Three-Dimensional Analysis of Changes in Location of Crowns and Root Apices of Maxillary Central Incisors

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Relocation of teeth in the dental arches may occur in response to various constraints. These force systems include growth of supportive bone, tooth eruption, interaction of inclined planes of opposing teeth, lateral forces derived from function of the faciolingual muscles, and the action of orthodontic mechanisms. The direction and extent of tooth relocation produced by these factors has traditionally been studied by serial radiographs and serial dental casts. However, current cephalometric techniques only provide two-dimensional data despite attempts to make stereoscopic radiography practical for routine use. On the other hand, dental casts give accurate three-dimensional information on changes in the position of the tooth crowns relative to each other. Yet traditional cast inspection gives little indication of changes in tooth crown position relative to "stable" structures in the supporting craniofacial skeleton. Moreover, there does not appear to be a published method for detailing the trajectory of the moved root apex relative to nondental landmarks although some techniques seem to have such potential.[1,2]

This paper describes a mechanism for correlating data from radiographs and dental casts to describe, in three planes of space, the direction and extent of maxillary incisor movement resulting from orthodontic treatment. The reference datum was a point in the palatal vault; movement of root apices and midincisal edges were determined relative to this datum point.

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Materials and Methods

For each patient the basic requirements for the analysis were: a) pretreatment and serial lateral cephalograms taken with conventional techniques; b) pretreatment and serial intraoral radiographs with radio-opaque markers placed on the tooth crowns; c) pretreatment and serial maxillary dental casts; and d) a system for graphic reproduction of dental cast contours.

A tracing was made of the pretreatment cephalogram in which the angulation of each upper central incisor was measured relative to a plane that ran from the distal cusp of the ipsilateral maxillary first molar to the incisal edge of the maxillary central incisor (Fig. 1). This was designated the "incisal-occlusal" plane.

The intraoral radiographs were taken with a Rinn holder which ensured that the film was at right angles to the central beam of the X-ray. Prior to exposing the film, lead markers were affixed to the labial enamel near the gingival margins, and the distances from midincisal edges to the centers of the markers were measured intraorally. It was thereby possible to calculate from the radiograph the actual length of the tooth from midincisal edge to root apex. Additionally, these radiographs were used to determine the angulation of the long axes of the teeth to each other and to the midsagittal plane.

The midpalatal raphe on each den-

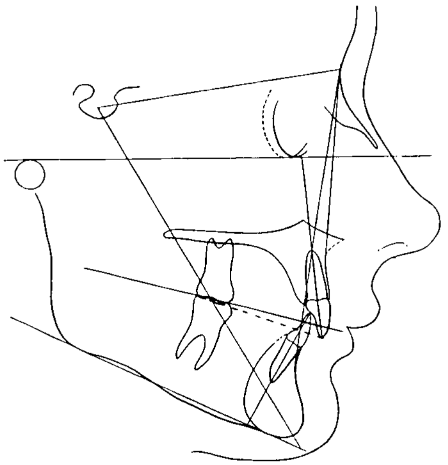

Fig. 1 Cephalometric tracing showing "incisal-occlusal plane" (broken line). This plane was chosen in preference to the traditional "occlusal plane" (solid line) since the "incisal-occlusal plane" is more readily defined on a dental cast and such definition was essential to the construction of the locating block depicted in Figure 2.

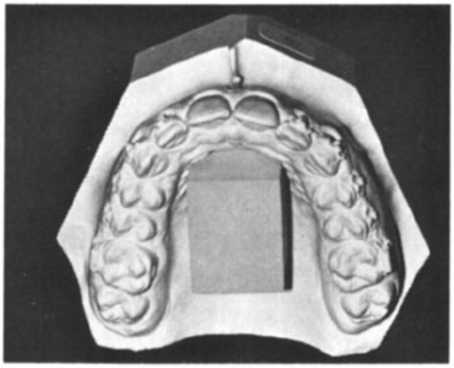

Fig. 2 Plaster locating block covering part of the palatal vault. The extremities of the block were determined by landmarks described in the text. Since the anatomical surface covered a stable area, the locating block made on the pretreatment cast would also fit all subsequent casts of a series taken during the course of treatment.

