Rapid prototyping as a tool for diagnosis and treatment planning for maxillary canine impaction

Jorge Faber,ª Patricia Medeiros Berto,b and Marcelo Quaresmaa

Brasília, Brazil

Treating an impacted maxillary canine requires identifying its exact position; this can pose a challenge to both orthodontists and oral surgeons. The purpose of this article is to present a new method for diagnosis and treatment planning of maxillary canine impaction by using computed tomography combined with rapid prototyping. Computed tomography image files of a patient with tooth 13 impaction were edited to produce, by means of rapid prototyping, an anatomic model of the maxillary teeth and a single attachment model that was later used to fabricate a metal attachment to be bonded to the impacted tooth. The dental model was used in the diagnosis and orthodontic treatment planning, and to communicate with the patient and his parents. The model showed the exact anatomical relationship between the impacted tooth and the other teeth; it was the main aid in intraoperative navigation during surgery to expose the tooth. The metal attachment built from the prototype was bonded to tooth 13 during surgery. Prototyping could become a new tool for fabricating brackets and other precision accessories for specific needs. Dental models made with rapid prototyping could become the diagnostic procedure of choice for evaluating impacted maxillary canines. (Am J Orthod Dentofacial Orthop 2006;129:583-9)

Impaction of maxillary canines is a relatively common clinical problem; its incidence ranges from 0.92%1 to 2.2%2 in the general population. It poses a challenge to orthodontists in terms of diagnosis, treatment planning, and treatment management. Several treatment options are available for a patient with an impacted maxillary canine: (a) autotransplantation of the canine; (b) removal of the canine followed by orthodontic closure of spaces or prosthetic replacement of tooth; and (c) surgical exposure of the canine followed by orthodontic treatment to bring the tooth onto the occlusal plane.3-5

The correct identification of the position of the impacted tooth plays a crucial role in determining treatment. Although visual inspection and palpation can be useful to determine the position of impacted maxillary canines, radiographic evaluation provides a more accurate approach to the problem.3,6 Various radiographic techniques can be used to obtain visual information about the exact position of an impacted canine. However, a 3-dimensional (3D) image might be formed only in the dentist’s mind when radiographic techniques, such as tube shift, are used, or when images are obtained with computed tomography (CT). CT studies provide a good visualization of the spatial relationship between anatomical structures. However, even when a 3D reconstruction is obtained,7,8 the analysis by the orthodontist and the dental surgeon is still limited: 3D images are seen as 2-dimensional (2D) on film and the computer screen. (For a video clip, go to this article on the journal’s web site at www.mosby.com/ajodo.)

This limitation can be overcome with the use of CT to make a model by means of rapid prototyping. This technique comprises several technologies that use data from computer-aided design files to produce physical models and devices by a process of material addition.9 Rapid prototyping differs in many aspects from subtractive and molding techniques used for many years in the manufacture of brackets and other devices. Its most impressive difference, however, is its capability to reproduce complex designs that are unthinkable by any other method.9 For example, it can reproduce the maxilla with the maxillary sinus and, inside this cavity, a third molar that might have inadvertently been pushed into the cavity during the removal of a tooth. Models can be produced by this technique close to actual

ªPrivate practice, Brasília, Brazil.
bGraduate orthodontic student, Universidade Federal de Goiás; and private practice, Brasília, Brazil.
Marcelo Quaresma is the project manager at Artis Prototyping in Brazil and helped develop the models for evaluating impacted teeth.
Reprint requests to: Dr Jorge Faber, SCN Brasília Shopping & Towers sala 408, Brasília-DF, Brazil 70715-900; e-mail, jorgefaber@terra.com.br.
Submitted, June 2005; revised and accepted, September 2005.
0889-5406/$32.00
Copyright © 2006 by the American Association of Orthodontists.
dimensions, and can be manufactured and handled similarly to plaster casts. The purpose of this article is to present and discuss a new methodology for the diagnosis and treatment planning of impacted maxillary canines. This methodology makes use of dental models manufactured with rapid prototyping.

**STEPS FOR MANUFACTURING A DENTAL MODEL WITH RAPID PROTOTYPING**

CT should follow a number of criteria to produce high-quality prototyping models. The area of interest must be scanned at axial slices no thicker than 1.0 mm—the thinner the slices, the higher the quality of the model. During the CT study, the patient should bite into a wax block or a piece of gauze to keep the maxillary and mandibular teeth separated. Separation is necessary to reproduce occlusal anatomy and avoid blurring the dental images. When the study is performed with a helical CT scanner, the gantry tilt must be set to 0°.

