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Digital Models: An Introduction

Matthew J. Peluso, Stuart D. Josell, Sam W. Levine, and Brian J. Lorei

Dental study models are a cornerstone in the armamentarium used by orthodontists to both classify malocclusion and formulate treatment plans. Recent technological advances have allowed the generation of digital dental models that can be saved and viewed three-dimensionally on a computer. These new digital models solve many problems encountered with conventional plaster study models. This article overviews the advent of digital models and the advantages of their use. OrthoCAD™ and emodels™ will be compared relative to the technology used to generate these models, software capabilities, additional services, and available research.
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The procedures for taking dental impressions and forming study models have progressed since their introduction in the early 1700s. Philipp Pfaff first described an impression-taking technique by using heated sealing wax to obtain a negative representation of the dental arches that was then used to pour a cast in Plaster of Paris.[1] In 1839, Chapin A. Harris advocated using a calcined plaster to fabricate casts from wax impressions.[1] In the mid-19th century, other materials such as Plaster of Paris, gutta-percha, and thermoplastic modeling compound became popular for taking impressions.[1] Reversible hydrocolloid alginate and later irreversible hydrocolloid alginate revolutionized impression taking in the early 1900s by eliminating many of the inadequacies of the previously used materials. The new materials proved to be accurate, dimensionally stable, and easy to use, while maintaining cost effectiveness. Later advances brought about even more accurate and dimensionally stable impression materials such as elastic polyether and polyvinylsiloxane; yet irreversible hydrocolloid alginate has remained the most common impression material used in the orthodontic office today with continued use of plaster, namely Type II Dental Stone, for fabrication of the casts.

Recent technological breakthroughs have enhanced the process of cast fabrication and manipulation. This process still requires traditional alginate impressions to be taken in the orthodontic office. Instead of being poured by the orthodontist, impressions are shipped overnight to one of the companies offering digital models. There, a traditional plaster model is fabricated and, using CAD-CAM technology, is transformed into a digital, three-dimensional (3-D) image of the dentition. Within a few days, an electronic file is available to be downloaded from the Internet to a desired computer. Once downloaded, software enables the digital models to be viewed and manipulated.

In 2003, The American Association of Orthodontists (AAO) published a list of recommended basic orthodontic records in their Clinical Practice Guidelines for Orthodontics and Dentofacial Orthopedics. According to the AAO, pretreatment and posttreatment records should include extraoral and intraoral photographs, dental models, intraoral and/or panoramic radiographs, and cephalometric radiographs, as well as any additional indicated tests or procedures. Thus, study models are an integral part of the orthodontist's armamentarium.

The information obtained from these dental casts is invaluable to help the orthodontist classify malocclusions, identify aberrations, and to formulate treatment objectives. As a static record of dental classification, models are used to visualize the morphology and position of the teeth in their respective dental arches, as well as the degree to which the teeth are malpositioned. In addition, diagnostic set-ups of treatment options are accomplished by using sectioned models. In fact, study models appear to be the major record used for treatment planning. Han and coworkers[2] showed that there was little difference between the treatment plan formulated by orthodontists using only study models when compared with using models, photographs, panoramic and lateral cephalometric radiographs, and a cephalometric tracing. Orthodontic models document initial conditions, treatment progress, and the final treatment result. Orthodontists also use these models to present their treatment results to colleagues and

From the Department of Orthodontics, University of Maryland, Baltimore College of Dental Surgery, Department of Orthodontics, Baltimore, MD.
Address correspondence to Stuart D. Josell, DMD, M Dent Sci, University of Maryland, Baltimore College of Dental Surgery, Department of Orthodontics, 666 West Baltimore Street, Room 3-E-08, Baltimore, MD 21201-1586.

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Table 1 Comparison of Plaster and Digital Models

	Plaster Models	Digital Models
Cost	Less expensive	More expensive
Diagnostic setups	Laboratory procedure	Virtual on computer
Storage space	Large space required	Negligible
Storage costs	Costly	Negligible
Fast and efficient retrieval	Yes	Yes
Retrieval at multiple locations	No	Yes
Subject to physical damage	Yes	No
Transfer of models	Laboratory duplication and shipping	Transfer of digital file
Integration with office management software	No	Yes
Patient education	Yes	Yes

patients for the purposes of education, evaluation, and research.

Study models are a reliable and popular form of diagnostic record[3] (Table 1). Since they are a dimensionally accurate representation of the dentition, a number of measurements and analyses such as tooth size-arch length discrepancy and prediction of permanent tooth size can be obtained from plaster study models. Measurements of tooth size-arch length discrepancies are recorded more accurately on the study model compared with intraorally, eliminating the need to estimate the amount of crowding. Additional measurements include arch widths. Models are also mounted on articulators to visualize centric relation-centric occlusion discrepancies.

Although traditional plaster study models have been used for many years, they have many limitations. For one, plaster study models break. Continued use for measurements and display can wear away plaster, decreasing accuracy and increasing the likelihood of fracture. Storage is another concept presenting both space and time problems. Models are usually kept in boxes for easy retrieval while keeping them from physical and chemical damage. A busy orthodontic office may start upward of 300 cases in 1 year, requiring an entire room for model storage. Time is an exacerbating factor as well. The shortest amount of time that records should be kept is based on the applicable statute of limitations period during which a malpractice suit may be filed.[4] This period of time varies from state to state and ranges from 5 to 15 years. This statute may start at the last day of treatment or may be delayed until the patient reaches the age of maturity. Either way, long-term storage is required. Three hundred cases per year for 10 years equal 6000 sets of pretreatment and posttreatment models. This might necessitate an off-site storage facility, increasing cost. Another problem is portability. Traveling with even a few sets of fragile study models is a difficult task. Communication is difficult when only one set of models exist. The treating orthodontist might have to duplicate a patient's models, a process that is both costly and time consuming, to communicate with other dentists and specialists.

Digital models alleviate many of the obstacles encountered with using plaster models (Table 1). They are not subject to physical damage and do not create any dust or other mess. They also require negligible storage space. The digital information for each case can be stored on an office computer's hard drive, on portable storage devices such as CDs, or on a central server. Digital information of a set of orthodontic study models is less than 1 megabyte in size. The software programs required to view these digital models are 8 to 12 megabytes in size. A typical 700-megabyte CD-R, which costs less than one dollar, holds over 700 cases. A 20-gigabyte hard drive that costs around one hundred dollars can hold around 24,000 cases. Retrieval is fast and efficient because the models are stored by patient name and number. Another advantage is that it is possible to view digital models at multiple locations from any office computer linked to the practice's central server,[5] allowing patients to be treated at multiple sites with easy access to their records. The electronic files in JPEG format contain all of the model information of numerous views of the models and can be transferred electronically to colleagues, specialists, and insurance companies. This decreases the time and expense of model duplication and shipment.

Digital models also minimize problems when purchasing a practice. It is in the best interest of patients in active treatment that both the incoming and outgoing clinicians have complete copies of the patients' records. With digital models, each orthodontist can have a copy for their archives without the expense of model duplication. In addition to all of these advantages, digital models are also an excellent presentation tool. From the first-year resident creating a case presentation, to the experienced practitioner presenting cases to a study club, digital models enable the projection of the model images for all in the audience to see without the concern of damage.

