations, mitigating potential ethical violations that can occur when "wet specimens" are mishandled (12). Using digital models also provides significant cost savings for post-secondary institutions, since the average expense to acquire and maintain a single cadaver is approximately US$8,385 (13). Finally, instructor and student interactions with XR anatomical models are non-destructive, in contrast to the limited useful lifespan of chemically fixed hard and soft tissues that are prone to accidental breakage, perforation, and laceration.

Although the benefits of virtual models are extensive, most 3D models found in traditional digital atlases lack the accurate portrayal of the large variability of clinical anatomy, especially dental anatomy. In other words, the models developed for traditional atlases are usually sculpted by digital artists and idealized, therefore lacking clinical fidelity. These limitations impress upon students a very narrowed view on the broad range of normative dental anatomy, which can result in inadvertent iatrogenic damage during their clinical training and future practise.

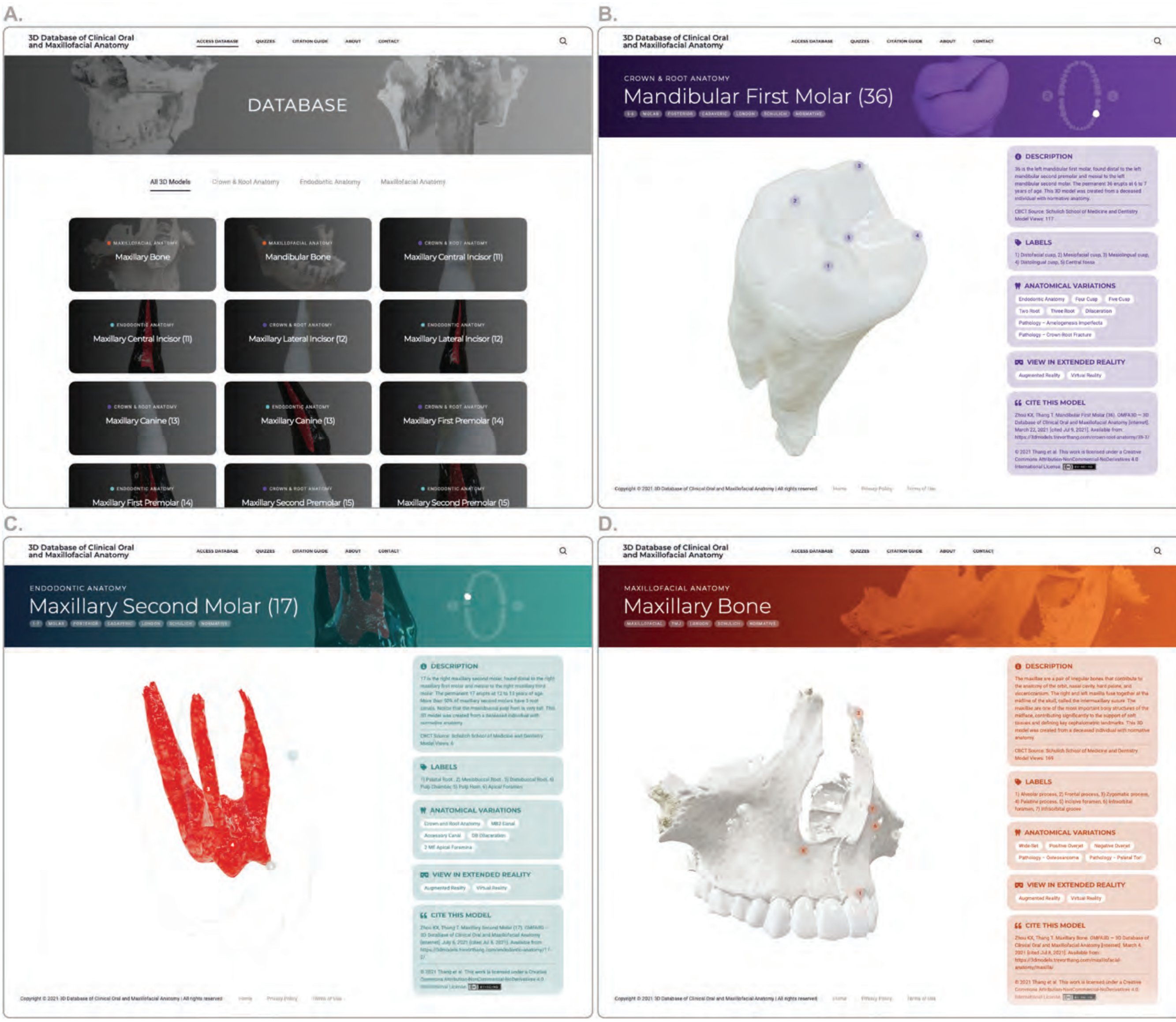

Figure 1. A. The online database contains various colour-coded 3D models. B. An example of a crown and root anatomy model of the left mandibular first molar. C. An example of an endodontic anatomy model of the right maxillary second molar. D. An example of a maxillofacial anatomy model of the maxillary bone and associated dentition.

