THE CUTTING EDGE

(Editor's Note: This quarterly column is compiled by JCO Technology Editor Ronald Redmond. To help keep our readers on The Cutting Edge, Dr. Redmond will spotlight a particular area of orthodontic technology every three months. Your suggestions for future subjects or authors are welcome.)

Dr. James Mah's article, "The Evolution of Digital Study Models", describes what I believe to be a pivotal period in the history of orthodontics. Although dental study casts have improved gradually over the past century, they have changed dramatically within the last five to seven years. Now, cone-beam computed tomography and three-dimensional software are on the verge of replacing plaster casts, articulators, and even diagnostic wax setups. A single cone-beam scan will provide data for cephalometric, panoramic, TMJ, airway, sinus, and virtual study model analyses. The data will be stored electronically and transmitted to the end-user, whether that is the orthodontist or the laboratory fabricating custom appliances. What better articulator than the temporomandibular joints? Where is a diagnostic setup more valuable, on the lab bench or in the "virtual reality" patient, where the tooth positions can reflect soft-tissue alterations?

I have the honor of teaching digital orthodontics with Dr. Mah at the University of Southern California, and his insight into the future of 3D technology never ceases to amaze me. Recently, with the help of InVivoDental 3D software developed by Jack Choi of Anatomage, Dr. Mah determined the cause of death of an Egyptian girl who had been mummified 2,000 years ago. Scans revealed tooth fragments of a primary second molar lodged in the throat and nasopharynx. These fragments, along with bone-density calculations, pointed to advanced dental disease, osteitis, systemic infection, and eventual death. If we can obtain that degree of detail from a mummy, imagine what we'll be able to do for our patients in the future.

Please read this month's column carefully. I believe you will find Dr. Mah's contribution to be enlightening and thought-provoking.

W. RONALD REDMOND, DDS, MS

The Evolution of Digital Study Models

Since the beginning of modern orthodontics more than 100 years ago, plaster casts have been used to reproduce the patient's dentition for diagnostic, therapeutic, and research purposes. These study models have served as a key record of tooth size, dental morphology, archform, local soft-tissue anatomy, and the relationship of the jaws.

The present article describes the recent evolution of plaster casts toward digital study models.

Relating Plaster Models to the Patient's Anatomy

Early on, one of the pioneers in orthodontics, Calvin Case, recognized that plaster casts served a limited purpose unless they were related to the face.[1] To achieve this goal, Van Loon took a plaster impression of the face, with the lips parted so that the plaster would flow over the anterior surfaces of the teeth (Fig. 1). This region of the model was used to interlock and relate the plaster casts. More plaster was added to fill in the space between the

Dr. Redmond

Dr. Mah

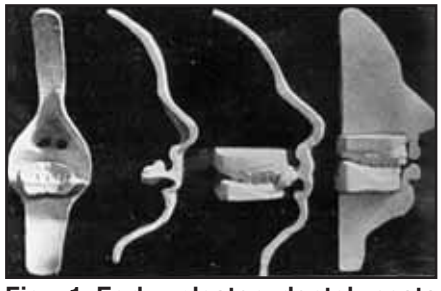

Fig. 1 Early plaster dental casts interlocking with plaster facial cast.

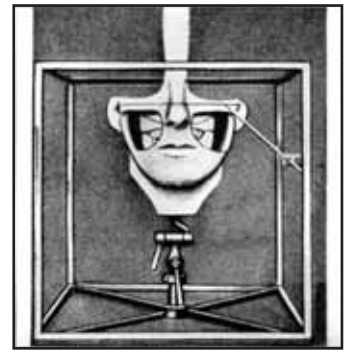

Fig. 2 Facial and dental casts related to one another inside metal cage.

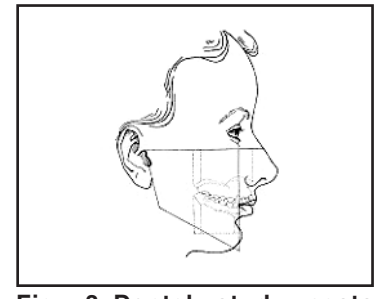

Fig. 3 Dental study casts related to Frankfort horizontal plane.

Fig. 4 First cranial x-ray. (Image used with permission from Radiology Centennial, Inc., Reston, VA.)

Fig. 5 Dental study casts mounted on articulator.

facial and dental models and thus create a "facial moulage".[2] Another alternative was to relate the facial and dental plaster models to one another within a three-dimensional metal cage (Fig. 2).[3]

Establishing an accurate relationship of the jaws was impractical with early plaster dental casts. In the 1920s, Simon proposed that the base of the maxillary model be oriented parallel to the Frankfort horizontal plane (Fig. 3).[3] The advantage of this approach was that the casts were related to the craniofacial skeleton rather than the face. The same principle is still followed in model trimming, where the maxillary cast is trimmed first, with the occlusal plane parallel to the table, and the mandibular cast is then related to it.