Digital models are also an excellent tool for patient education. The younger generation of patients currently in treatment are familiar with computers and are comfortable with computer-generated images. They can relate to digital models and probably expect to see this technology when they visit their orthodontists. Digital models can be shown to the patient and their guardians during treatment conferences, during treatment, and at the conclusion of treatment to illustrate the improvement in their dentition. There are also services that will set up secure Web sites that contain patient records and treatment information so that the patient can view these images from their home. Ultimately, digital models improve communication between the clinician and the patient, enhancing informed consent.

Table 2 Comparison of the OrthoCAD™ and emodels™ Services

	OrthoCAD™	emodels™
Cost of basic file	Less expensive than emodels™	More expensive than OrthoCAD™
File size	Slightly over 800 kb	About 800 kb
Technology used	Proprietary scanning process	Nondestructive laser scanning
Software charge	None	None
Fee for return of metal impression trays	None	Yes
Plaster copies available for additional cost	Yes	Yes
Files saved on company's Web server	10 Years	Indefinitely
Ships plaster to lab for appliance fabrication	Yes	Yes
Point-to-point measurements	Yes	Yes
Curve-length measurements	Yes	Yes
Bolton analysis	Yes	Yes
Tanaka-Johnson analysis	Yes	No
Cross-sectioning tool	Yes	Yes
Visualized occlusal contacts	Yes	Yes
Virtual diagnostic setup (extra cost)	Yes	Yes
Integration with office management software	Dolphin, Vistadent, Walrus, Sirona, Practice Works Imaging, Dr. Views, Oasys, Ortho II, Orthochart, Televox, and OrthoSesame	Dolphin, IMS, and Vistadent
Software size	8 mb	12 mb
Shipping	FedEx next-day shipping	UPS next-day shipping
Plaster models fabricated at a later date	Possible for a fee	Possible for a fee
Ability to create digital models from preexisting plaster models	Yes	Yes

As a result of these advantages and the advances in quality and affordability of digital radiographic and photographic technology, many orthodontic offices have implemented computerized practice management and imaging systems. The digital models available today offer seamless integration into most of these management and imaging systems. Digital models are part of the totally digital orthodontic office.

There are three basic requirements needed to utilize digital models. A personal computer (PC) with Internet access is the most basic requirement.[6] Internet access can be DSL, cable, or dial-up. It is important to note that DSL and cable Internet access can provide a fast download time of the electronic information from the company that produces the digital models. Once the equipment and internet access are set up, a designated folder must be made in the computer for the incoming digital information. Finally, a software program is needed that allows the electronic information to be retrieved and generates the images of the digital models. This software is usually provided free of charge by the company chosen to generate the digital models.

The two major computerized model systems creating digital models are OrthoCAD™ (Cadent, Inc, Fairview, NJ) and emodels™ (GeoDigm, Corp, Chanhassen, MN) (Table 2). A short summary of each follows:

OrthoCAD™

OrthoCAD™ was the first company to introduce a digital model service to the orthodontic market in early 1999. OrthoCAD™ is operated by Cadent, Inc, located in Fairview, NJ. This company was started by two CAD/CAM engineers who consulted with doctors and other experts to develop their 3-D system. The startup software for OrthoCAD™ is free of charge and is about 8 megabytes in size. There are no service contracts required to allow OrthoCAD™ to generate digital models.

A practitioner can get started with OrthoCAD™, log onto www.orthocad.com or call 800-577-8767. The software can be downloaded directly from the Internet or the company can send a CD at no charge. The cost of a set of digital models from OrthoCAD™ is approximately the laboratory charge for a set of trimmed study casts. At the request of the orthodontist, OrthoCAD™ will send postage-paid next-day shipping kits for shipping impressions and a bite registration. Orthodontists could either send disposable or metal trays. OrthoCAD™ recommends using specific disposable trays, alginate, and wax bites.

When OrthoCAD™ receives the impressions and bite registration, the models are poured and scanned through a proprietary process. The maxillary and mandibular digital casts are articulated by using the bite registration that was sent with the impressions. Although a wax bite is said to be acceptable, it is strongly recommended that a fast setting polyvinylsiloxane be used for bite registration since its accuracy is critical especially when making measurements of interarch relationships, digital images are fabricated from the digital models using stereo lithography. Within 5 days of receiving the impressions, the electronic information is posted on the OrthoCAD™ server as an electronic

