Three-dimensional digital modeling and setup

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Obtaining accurate images of the craniofacial region is critical when developing an orthodontic diagnosis and treatment plan. The purpose of this article is to describe a new imaging method that provides complete 3-dimensional views of the maxilla and the mandible, and the model setup with individual anatomic roots. The method uses computed tomography technology and laser scanning; it offers high-resolution images with relatively low radiation exposure. Technical aspects of the new procedure and its possible uses for orthodontic diagnosis and treatment planning are discussed. (Am J Orthod Dentofacial Orthop 2006;129:605-10)

New trends in medicine and dentistry include 3-dimensional (3D) digital imaging of the craniofacial region.[1-4] Until now, imaging technology for orthodontic diagnosis and treatment planning has been largely confined to 2 dimensions. Clinicians today routinely use 2-dimensional images, including panoramic x-rays, frontal and lateral cephalometric radiographs, and facial and intraoral photographs. Diagnostic setups are usually limited to the display of the crowns only, without considering root morphology and the surrounding bone. Individual teeth on these models can be manually sectioned and repositioned with wax, or, if digital, the teeth are electronically separated with an algorithm that recognizes interproximal embrasures and gingival lines around each tooth. Computer-modeled gingiva can be placed around the cut teeth. The technician then moves the teeth to the desired locations, according to the doctor's prescription.[5]

Some 3D imaging techniques have been developed, but they are limited in the amount of information they can display by their static nature.[4]

Recently, some techniques were developed that create 3D digital study models of the teeth that can be viewed on a computer screen, but those models are not accurately merged or calibrated with the other diagnostic information. Although these might be accurate representations of the occlusal anatomy, they still have the limitation of showing only the crowns and occlusal surfaces of the teeth; they cannot show the true size, location, or relationship of the roots of the teeth and their relationships with other anatomic structures.

The development of a 3D setup that displays individual crowns and roots and craniofacial structures would greatly help the clinician in diagnosis and treatment planning to determine various treatment options, monitor changes over time, predict and display final treatment results, and measure treatment outcomes accurately.

PROCEDURE

A computed tomography (CT) scan of the maxillofacial region is acquired (LightSpeed Ultra Plus, GE Medical Systems, Milwaukee, Wis), so that both bony structures and teeth can be viewed in 3 dimensions (Fig 1). Based on the occlusion visualized from the models, the mandible is then rotated into maximum occlusion. The anatomic teeth including the roots are then cut from the CT scan by using computer software (Mimics 8.13, Materialise, Leuven, Belgium) (Fig 2). At the same time, the patient's plaster models are laser-scanned. Then the crowns are eliminated from the CT scan (Fig 3, *A*), the roots are separated (Fig 3, *B*), and they are merged with the separated crowns acquired from the models (Rhinoceros, Robert McNeel and Associates, Seattle, Wash) (Fig 3, *C*). An example of this procedure for a maxillary premolar is shown in Figure 4.

A 3D setup can be produced (Fig 5, *A*), eg, with extraction of 2 first premolars (Fig 5, *B*), and subsequent space closure (Fig 5, *C*). It is then possible to view the aligned 3D crowns and roots (Fig 5, *D*) and their anatomic relationships with the surrounding bone, and to assess the bony thickness and any fenestrations (Fig 5, *E*). It is also possible to change the torque of a single tooth or a group of teeth and evaluate the amount of bone before fenestration is evident (Fig 6). Another feature is the 3D superimposition of the anatomic teeth before (Fig 7, *A* and