tal cast was identified and the second rugal ridge on the right marked. This was a necessary prerequisite to constructing a removable locating block that covered the area immediately adjacent to the posterior rugae and the posterior part of the midpalatal raphe. Lebret's[3] studies indicate that this area of the palatal vault remains stable after the deciduous teeth have been shed. The locating block was constructed as follows: A fine rod was placed on the tips of the distopalatal cusps of the maxillary first molars. A perpendicular was dropped from this rod to the midpalatal raphe, and a mark was inscribed on the cast. This mark was used to determine the distal extremity of a plaster locating block made to fit the vault of the initial cast. Since it covered an anatomically stable area, it fitted all subsequent casts of a series for an individual (Fig. 2). The flat upper surface of the locating block, when fitted to the pretreatment cast, was trimmed to coincide with the incisal-occlusal plane already defined. The front surface of the block (perpendicular to the incisal-occlusal plane) was in register with the maximum prominence of the second rugal ridge of the right as already defined. The point at which the front surface of the block intersected the midpalatal raphe was designated "cast zero." This point could be established on any cast of a series for a given individual.

In the initial stages of this investigation an examination was made of the problems involved in graphing tooth contours. Potentially suitable methods include mechanical contour tracers,[4,5] photostatic[6] and radiographic[7,8] techniques, photogrammetry,[9] and mathematical printouts from optical scanners.[2] For our purposes the electronic contour tracer, described simultaneously in 1972 by Atkinson and Grant[10] and Erikson,[11] was the most suitable system, inasmuch as it employed the very high resolution and stability of linear voltage displacement transducers to produce an immediate graphic readout at any desired magnification on the traced surface. In this system a dental

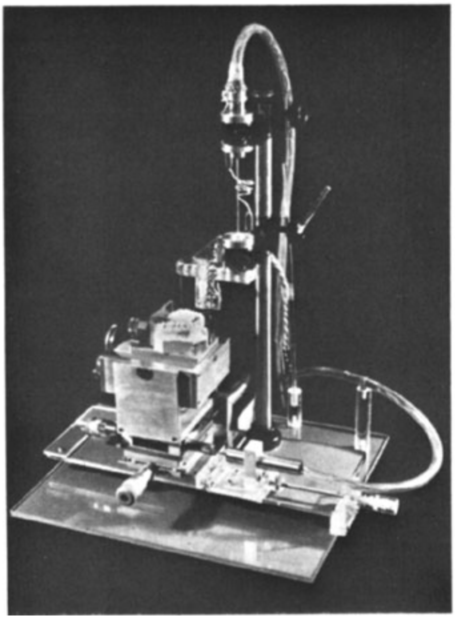

Fig. 3 Apparatus used to orient pretreatment cast and to reproduce this orientation for all casts of a series for an individual. Additionally, signals from the electrical sensors operating in the three planes of space were used to graph central incisor contours relative to the datum point (cast zero).

cast was clamped in a special universally jointed platform. Transducers were aligned relative to the base of the platform in the x, y and z planes (Fig. 3). The platform was movable in the x-y plane and could also be independently rotated in azimuth, pitch and roll. The cast to be examined, together with its locating block, was clamped on the platform and adjustments were made to align the incisal-occlusal plane and the midpalatal raphe to the x and y axes. The vertical shaft carried an electrically conductive probe which was used to make a series of point contacts with the cast in the z-axis. (Interchangeable sickle-shaped or straight probes were used depending on the contour being traced.)