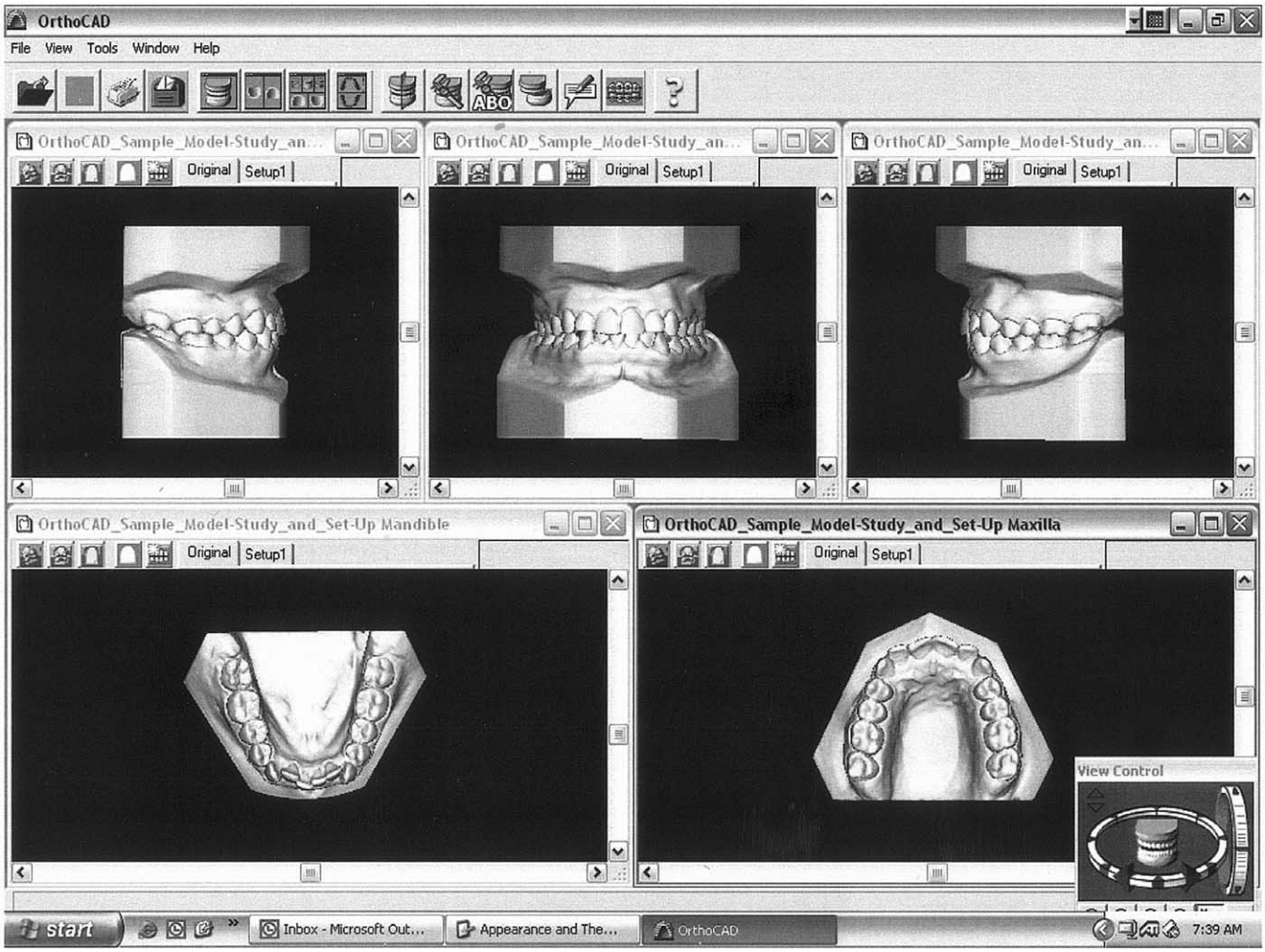

Figure 1 OrthoCAD™ five simultaneous views of the digital models.

file. The file, which is typically 400 to 800 kilobytes for children and a little larger for adults, is then downloaded to a designated folder on the practitioner's PC or server, either automatically or manually. OrthoCAD™ saves the file on their server for 10 years.

Plaster copies of these models can be ordered at an additional price and can be shipped to either the orthodontist or to a laboratory of choice for appliance fabrication at the time the impression is submitted. OrthoCAD™ also offers a service by which digital models can be generated from previously trimmed plaster casts.

OrthoCAD's 3-D browser software allows the clinician five simultaneous views of the models[7] (Fig 1). This enables the models to be viewed from multiple perspectives at the same time. These views of the models can be rotated or enlarged to evaluate tooth position and make measurements in any plane of space. Bolton analyses,[8] Tanaka-Johnson analysis, tooth width, curve-length, point-to-plane measurements, and any point-to-point measurements can be performed (Fig 2). OrthoCAD™ also features a cross-sectioning tool that can slice the digital models in any vertical or horizontal plane to check symmetry, overjet, overbite or to measure any location (Fig 3). The "Jaws Alignment Tool" can be used to move the lower jaw in different directions, thus enabling assessment of the occlusal contacts (Fig 4). The Occlusogram feature is a visual multicolor representation of these occlusal contacts that displays the distance between opposing teeth. OrthoCAD's Virtual Set-Up[9] (Fig 5) enables the clinician to simulate and visualize any desired treatment option including virtual extractions, interproximal reduction, expansion leveling, and to apply various fixed appliances. The Virtual Set-Up service option has an additional charge, which does not include the digital study models.

A new innovation introduced by OrthoCAD™ is their Bracket Placement System. The clinician generates a digital model of the desired treatment objective by using the Virtual Set-Up software. Based on this model, the clinician then places each bracket in the desired position virtually on the digital model (Fig 6). A bracket placement wand has a miniature video camera that transmits high resolution images of the intraoral environment and a removable sleeve that can be sterilized (Fig 7). The system determines the relative position of the wand versus the actual tooth and gives the practitioner a positioning target and signals when the virtual placement coincides with the actual placement (Fig 8). A bracket is then

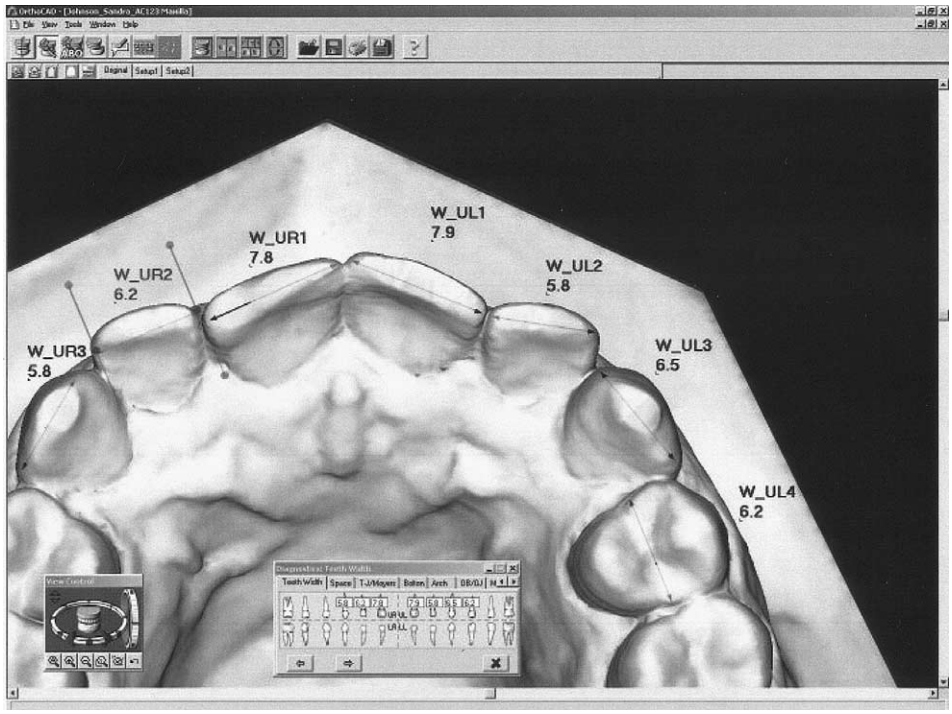

Figure 2 OrthoCAD™ measurement tool demonstrating tooth width measurements.

tacked in place by using the wand's internal curing light. Thus, bracket placement becomes more accurate and time efficient. There are a number of bracket systems that are programmed into the software to correspond to the size and shape of the actual brackets. This bracket placement service also has an additional charge. The cost for this bracket placement system must include a cart, CPU, flat panel monitor, intraoral wand with tips, wireless connection, battery backup, onsite training, and all travel expenses for the trainer.