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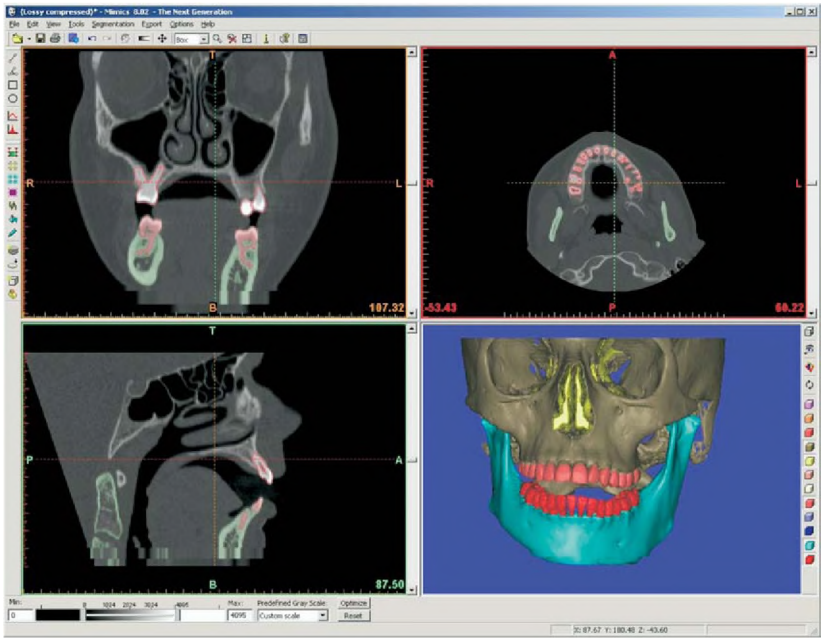

Fig 1. CT scan of maxillofacial region with 3D reconstruction.

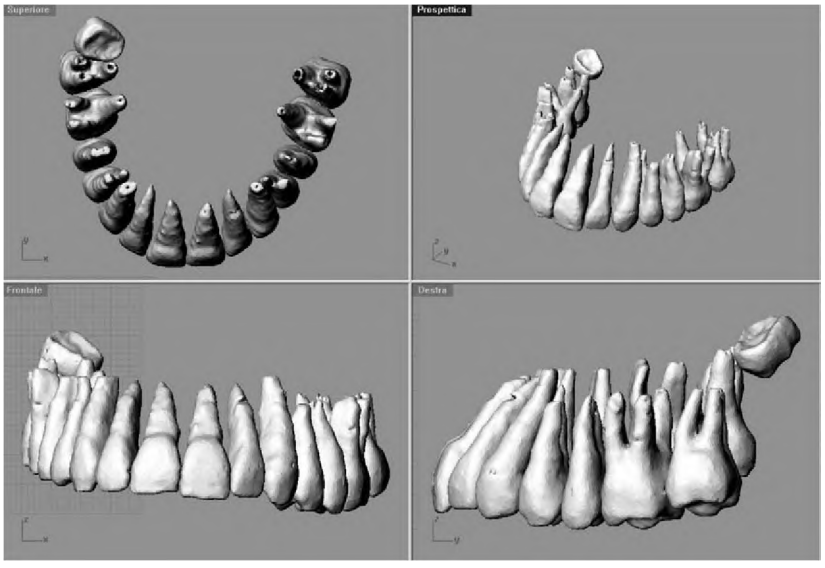

Fig 2. Separation of anatomic teeth, including roots, from CT scan.

B) and after (Fig 7, *C* and *D*) the setup to visualize the amount of movement before and after treatment (Fig 7, *E*).

CONCLUSIONS

With traditional orthodontic imaging techniques, some areas of anatomy are poorly visualized. Gateno et al[6] described a technique for creating a computerized composite skull model. They also assessed its accuracy and found it to be high. Similarly, using CT technology and laser scanning, they described a new method that provides a complete 3D view of the maxilla, the mandible, and the model setup with individual anatomic roots.

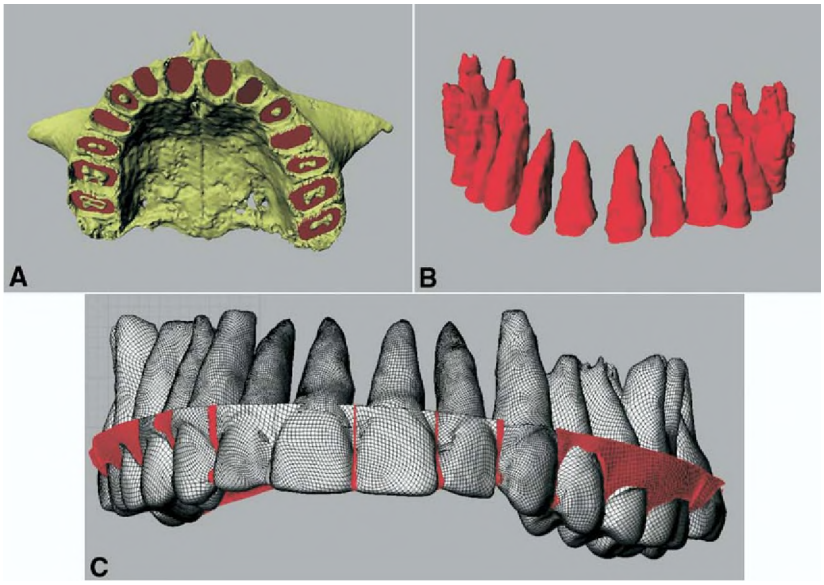

Fig 3. A, Removal of crowns from CT scan; **B,** separation of roots; **C,** merging with separated crowns acquired from models.