With the discovery of x-rays and the introduction of cephalograms (Fig. 4), another method of establishing the relationship of the dentition to the skeleton became available. Although the lateral cephalogram is only a two-dimensional representation, it remains in common use today.

Perhaps the most controversial issue involved

Fig. 6 Three-dimensional relationships readily visualized in virtual modeling of entire craniofacial complex, including face, skeleton, dentition, and TMJ, using CBCT data and photograph of patient's face. (Image provided by Anatomage, Inc.)**

with dental study models has been how to relate them to one another as well as to the skeleton. The accuracy of occlusal bite registrations has often been called into question. Articulators (Fig. 5) and facebow registrations have been used to relate the mandibular model to the TMJ, but their efficacy has been much debated,[4,5] and relatively few orthodontists use them routinely.

Digital Orthodontic Study Models

The concept of digital study models is not entirely new. An early version* involved taking photographs of the plaster casts in five orientations. By the mid-1990s, digital scanning technologies were able to create three-dimensional models.[6,7] Since then, hardware and software refinement has lowered costs and thus increased the utilization of virtual models.

Studies comparing digital models with plaster casts have shown that there is no difference in diagnostic accuracy,[8] and have concluded that digital models do not compromise orthodontic diagnosis or treatment planning.[9] The ABO currently accepts digital study models for pretreatment records, but still requires physical models for finishing records.

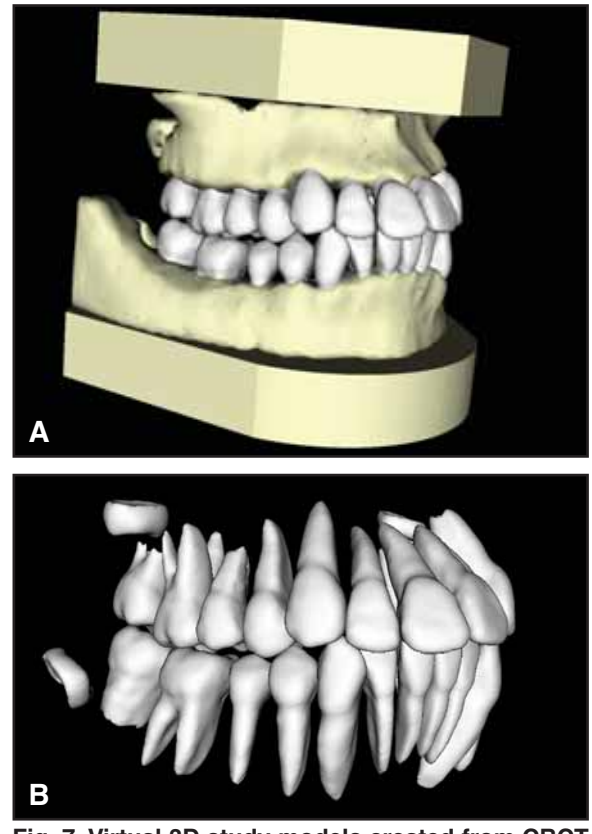

Fig. 7 Virtual 3D study models created from CBCT data. A. Models with conventional bases. B. Models with transparent bases, allowing 3D visualization of complete dental crowns and roots. (Images provided by Anatomage, Inc.)

Cone-beam computed tomography (CBCT) has recently enabled 3D visualization of the entire craniofacial complex, including the dentition (Fig. 6). Virtual study models can be produced from the CBCT data, with conventional model bases or with transparent bases that allow unobstructed 3D visualization of the dental

*QuickCeph Systems, Inc., 9883 Pacific Heights Blvd., Suite J, San Diego, CA 92121; www.quickceph.com.

**Anatomage, Inc., 111 N. Market St. #899, San Jose, CA 95113; www.anatomage.com.

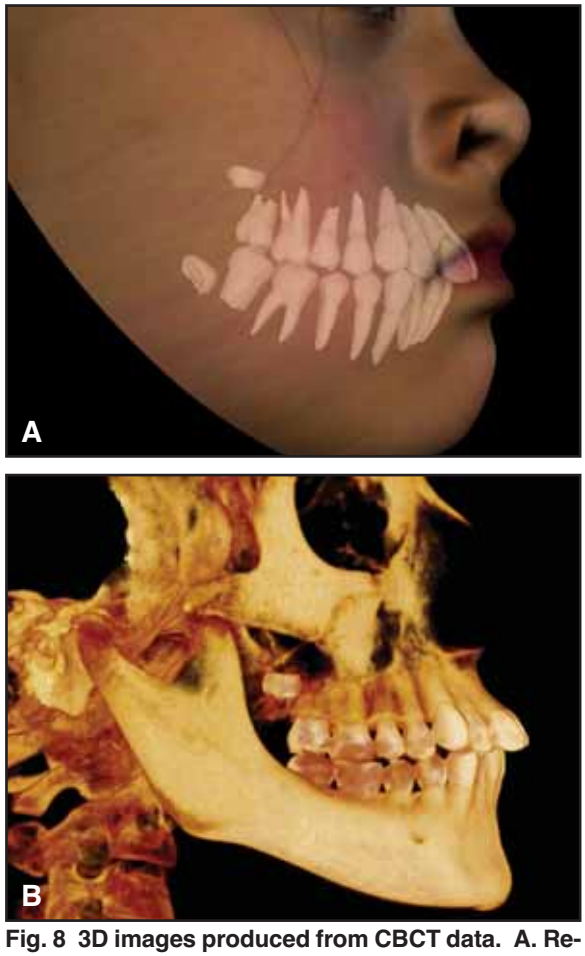

Fig. 8 3D images produced from CBCT data. A. Relationship between dentition and face. B. Relationship between dentition and condylar position within fossa. (Images provided by Anatomage, Inc.)