After the CT study, the 2D images must be saved as digital imaging and communications in medicine (DCM) files in a CD-ROM, 8.0 mm DAT tape, 5.25 in optical disk, floppy disk or zip drive to be sent to the prototyping company. Alternatively, they can be directly sent to the company via the Internet. The CT film does not have to be forwarded.

The DCM files are imported into CT image-processing software, which builds up the image and constructs the virtual 3D model. Once the software has reconstructed the area of interest, various anatomic structures can be selected according to their tissue densities because DCM files keep information about the density of each region. Minimum densities are 1476 Hounsfield units (HU) for mineralized dental tissue, 176 HU for the compact substance of bone tissue, and −324 HU for soft tissues. Therefore, the software operator should choose structures with densities greater than 1476 HU to eliminate all except dental hard tissues.

The prototyping company also eliminates image artifacts produced by restorations or metal implants; this improves the final quality of the model. When the image is ready, a structured triangular language (STL) file is created. STL files provide visualization of 3D models by using a triangular-mesh rendering.

A prototyping software sends the STL file to the rapid prototyping machine, which receives the triangular-mesh image in thin image slices. The prototyping machine builds a resin model by adding layer by layer according to the thin slices and reliably reproduces the CT information.

Several rapid prototyping technologies are currently available. The most accurate and highest quality are selective laser sintering, stereolithography, and PolyJet (Objet Geometries, Rehovot, Israel). To build models, all technologies use polymerization of resin layers that are thinner than the slices of a CT scanner.

Fig 1. Intraoral photographs. Arrow on occlusal plane shows protuberance in palatal mucosa caused by impacted canine.
This means that current CT resolutions do not explore all the quality possible for a prototyping model.

CASE REPORT
Clinical history
A boy, age 13 years 6 months, came for his first visit with his parents. Their main complaint was the boy’s poor tooth alignment. Detailed anamnesis showed that medical and dental histories were irrelevant. Clinical examination and models showed a Class I malocclusion with maxillary and mandibular anterior crowding and tooth 13 missing (Fig 1). The radiographic analyses (cephalometric, panoramic, and full-mouth periapical radiographs) showed that tooth 13 was impacted, and its crown was palatal to the root of tooth 12 (Fig 2).

After discussion of treatment options with the patient and his parents, fixed orthodontic treatment was selected. The treatment included the extraction of the maxillary and mandibular first premolars and traction of tooth 13. The patient’s parents showed us a previous panoramic radiograph in which tooth 13 was seen in a better position; this led to the conclusion that the tooth was not ankylosed.

To better evaluate the position of the canine and facilitate its traction, 2 prototypes, 1 of the maxillary teeth and the other of a single attachment to be bonded to tooth 13, were fabricated. A multislice helical CT study of the maxilla was used for both prototypes.

Prototype fabrication
One hundred fifty 1.00-mm CT slices were obtained. Each slice overlapped the next by 0.5 mm (Fig 3, A). The DCM CT files were imported into CT image processing software (Vworks 5.0, Cybermed, Seoul, Korea), which reconstructed the target area (Fig 3, B). After elimination of all except dental hard tissues (Fig 3, C-E), an STL file (Fig 4) was generated. This file was imported twice into 3D animation and modeling software (3ds Max 6, Autodesk, San Rafael, Calif) and generated 2 different files.

The first file was edited to create cylindrical bridges that connected all teeth. Some teeth—ie, the maxillary right canine—lost continuity with other structures after the elimination of bone tissue. Without the connections,
the tooth’s positional relationship to the other teeth would be lost.

The second file was used to fabricate a customized attachment to aid the forced eruption process. It was modeled over tooth 13, with software tools that simulated the impression of the impacted canine for later production of an attachment with anchoring loops (Fig 5, A and B).

Both files were exported back into STL format. They were then opened in a prototyping software (Objet Studio, Objet Geometries) and sent to a rapid prototyping machine (Eden 330 PolyJet, Objet Geometries), where the models were built by overlaying 0.016-mm layers of acrylic resin polymerized with ultraviolet light curing. The teeth model cost $125, and the attachment prototype cost $25 (US).

Prototyping application and findings

The attachment model (Fig 5, C) was used to fabricate a metal attachment to be bonded to the tooth (Fig 5, D). For that purpose, it received a high-fusion phosphate base coating (Heat shock, Polidental, Cotia, Brazil) used to fabricate the nickel-chromium alloy (Verabond II, Albadent, Fairfield, Calif) attachment that was later bonded to the tooth (Fig 5, E). The purpose of this attachment was to facilitate canine traction.