The OrthoCAD™ digital models may be retrieved within many practice management and imaging software

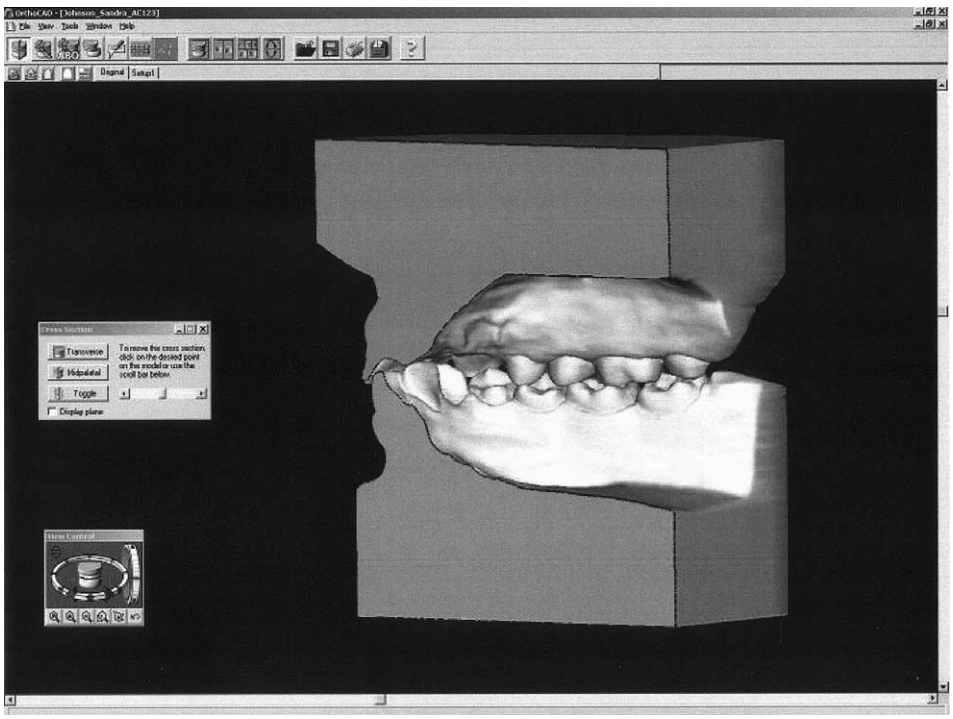

Figure 3 OrthoCAD™ cross-sectioning tool demonstrating a vertical cutting of the digital models to check overjet and overbite.

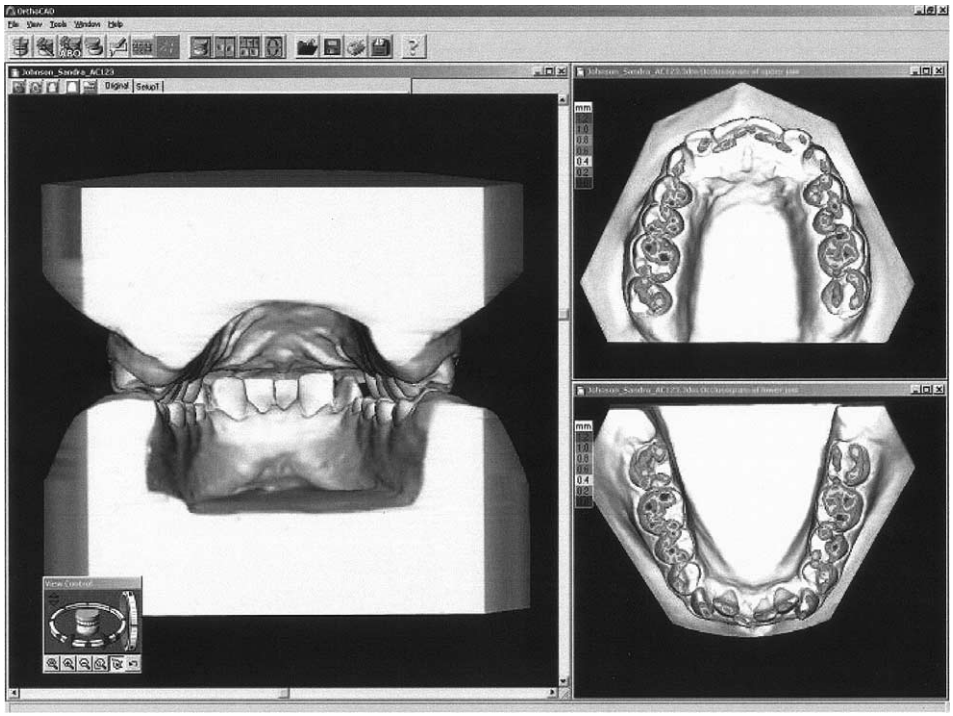

Figure 4 OrthoCAD™ Jaws Alignment Tool demonstrating the occlusal contacts after moving the mandibular model in different directions.

programs. Currently Dolphin, Vistadent, Walrus, Sirona, PracticeWorks Imaging, Dr. View, Oasys, Ortho II, IMS, Orthochart, Televox, and OrthoSesame are compatible with the OrthoCAD™ software. As the products are continually enhanced and the company grows, OrthoCAD™ plans to continue to add additional services to their current suite of services. Those new services include construction of retainers with the final records either through OrthoCAD™ or through the orthodontist's laboratory of choice. One of the new innovations that OrthoCAD™ is currently testing is a centric occlusion-centric relation (CO-CR) feature in their software. OrthoCAD™ is work-

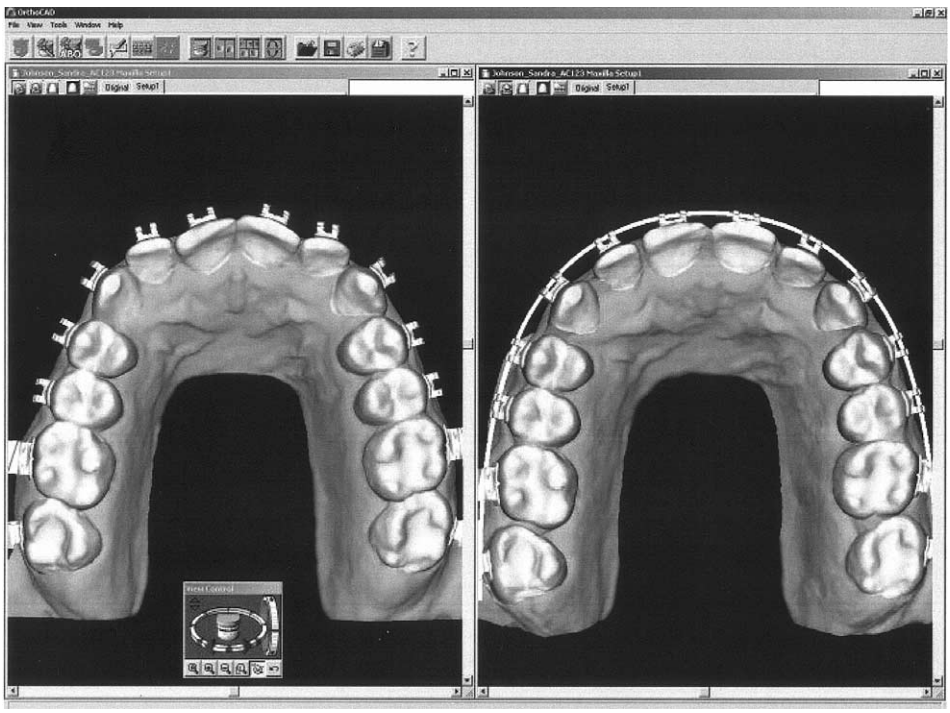

Figure 5 OrthoCAD™ Virtual Set-Up tool.