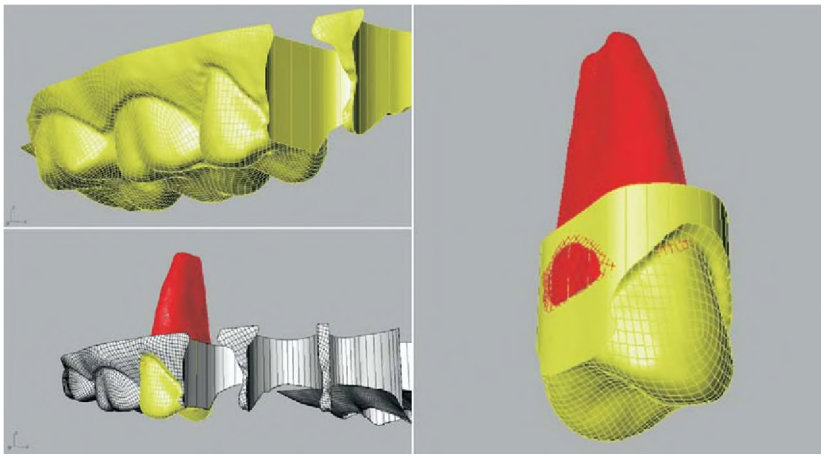

Fig 4. Merging of crown and anatomic roots of maxillary premolar.

The merging of 3D setups and CT scans gives valuable information about various areas of the dentition, such as the position of the maxillary incisor roots relative to the lingual cortical border of the palate to plan retraction or torque movements; the amount of bone in the posterior maxilla available for molar distalization; the amount of bone lateral to the maxillary buccal segments available for space closure, or dental or skeletal expansion; maxillary root proximity to the maxillary sinus; the 3D volume of an atrophied alveolar ridge; and the position of the mandibular incisor roots relative to the buccal cortical bone. This new procedure, allowing a 3D setup that displays crowns, roots, and craniofacial structures, can be of great help for the clinician in diagnosis and treatment planning to assess various treatment options, monitor changes over time, predict and display final treatment results, and measure treatment outcomes accurately. However, the software mentioned in this article does not perform the described steps automatically; significant user skill is required.