crowns and root morphology (Fig. 7). These images satisfy the original requirements of study models—recording tooth size, dental morphology, archform, and the relationship of the jaws. Studies have found no significant difference in orthodontic model analysis between plaster study models and 3D images of the dentition taken from CBCT.[10]

State-of-the-art CBCT devices now provide 3D visualization of specific relationships, such as those between the dentition and the face or between the dentition and the condylar position (Fig. 8).

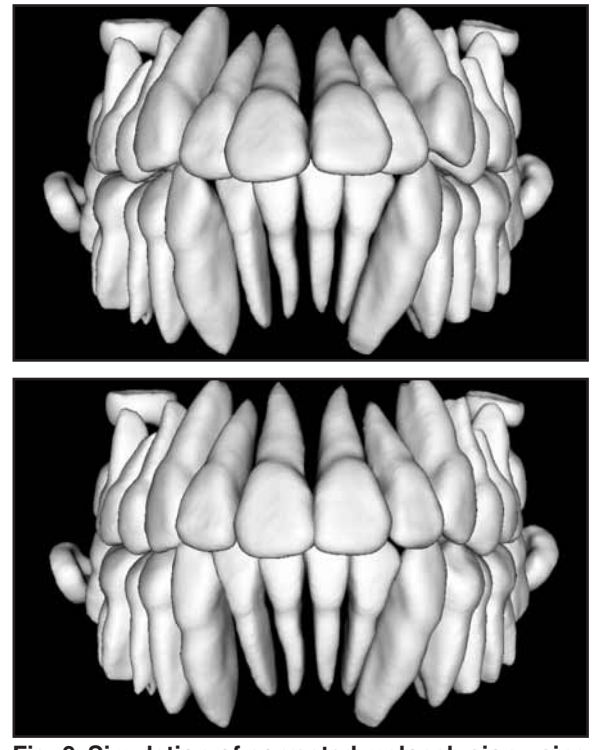

Fig. 9 Simulation of corrected malocclusion using virtual study models from CBCT data. (Images provided by Anatomage, Inc.)

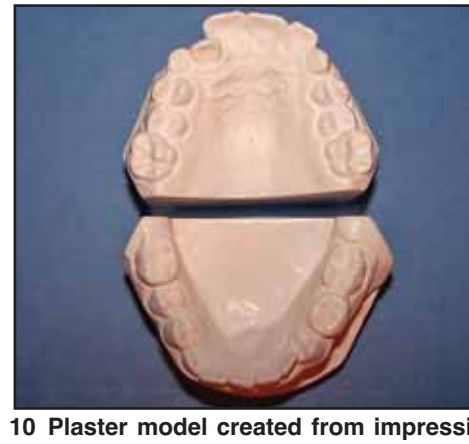

Fig. 10 Plaster model created from impression of rapid-prototyped study model.

Simulations of treatment outcomes—virtual diagnostic wax setups—are also possible (Fig. 9). Given these diagnostic advantages, along with the

potential to eliminate dental impressions and their related laboratory and storage costs, CBCT virtual study models are clearly emerging as superior patient records.

Reproduction of Physical Study Models

Rapid prototyping technologies have also emerged in recent years to allow the production of physical models from 3D data. These devices "print" 3D models in a variety of materials such as wax, starch, or plaster. An early criticism—that the product did not have the same look, weight, and feel of plaster models—has been overcome with a process that takes an impression of the rapid-prototyped model, allowing a conventional plaster model to be produced in the laboratory (Fig. 10). Since the final product is indistinguishable from a traditional plaster cast, this solution seems to satisfy the requirements of the ABO as well as medicolegal concerns.

Discussion

A common concern about digital records in general has been how well they will hold up in court. The AAO *Bulletin* recently reported that courts and juries have been strongly supportive of digital records for reasons including the ability to back up, search, transport, store, and standardize the records.[11] Particularly in light of recent natural disasters, digital records should be considered a prudent choice.

Although the concept of the orthodontic study model has been central to the profession, it is not the plaster cast itself that the clinician needs, but rather the diagnostic information it provides. If this information can be obtained from another source and serve the patient as well or better, digital evolution will continue.

JAMES MAH, DDS, MS, MRCD, DMS
Associate Clinical Professor
Director, Craniofacial Virtual Reality Laboratory
University of Southern California
Los Angeles, CA 90089
e-mail: jamesmah@usc.edu

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