3D Tooth Modeling for Orthodontic Assessment

J. Treil, J. Braga, J.-M. Loubes, E. Maza, J.-M. Inglese, J. Casteigt, and B. Waysenson

Use of three-dimensional (3D) imaging data from cone beam computed tomography (CBCT) together with the mathematical concept of axes of inertia permits characterization of three-dimensional (3D) geometry for discrete anatomical objects including teeth. A study was conducted to investigate this concept. With Institutional Review Board approval, the "axes of inertia" concept was applied to image data sets from a cohort of 205 subjects. Following analysis, this cohort was found to fit into 18 categories. Starting with a calculation based on tooth axes of inertia and dental arches morphology, 3D images were related to the 18 categories. Teeth and the dental arches were integrated into a 3D architectural model of the visceral skull using Cartesian coordinates of 14 anatomic landmarks. Axes of inertia are a mathematical tool for 3D modeling of discrete anatomical objects such as teeth, using CBCT image data bases. (Semin Orthod 2009;15:42-47.) © ***2009 Elsevier Inc. All rights reserved.***

"Plane geometry is unsuited to the analysis of an anatomical volume and to growth study." This aphorism of Delaire,[1] a French anatomist, led us to propose the use of a mathematical tool to characterize the three-dimensional (3D) geometry of anatomical structures such as teeth and jaws.

The transition from 2D to 3D biometry has been made possible by advances in digital imaging.[2] 3D image data can be saved in DICOM (digital imaging for communication in medicine) format. With this format, native data can be stored and transferred to be remotely processed through DICOM-conformant software, to create different types of image representations such as MPR (multiplanar reconstruction), MIP (maximum intensity projection), and 3D reconstructions using a variety of segmentation protocols.

In orthodontics and orthognathic surgery, the practitioner's concern is the quantification of malocclusions and to offer therapeutic outlines capable of correcting them. 3D imaging permits 3D biometrics capable of alleviating incoherence between malocclusion quantification performed with 2D skull radiography and their correction through the mobilization of anatomical elements in the 3D space.

Use of a 3D geometrical tool, novel in biology development, the "axes of inertia," allows determination of the spatial distribution of teeth and the architectural organization of the dental arches. For orthomorphic subjects, this architecture is generally characterized by balance and symmetry. The statistical study based on 205 subjects is compatible with evidence-based medicine as applicable to research with clinical applications.[3] The purpose of this article is to illustrate one use of cone beam computed tomography (CBCT) or medical computed tomography (MDCT), 3D image data within the domain of orthodontics.

Materials and Methods

The cohort of 205 individuals consisted of 123 females and 82 males, aged 13 to 65 years (average, 24 years). All individuals had 28 teeth (excluding third molars) and no sinus or maxillofacial pathologies. Use of anonymous digital data was authorized by the Institutional Review Board.

Characterization of 3D geometry of teeth and jaws was performed in two steps: (1) tooth segmentation from 3D image data sets; and (2) calculation of the

FRE 2960 CNRS Toulouse, UPS University III, Toulouse, France; Mathematics Institute of Toulouse, UPS University III, Toulouse, France; Carestream Health, Dental Systems, Marne-la-Vallée, France; Honorary Professor, Dental School Toulouse, UPS University III, Toulouse, France.

Address correspondence to: Dr. J. Treil, Service de Radiologie Clinique Pasteur, 45 Av. de Lombez, Toulouse 31300, France. E-mail: jtreil@free.fr