Introducing OMFA3D

The 3D Database of Clinical Oral and Maxillofacial Anatomy (OMFA3D) was developed as a response to the relative lack of open-access resources for dental education and the limitations of traditional atlases. Our curated database has more than 100 unique 3D models derived from cone-beam computed tomography (CBCT) scans containing both normative and uncommon anatomical features. The models are organized into three sections: crown and root anatomy, endodontic anatomy, and maxillofacial anatomy (Figure 1). Users can navigate models via keywords, tags, categories, and an interactive "tooth map" based on FDI World Dental Federation (FDI) notation. Each model page features an interactive 3D viewer with anatomic labels, in addition to a sidebar containing a model description, links to anatomical variations, and XR modalities. To enter AR mode, users can simply navigate to the appropriate button under the "View in Extended Reality" card. A quick response (QR) code is then displayed for the user to scan, which enables the AR experience on a smartphone (Figure 2). Similarly, a stereoscopic VR environment can be enabled by clicking "Virtual Reality" and scanning the associated QR code (Figure 3). All models were developed via an in-house workflow using open-source software and are provided for educational use under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.

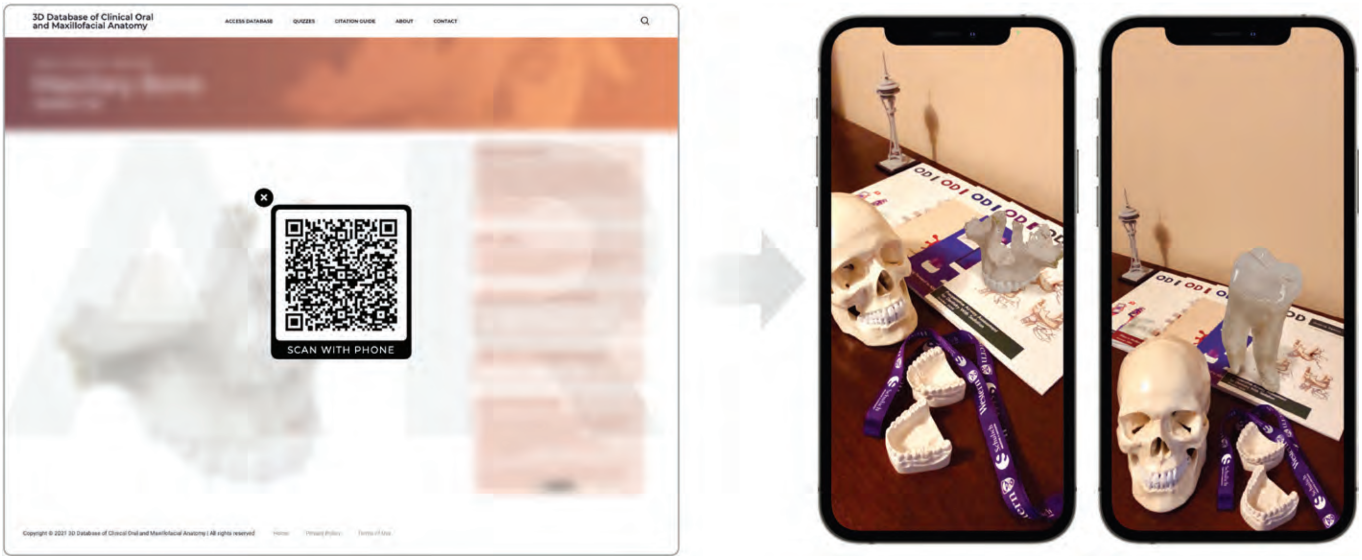

Figure 2. A QR code interface activates the augmented reality (AR) functionality; example AR environments display a maxilla and mandibular first molar. The maxillofacial anatomy models are highly detailed, ranging from 20 to 80 MB.