The rapid prototyping model of teeth (Fig 6) was
Fig 5. Attachment fabrication. A, Computer-modeled attachment produced over impacted maxillary canine as seen in B. C, Attachment prototype over canine prototype. D, Cast attachment ready to be bonded to tooth. E, Periapical radiograph showing attachment bonded to canine.

Fig 6. Several views of dental prototype: A, frontal; B, right lateral; C, oblique; D, superior.
initially used for the diagnosis and orthodontic treatment planning, and for communication with the patient and his parents. This model showed that the impacted canine root had its crown tipped toward the palate, and the root apex was over the apex of the maxillary right first premolar. The crown of the impacted canine was 2.1 mm from the root of the maxillary right lateral incisor.

The model was also used as the main aid in intraoperative navigation during the surgery to extract tooth 14, expose tooth 13, and bond the attachment. The surgery, including anesthesia and suture, lasted 40 minutes.

DISCUSSION

The use of a rapid prototyping dental model seems to provide significant advantages in the diagnosis, treatment planning, and communication with patients for impacted maxillary canines when compared with conventional radiography and CT scans.

The disadvantage of conventional radiographs (Fig 2, C-E) is that a 3D image can be formed only in the clinician’s mind. Therefore, it is difficult to clearly explain the exact nature of the problem and the treatment procedures to patients or their guardians.

CT provides better diagnostic interpretation than conventional radiography because it is a detailed study of the positions of teeth, particularly when using 3D reconstructions. However, visualization of the image on a computer screen or CT film is 2D, and tactile sensation cannot be used to evaluate the problem.

The advantage of using tactile sensation in diagnosis and planning can be understood by comparison with another diagnostic procedure: intraoral photographs provide a detailed evaluation of occlusion, but less information than the study models, whose handling can be indispensable for orthodontic diagnosis and treatment planning.

The use of models is also advantageous when treatment planning consists of tooth exposure so that orthodontic movement occurs only after spontaneous eruption. Surgical access is made easier because models provide an accurate understanding of the anatomic relationships between the impacted tooth and the other teeth. When forced eruption is planned, rapid prototyping dental models provide an additional advantage: the probability of orthodontic complications is decreased because the orthodontist obtains the information necessary for optimal orthodontic mechanics.

The main disadvantage in the use of this procedure is the exposure of the patient to CT radiation. However, the amount of radiation required has decreased as more advanced software and hardware technologies are developed. Although the production of a prototype by using CT might provide state-of-the-art analysis of canine position, conventional radiographs are still necessary as part of routine orthodontic records. The exception is the tube shift technique (Fig 2, C-E), which can be abandoned when prototyping is routinely used for the evaluation of canine impaction. This technique was still used for this patient because the decision to use prototyping was made only after the complete conventional radiographic evaluation had been performed.

The use of rapid prototyping models seems to facilitate the surgical procedures and the communication with colleagues and patients. Benefits have already been demonstrated for surgeries other than the removal or exposure of impacted teeth. Surgery duration is reduced in 17% to 60% of patients,14 with less trauma, a more comfortable postoperative recovery,18 and fewer complications. However, no studies have focused on the use of prototyping models in the removal or exposure of impacted teeth. Future studies might provide a clearer definition of the advantages and disadvantages of this procedure, especially in the evaluation of impacted teeth with severe malpositioning.

CT and prototyping models have higher costs than conventional radiographs; this is another disadvantage of this procedure. However, these technologies have gradually become more affordable and might soon be more frequently used in orthodontic clinics.

Three-dimensional modeling made possible the fabrication of the attachment for canine traction (Fig 5). Prototyping can become a new tool in the production of brackets and other precision apparatuses for specific cases. This process might also spur the development of orthodontic technology because researchers will be able to develop new products in their personal computers at a relatively low cost.

This new diagnostic and orthodontic treatment planning methodology might show better results for patients with impacted maxillary canines. However, further studies should be conducted to quantify the impact of this methodology in surgery time, duration of orthodontic treatment, and prevalence of surgical and orthodontic complications. Further studies should also investigate the use of this methodology in the analysis of impacted third molars and supernumerary teeth.

CONCLUSIONS

Dental modeling by means of rapid prototyping was an efficient auxiliary method in diagnosis, orthodontic treatment planning, and communication with this patient and the orofacial surgeon. Rapid prototyping
technology made possible the fabrication of an attachment for forced canine eruption. Rapid prototyping dental modeling might become the diagnostic procedure of choice in the evaluation of impacted maxillary canines.

We thank Drs Frederico Salles and Marcos Anchieta for this patient’s surgical procedure.

SUPPLEMENTARY DATA


REFERENCES