1073-8746/09/1501-0$30.00/0
doi:10.1053/j.sodo.2008.09.006

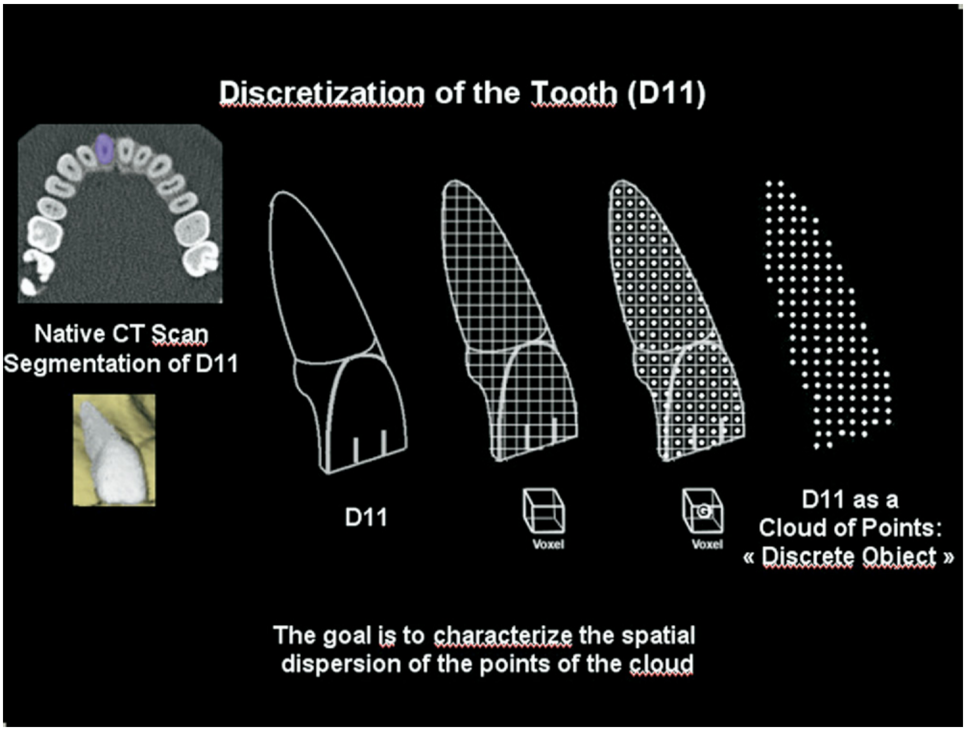

Figure 1. The right central maxillary incisor as a cloud of points: "discrete anatomical object." (Color version of figure is available online.)

axes of inertia for each tooth and group of teeth: the four jaw quadrants, the maxillary and mandibular arches. Teeth were selected and identified manually. To reduce the operating time, segmentation was performed each fifth image slice.

After segmentation of teeth, discrete anatomical objects (each tooth and group of teeth) are made up of voxels.

The aim was to find a relevant geometrical representation of the objects that would allow (1): quantification of the geometrical dispersion and shape of the objects, and (2) comparison of various image acquisitions of the same object and the same view of various objects. To simplify the calculation, each voxel was characterized by the values of the Cartesian coordinates, X, Y and Z, at its center of gravity. This allowed the discrete object to be represented as a cloud of points (Fig 1). The 3D geometry of the object was characterized by the dispersion of the points of the cloud, a value that was represented by the matrix of dispersion. The dispersion of the points of the cloud was characterized by calculation of the principal components axes (statistical approach) and by calculation of the axes of inertia (physical approach) using the matrix of dispersion. This resulted in a group of three axes, perpendicular to each other, linked to the cloud of points and revolving with it and for which the matrix was diagonal. For these three orthogonal axes, the dispersion of the orthogonal projection of the points of the cloud was maximal.

The principal components axes of inertia defined an ellipsoid that included more than 95% of the points of the cloud, in accordance with the Tchebycheff-Bienaymé theorem. The system was

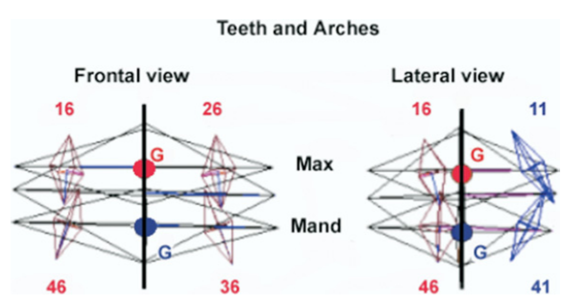

Figure 2. Axes of inertia of teeth 11, 16, 41, 46, (World Dental Federation, ISO 3950 notation) and maxillary and mandibular arches. Normal relationships: parallelism of the axes of inertia and location on the same vertical axis of the center of gravity of both arches on the frontal and sagittal projections. (Color version of figure is available online.)