To orient the pretreatment dental cast the platform was moved so that "cast zero," as defined, coincided with the tip of a straight probe in all three axes. The displacement transducers (x, y and z) were electrically nulled to this point. Thus the pretreatment cast was placed in a reproducible frame of reference. Since the locating block covered an area which was anatomically stable, any cast taken subsequently could be oriented in three planes of space relative to the initial frame of reference. These instrument frames of reference were graphed by connecting an x-y recorder to the transducers. Cast contour analysis was commenced by making a dotted line (Fig. 4) from a series of contacts between cast and sensing probe, starting at the distal contact point of a maxillary central incisor, running up and across the middle of the incisal edge and down to the mesial contact point. On the graph the lines that joined the contact points were bisected. At the points of bisection perpendiculars were drawn to give the midpoints of the incisal edges (MR and ML). These graphic definitions of the midpoints were then translated, via the transducers, back to the cast. The maxillary incisors were marked appro-

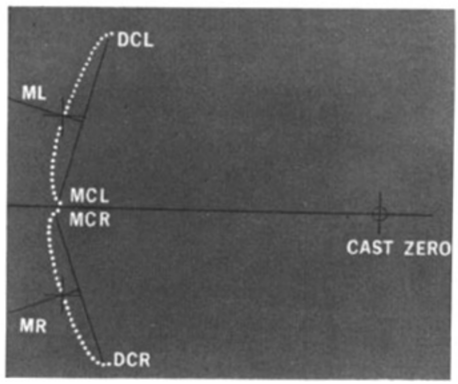

Fig. 4 Diagrammatic representation of incisal edge contours graphed on x-y recorder produced by manipulation of position sensors shown in Figure 3. The midpoints of the incisal edges (ML and MR for left and right, respectively) were determined from perpendiculars bisecting the lines (DCL-MCL and MCR and DCR) connecting the left and right contact points of the teeth.