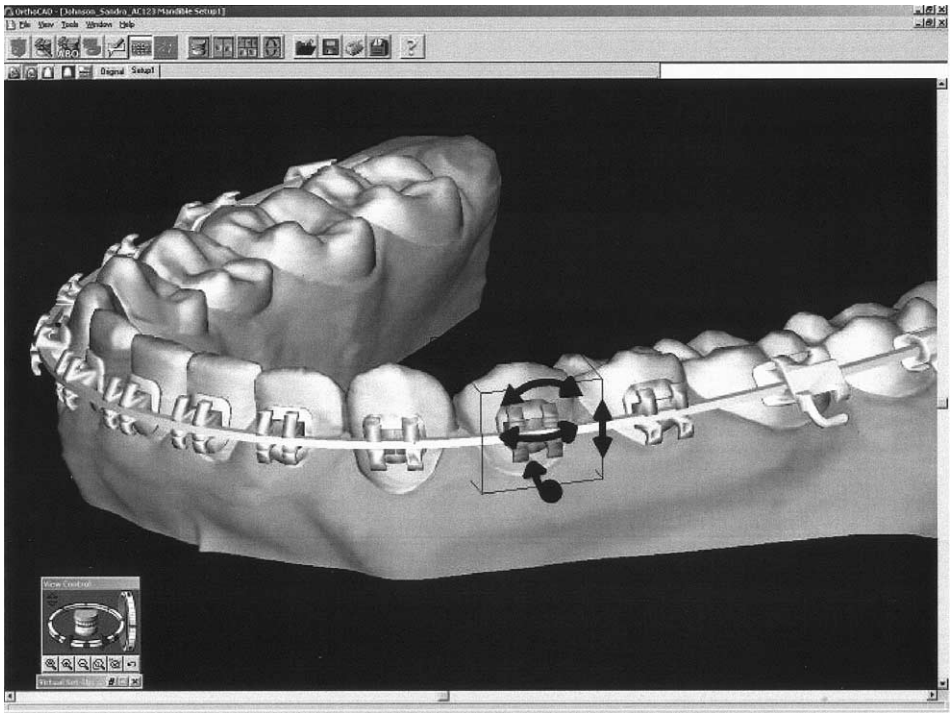

Figure 6 OrthoCAD™ Bracket Placement demonstrating the placement of a bracket in the desired position virtually on the digital model.

ing with the American Board of Orthodontics (ABO) toward the acceptance of their digital models for the Phase III certification process. Cadent, OrthoCAD's parent company, has developed a Crown and Bridge fabrication product that is currently in alpha testing.

emodels™

emodels™ by GeoDigm was founded in 1996 as Interactive Reflective Imaging System. It has since changed its name and has grown considerably. emodels™ became available to the

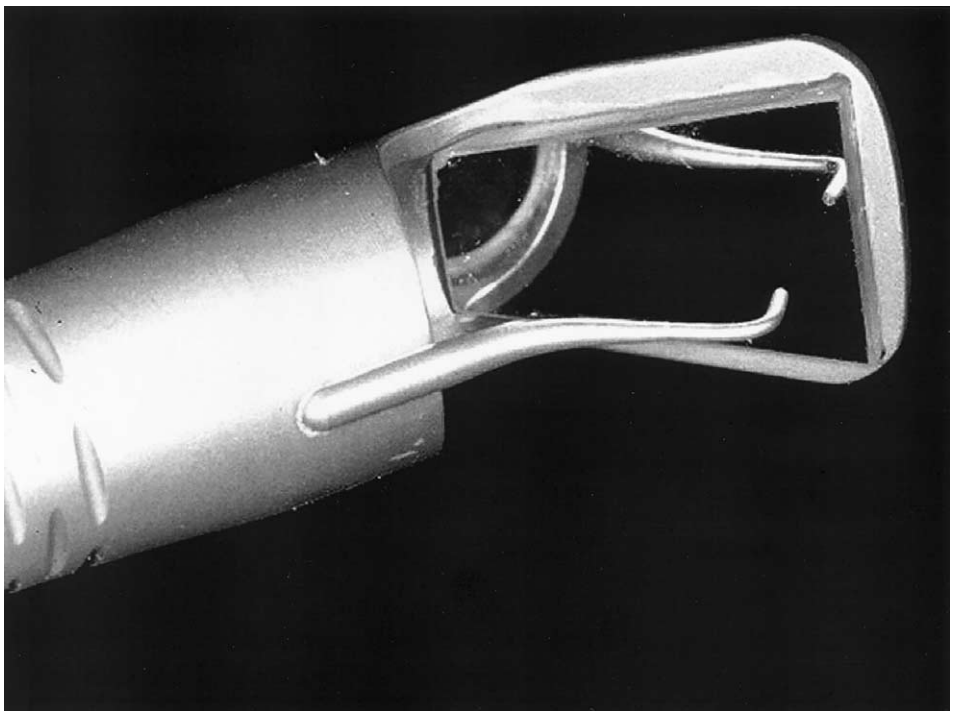

Figure 7 OrthoCAD™ Bracket Placement System wand.

Figure 8 OrthoCAD™ Bracket Placement System visual targeting indicator.