Figure 3. A QR code interface activates the virtual reality (VR) functionality. Note: An open-source cardboard VR headset is required.

Methodology

The study proposal was reviewed by the research ethics board at Western, the authors' university, and was deemed to be quality improvement, thus did not require ethics oversight. Dental records belonging to patients who visited the Department of Oral Radiology at the Schulich School of Medicine & Dentistry between 2010 and 2021 were identified, and CBCT scans of the maxillofacial region that showed normative anatomy, uncommon anatomy, or pathologies of interest were searched for.

The records that showed a limited CBCT field of view resulting in clipping of anatomical structures, insufficient contrast between structures of interest and surrounding anatomy, and radiographic artifacts caused by foreign objects (i.e. implants, crowns, etc.) were then excluded.

The remaining records were converted into 3D meshes via a semi-automated segmentation algorithm (14). The meshes then underwent manual post-processing to ensure closed geometry and the absence of loose vertices. Meshes with excessive segmentation artifacts (i.e. holes or islands) were discarded at this stage. Textures and material shaders were subsequently added to improve the cosmetic appearance and visual interpretation of the 3D mesh (Figure 4). The final models were published as .glb and .usdz files to a custom developed website and database management system. The identification of new patient records with anatomy of interest will be ongoing, such that future CBCT scans acquired at Schulich Dentistry may also be segmented and uploaded to the database.

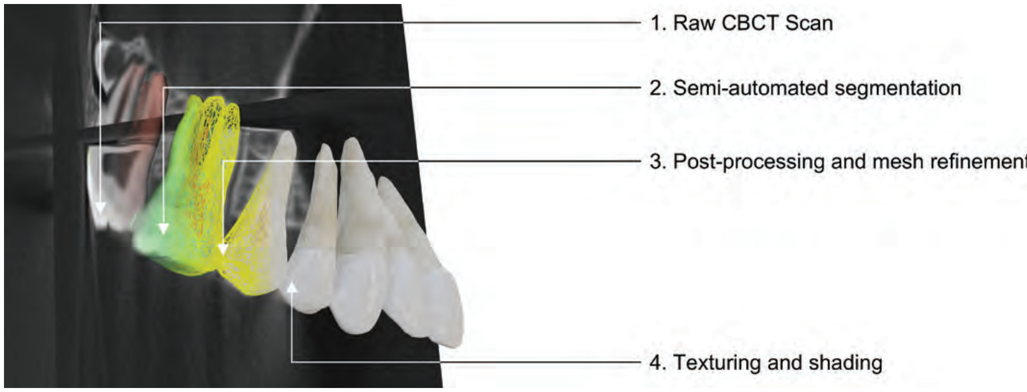

Figure 4. A high-level overview of the main steps involved in digitizing a patient's oral and maxillofacial anatomy.