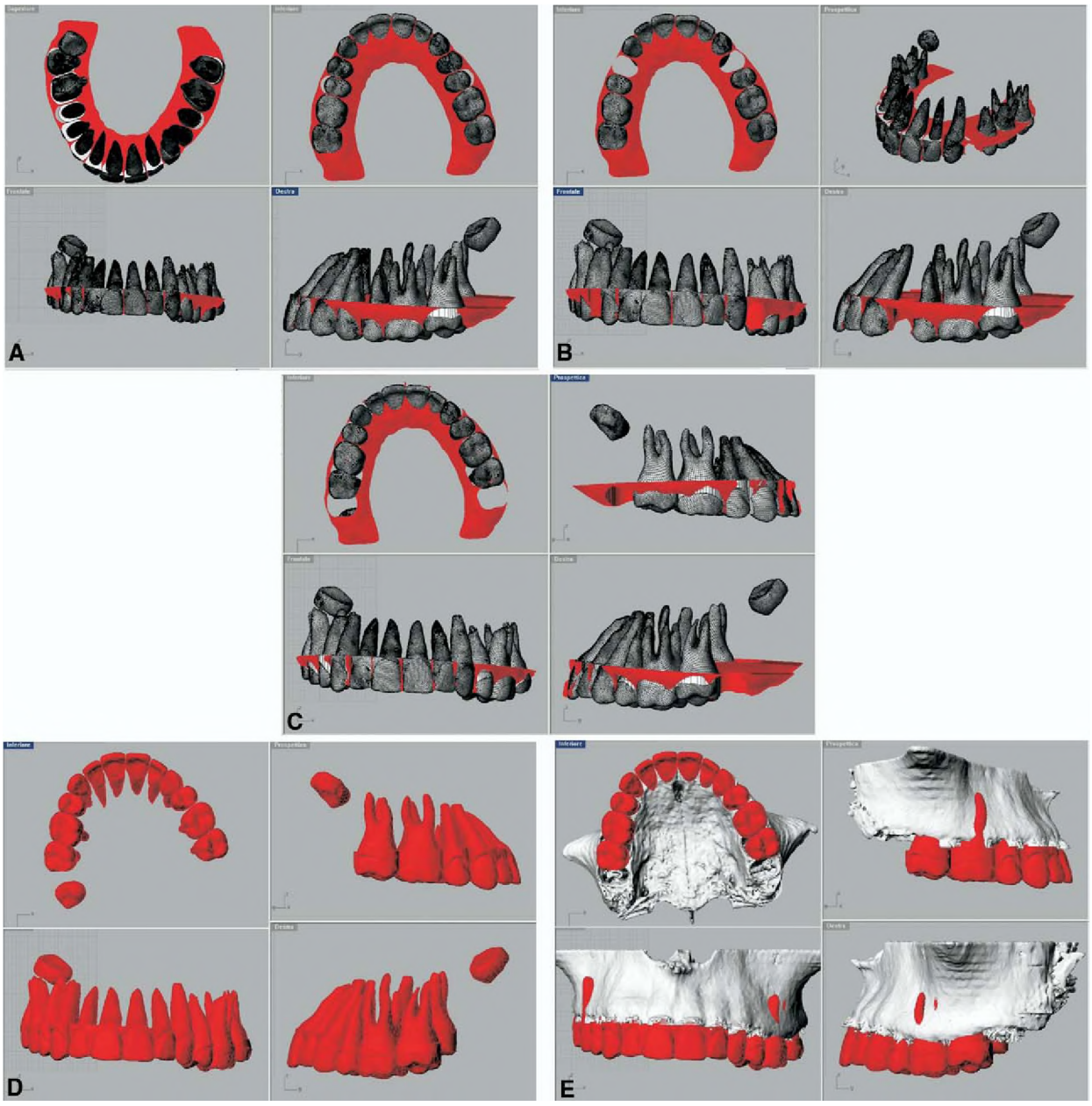

Fig 5. **A** and **B,** 3D setup simulating extraction of 2 first premolars; **C,** subsequent space closure; **D** and **E,** note aligned crowns and roots and their anatomic relationship with surrounding bone with possible fenestrations.