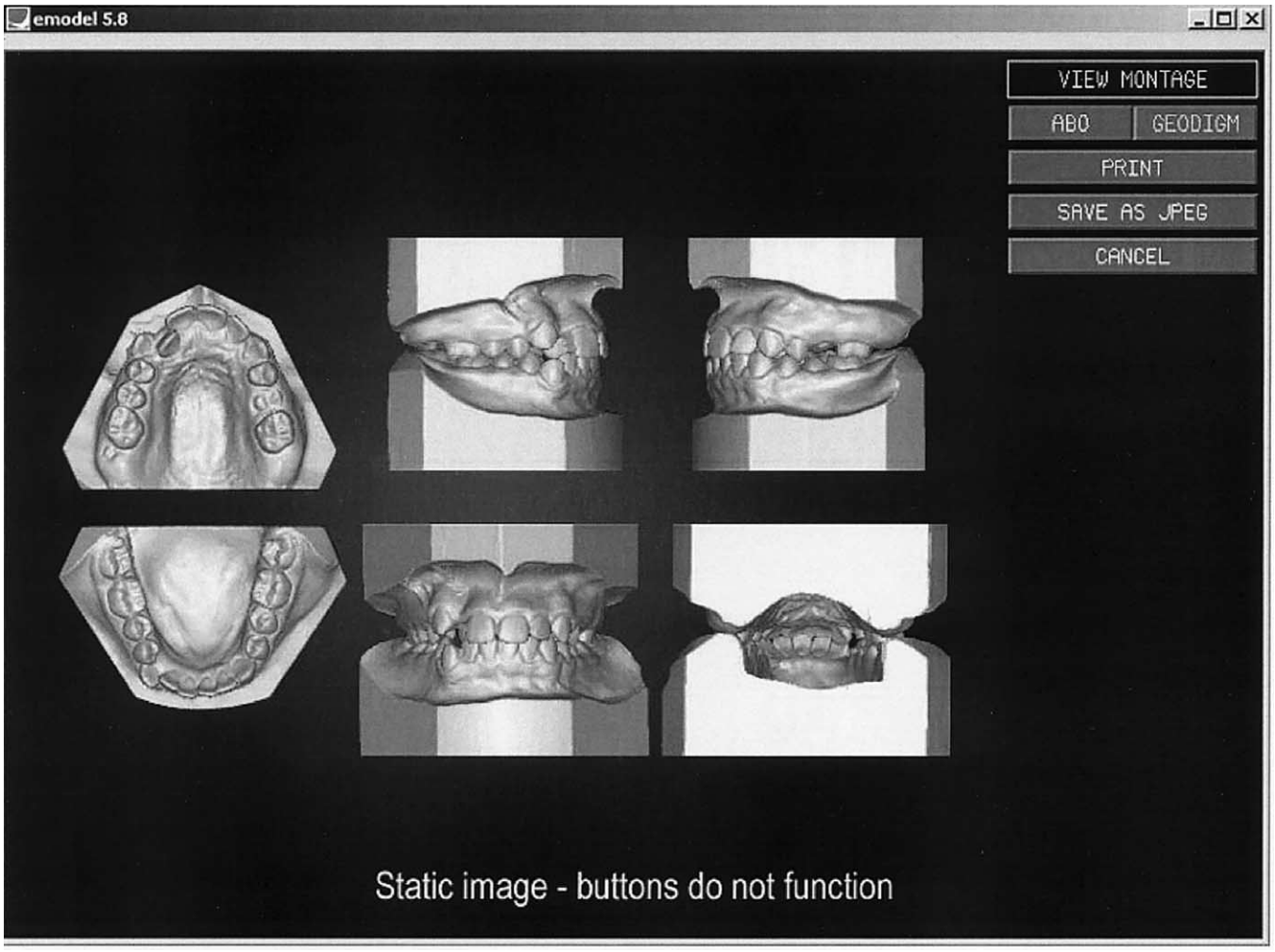

Figure 9 emodels™ models can be moved, rotated, and enlarged.

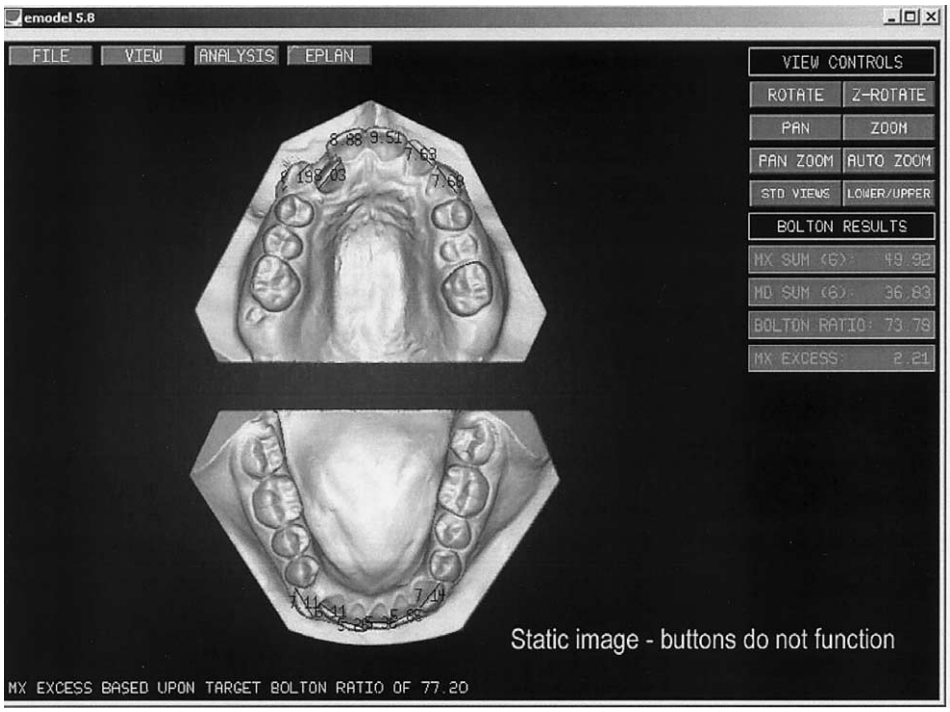

Figure 10 emodels™ measurement tool performing a Bolton analyses.

profession at the American Association of Orthodontists (AAO) National Meeting in 2001. To get started with emodels™, one could either log onto www.geodigmcorp.com or call 866-436-6335. The software, which is about 12 megabytes, is downloaded over the net or will be sent on CD at no charge. Geodigm will send postage-paid next-day shipping kits for the impressions and a bite registration. The orthodontist could either send disposable trays or metal trays.

When the impression is received by GeoDigm, a plaster model is fabricated. That plaster model is then scanned by using a nondestructive laser scanning process that digitally maps the geometry of the cast's anatomy with an accuracy of

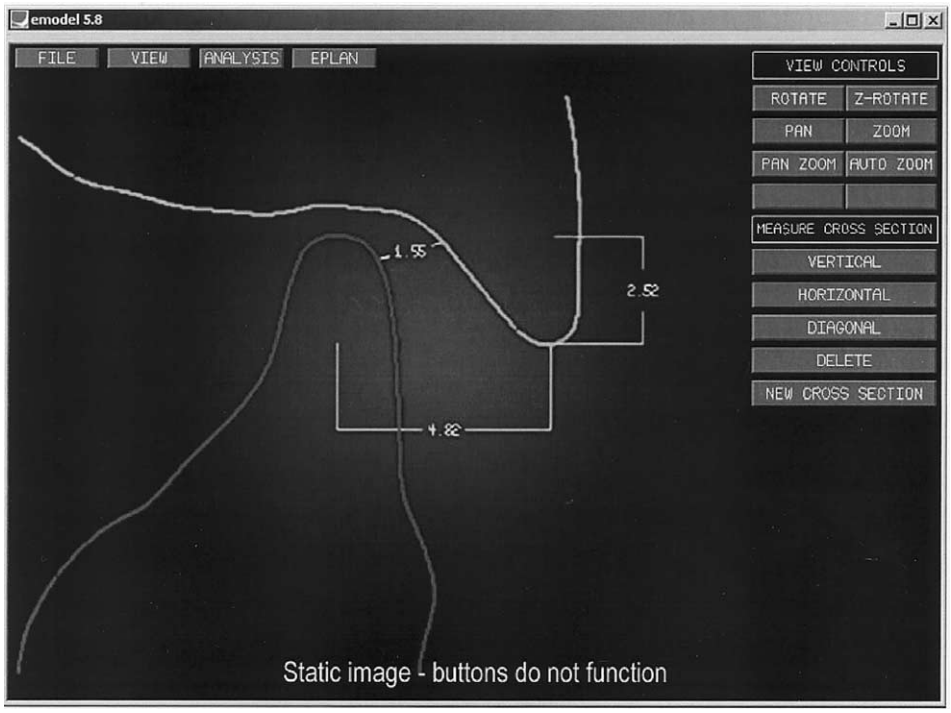

Figure 11 emodels™ cross-sectioning tool used to slice the digital models' overjet and overbite.