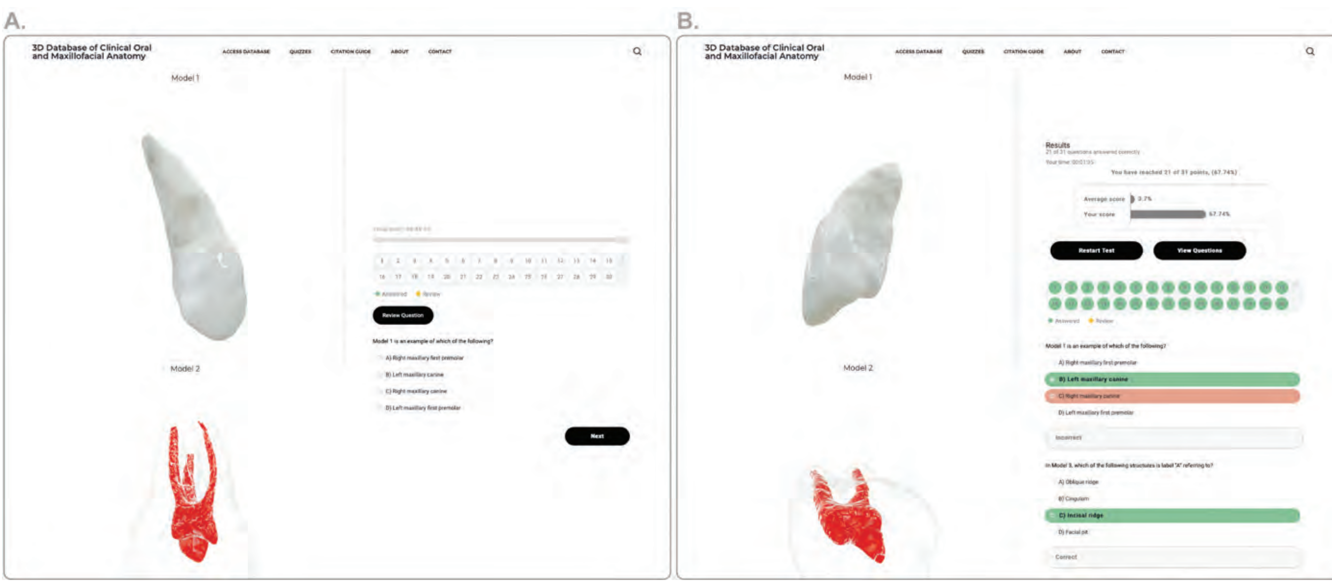

Figure 5. Currently in development: interactive 3D anatomy quizzes that will have automatic score calculation and feedback for pedagogic evaluations, leveraging the interactivity of the website's existing 3D models.

Discussion

Studying and understanding the wide range of dental anatomy and the associated maxillofacial structures is a fundamental skill for all future dental professionals. Therefore, physical models (predominantly, real teeth) remain a pivotal component of dental education. However, high-quality physical models of teeth are inherently rare due to the low probability that a virgin/unrestored tooth would be extracted. Furthermore, uncommon dental variations (e.g. accessory roots, cusps) are rarely captured in a physical collection due to their finite storage capacity and the inherently limited lifespan of biological specimens. The biggest limitation of physical models in dental education is the inability to non-destructively "look inside" a real tooth, which houses a complex and variable network of pulp chambers and canals. OMFA3D was designed to remedy these challenges and leverage the strengths of XR technology demonstrated in existing literature (3-5,7-11,15,16).

Despite the pedagogical, practical and economic benefits of XR technology over many traditional teaching aids, the exclusive use of XR in dental education remains controversial due to the poor acclimatization of some users to the VR world (termed "cybersickness"), and the lack of substantial enhancement in test performance over the current gold standard (physical models and cadavers) (2,5,6,17,18). Therefore, the authors suggest that XR should be incorporated into future curricula to supplement traditional non-physical pedagogical resources (i.e. video tutorial, slide deck, textbook, etc.) and used only as an alternative to physical laboratory models when the latter is unavailable.

Compared to other 3D modelling methods, our in-house digitization workflow has several advantages. Firstly, the acquisition of CBCT scans is non-destructive and does not require exodontia or cadaveric dissection, unlike photogrammetry or 3D scanning. Secondly, our protocol minimizes the amount of artistic discretion involved in model creation by using clinical CBCT scans as a data source and an algorithmic approach to segmentation. Thirdly, the web-based user interface for digitized models allows for ease of access and the possibility of crowdsourcing data. Finally, the implementation of a VR environment allows the viewer to achieve stereoscopic vision, a feature of physical models that was recently identified to be critical for learning anatomy (2). This work will have immediate applications in didactic and clinical dental education, improving student understanding of anatomical variations and promoting caution during operative procedures. Furthermore, OMFA3D can be used freely by practising dentists for patient education, allowing clinicians to easily demonstrate concepts such as pulp capping, dilacerations, and accessory canals. In academia, OMFA3D will aid future computational anatomy research by providing an existing source of high-quality segmented meshes that are representative of natural maxillofacial variation.

In the near future, clinicians and instructors from other institutions will be able to contribute their own medical images to OMFA3D, improving the database's breadth and representation beyond the Southwestern Ontario region. The authors are currently developing a 3D quiz functionality for pedagogic evaluations, leveraging the interactivity of the website's existing 3D models (Figure 5). A prospective validation study comparing OMFA3D to traditional resources is also planned.

Conclusion

OMFA3D is the first open-access database of clinical maxillofacial anatomy that supports both AR and VR learning modalities. Since the 3D models were built using pre-existing radiographic data of *in vivo* structures, the authors were able to construct a database that better captures the full variation of maxillofacial clinical anatomy without needing to use destructive procedures or cadaveric specimens. This novel educational resource is expected to improve patient outcomes at student dental clinics and will pave the road for future pedagogical and anatomical studies.

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OMFA3D can be accessed at
https://3dmodels.trevorthang.com or https://publish.uwo.ca/~kzhou54/.
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