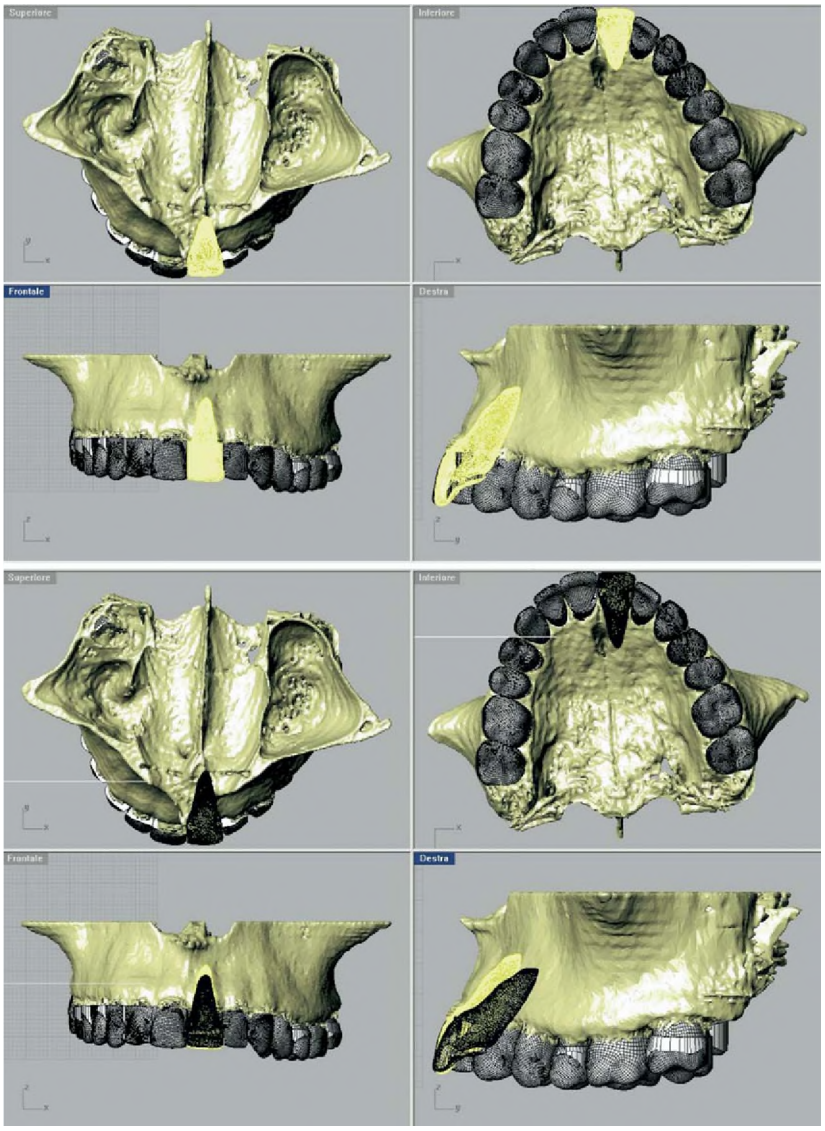

Fig 6. Simulation of torque movement of maxillary incisor.

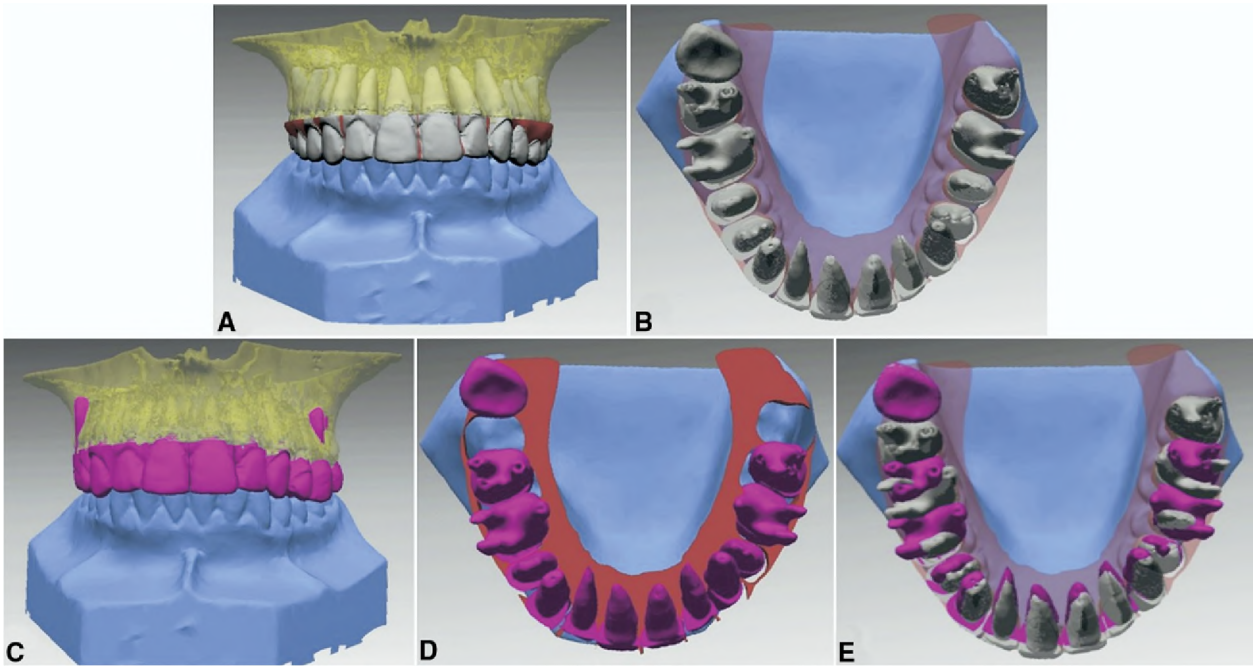

Fig 7. 3D superimposition of anatomic teeth. **A** and **B,** before, and **C** and **D,** after setup, to visualize amount of movement pretreatment and **E,** posttreatment.

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