Figure 12 emodels™ Color Bite Mapping feature that is a visual representation of occlusal relationships that can be adjusted by the clinician.

±0.1 mm.[10] A laser strip is projected onto the cast and its distortion is read by multiple cameras while the cast is oriented on multiple axes to expose all surfaces for scanning. The maxillary and mandibular digital casts are articulated based on the wax bite sent with the impressions. Within 5 days, the electronic information, which is about 800 kilobytes, is posted on the GeoDigm Web server and is accessible 24 hours a day. The company maintains a copy of the electronic file on its server.

Download speeds depend on the type of Internet connection to the orthodontist's computer. A dial-up modem will take 2 to 3 minutes to download, while a DSL or cable con-

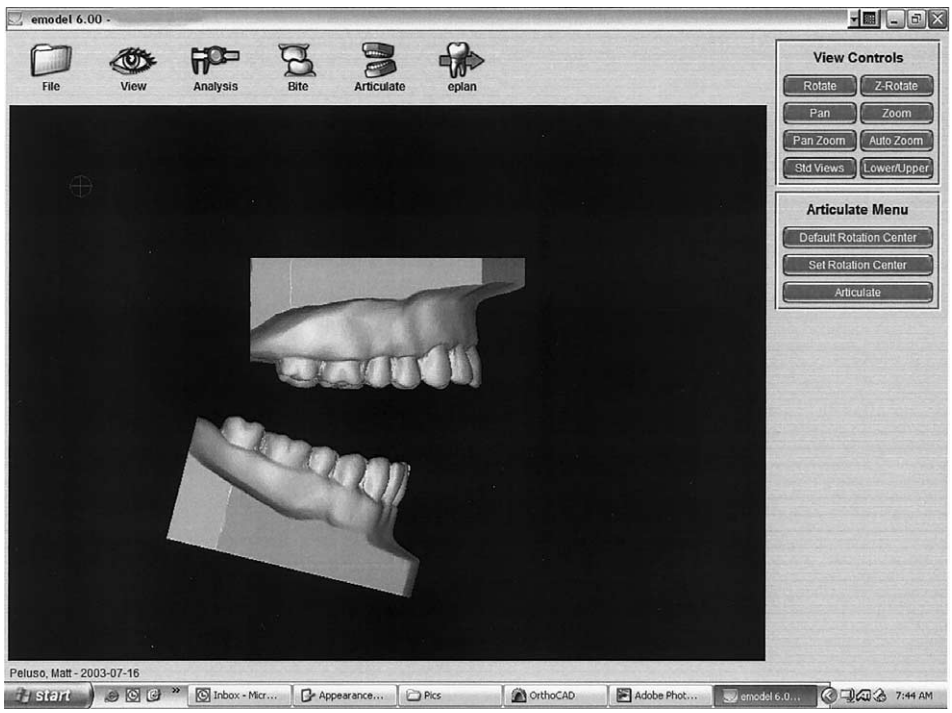

Figure 13 emodels™ articulation feature allows either a predetermined or a custom center of rotation to be chosen.

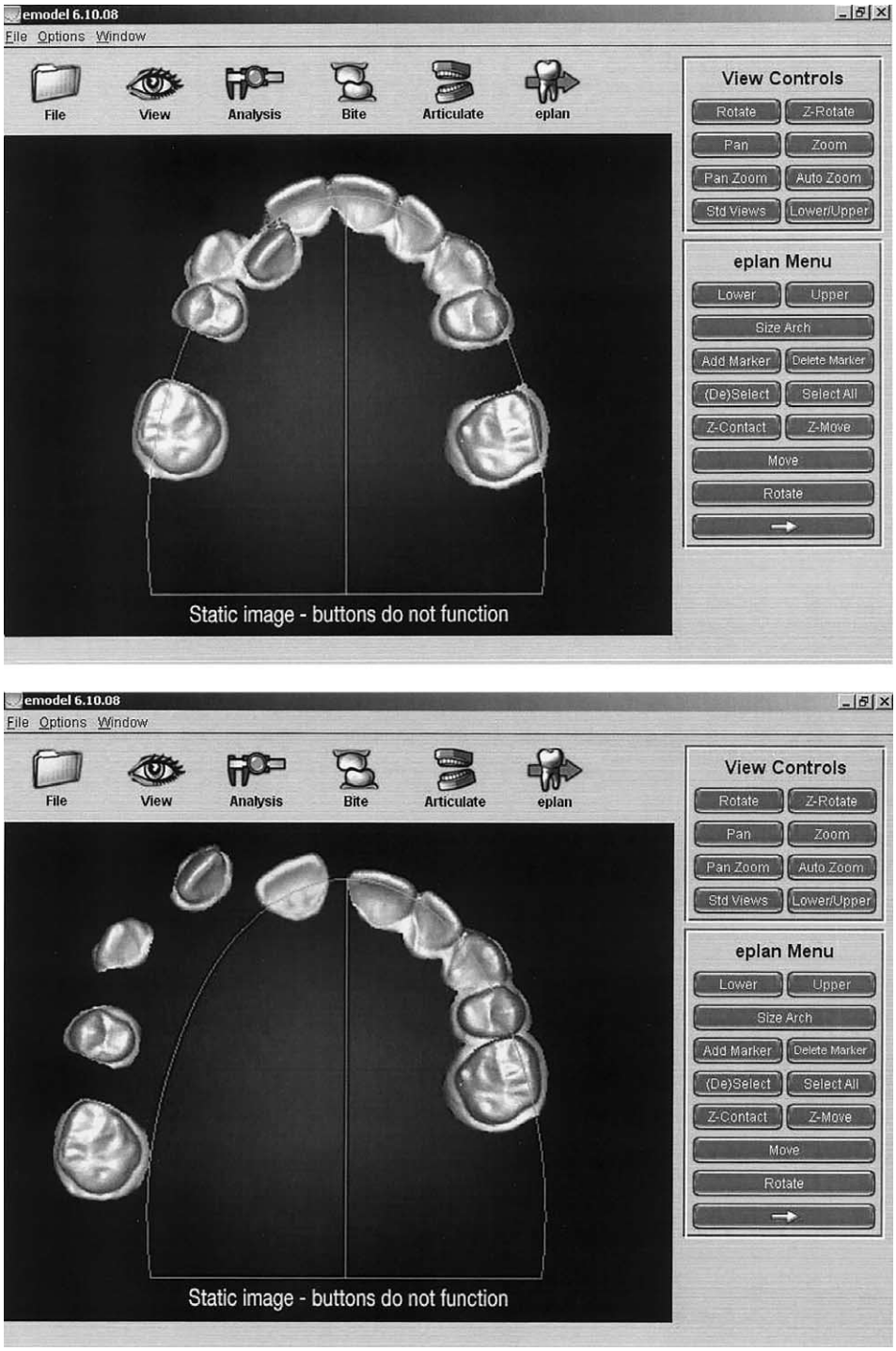

Figure 14 (A, B, and C) emodels™ *e*plan™ demonstrating the simulation of an extraction treatment option.

nection will take about 10 seconds. Referring dentists can download, at no charge, the digital model software. The orthodontist can then give the dentist the digital files for a patient that can be viewed on this software. For an additional fee, GeoDigm will send the plaster model directly to the orthodontist or to a laboratory of the orthodontist's choice for appliance fabrication. The original plaster models are kept for 4 weeks before being discarded. Plaster models can be generated after this time for an additional fee. GeoDigm also offers a service by which digital models can be generated from previously trimmed plaster casts.

The emodels™ software allows the models to be moved, rotated, or enlarged to evaluate tooth position and make measurements in any plane of space (Fig 9). Bolton analyses, tooth width, curve-length measurements, and any point-to-point or point-to-plane measurements can be performed (Fig. 10). emodels™ also feature a cross-sectioning tool that can slice the digital models in any vertical or horizontal plane

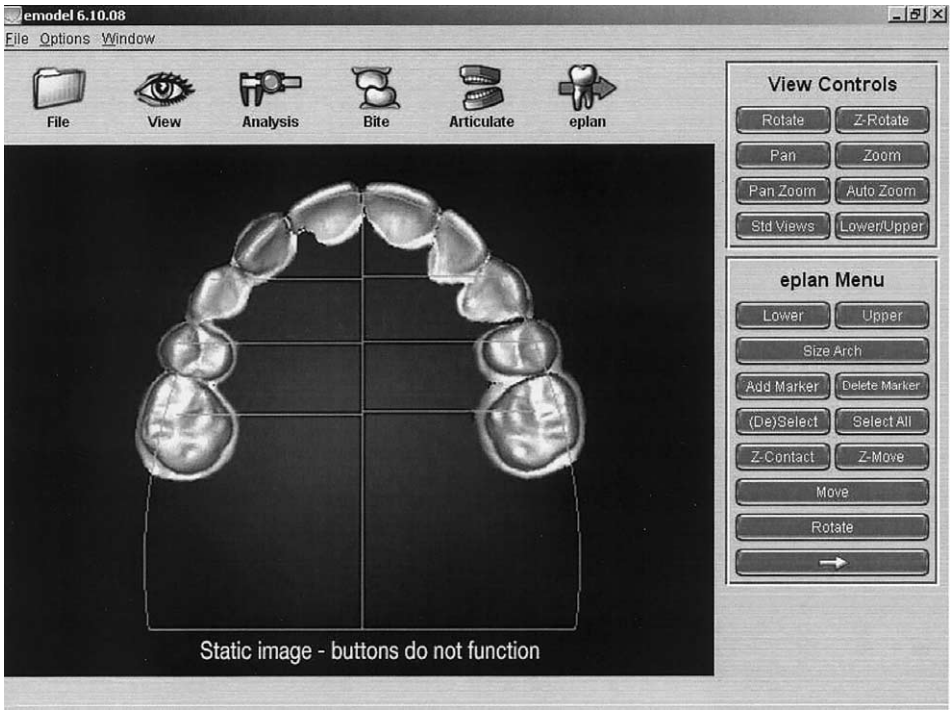

Figure 14 (*continued*)

to check symmetry, overjet, and overbite and to help measure any location (Fig 11). There is a Color Bite Mapping feature that is a visual representation of occlusal relationships (Fig. 12). An articulation feature allows either a predetermined or custom center of rotation option (Fig. 13). This allows the clinician to animate articulation and evaluate occlusal contacts during jaw closing.

Probably the most useful feature of the emodels™ software is the *e*plan™ (Fig 14 A, B, and C). This feature enables the clinician to simulate any desired treatment option by using a virtual diagnostic setup. Once a desired setup is entered, there is an animation function that can be used to illustrate to the patient how the teeth will move to correct the malocclusion. There are two different options that the clinician has to utilize this virtual diagnostic setup technology. The first option is to have the teeth of the digital model sectioned so that the orthodontist can manipulate the position of each individual tooth, simulating various treatment outcomes. The second option is the *e*plan™ service. The orthodontist simply prescribes a treatment outcome and the tooth position is determined by GeoDigm. Currently, Dolphin, IMS, and Vistadent (GAC) are compatible with the GeoDigm software.

One of the newest innovations that is offered by GeoDigm is a system by which the orthodontist places brackets virtually on the teeth of the digital models. An indirect bonding tray is then fabricated and sent to the orthodontist. This innovation allows more accurate bracket placement. GeoDigm also has Icon crowns, which utilize their core technology (software and laser scanning) to digitize the crown production process.

Evaluation

If diagnosis, treatment goals, and mechanics are to be made based on these digital models, they must be as accurate, if not more, than conventional plaster models. A few studies have evaluated the accuracy of digital models. A study by Garino and Garino[11] showed that there was a reduction in the dispersion of the variance around the means when using the OrthoCAD™ software compared with a digital caliper on a stone model. Measurements included tooth size and various arch dimensions. DeLong and coworkers,[12] using the Virtual Dental Patient System, compared standard measurements from the actual object and from the stone model to the measurements obtained from a digitized model. The results showed that the digital models were clinically acceptable. Most recently, Santoro and coworkers[13] showed a significant difference between plaster and digital model measurements with respect to both tooth width and overbite. While the digital model measurements were consistently smaller than the plaster model measurements, the magnitude of these differences was so small that they were not considered to be clinically significant. There was no significant difference in overjet measurement.

Ease of use is another consideration when evaluating digital model systems. This, however, is highly subjective. Both OrthoCAD™ and emodels™ software programs are self-explanatory and do not require any special training sessions. However, it takes some time to become familiar with the nuances of each program, such as rotating the models to view a desired aspect of the models and manipulating the dentition to perform a virtual diagnostic setup.

At this time both companies are in the process of developing programs for scoring the American Board of Orthodontics (ABO) objective cast grading system, which is used to evaluate case finishing on the Phase III clinical examination. The ABO is currently monitoring development of these programs and may in the future be able to accept digital models for case presentations. Several university studies are in progress to test the accuracy of these programs and to compare them to manual scoring of casts. Again, it must be stressed that the accuracy of the bite registration is of the utmost importance in evaluating interarch relationships such as overbite, overjet, occlusal contacts, and so on, which must be measured to evaluate case finishing.

HIPPA regulations impact the management of all orthodontic offices utilizing digital records. Patient information must be kept private. OrthoCAD™ and emodels™ abide by HIPPA guidelines. Both use encryption software to transmit patient information and have a number of firewalls protecting their databases. An orthodontist should not leave confidential patient information on the computer screen in plain view of others before, during, or after treatment.

Digital models are an accurate, efficient, and easy-to-use alternative to plaster models. With the current technology and future applications, digital models have the potential to advance the practice of orthodontics. They allow precise measurements and visualization of proposed treatment outcomes. The ability to quickly perform diagnostic setups, to achieve ideal bracket placement from the onset of treatment, and to facilitate better communication between patient and clinician have positive impacts on treatment. Ultimately, this process leads to higher quality of treatment and greater patient satisfaction.

Acknowledgments

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