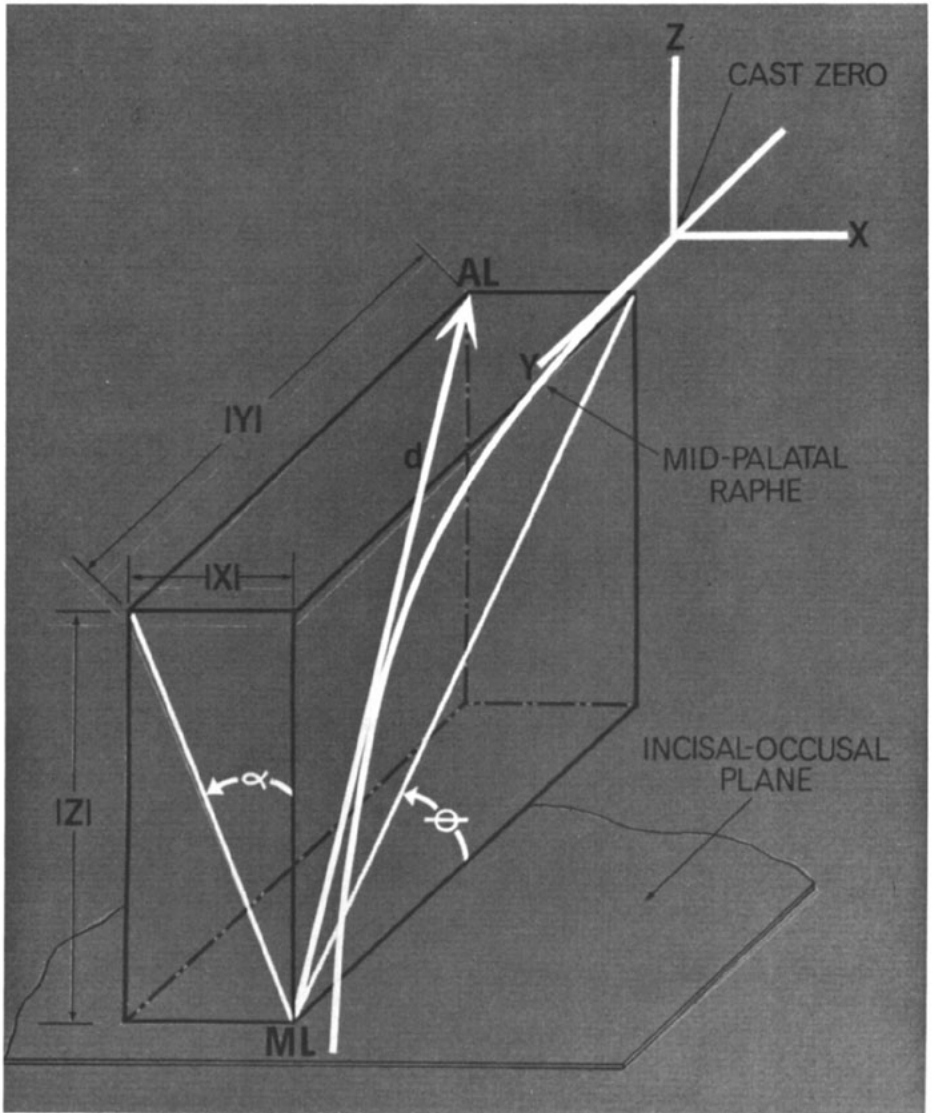

Fig. 5 Three dimensional orientation of long axis of tooth (ML-AL for the left central incisor) relative to "cast zero" (the datum point to which all changes in position of teeth were related).

priately. Thus the incisal edge midpoints, relative to cast zero, were defined in x, y and z coordinates. (Fig. 5 shows ML so defined.)

With reference to Figure 5, having determined the position of ML (the left incisal midpoint) in relation to cast zero, the position of the left root apex, AL, relative to cast zero, could be determined if the following quantities were known:

a) the angle between the long axis of the tooth and the incisal-occlusal plane (θ),
b) the total length of the tooth ML to AL,

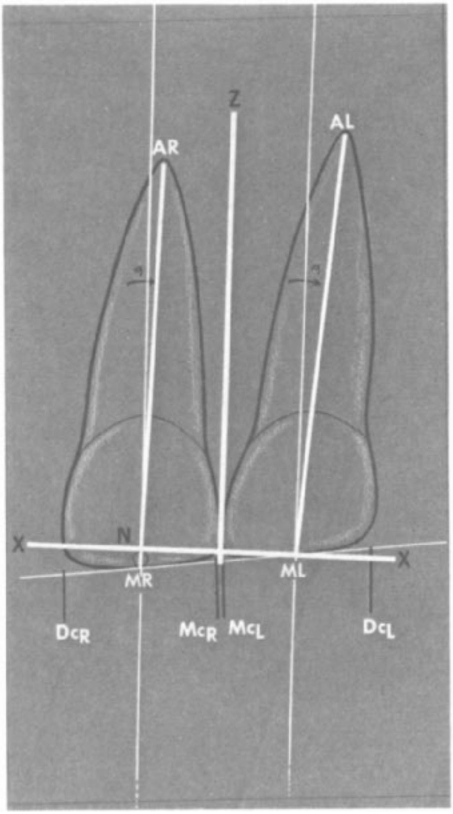

Fig. 6 System used to calculate the divergence (angles α) of the long axes of the teeth (ML-AL and MR-HR for left and right incisors, respectively) from the plane of the midpalatal raphe.

c) the frontal angulation of the teeth to the midpalatal raphe, α.

Considering these in sequence, the angle θ was obtained from the lateral cephalogram by relating the long axes of the incisors to the incisal-occlusal plane (Fig. 1).

The total length of the tooth (ML to RL) was derived from the frontal intraoral X-rays by a separate series of calculations. The amount of foreshortening or elongation on the radiographs was calculated by comparing the distance from the incisal edge to the lead marker *in vivo* with the corresponding radiographic dimension.

The angle α was determined as follows. A slide was made from the midsagittal intraoral radiograph of the central incisors. It was projected onto a sheet of paper. The enlarged outline of the tooth was traced, and the left and right root apices (AL and AR) were identified as well as left and right incisal edge midpoints (ML and MR) as previously defined. These latter points were joined by straight lines (Fig. 6). From previous calculations the co-ordinate positions of the incisal edge midpoints were known relative to the x-z frame of reference. Therefore, by drawing on the projection paper the x-z planes in their correct relation to the incisal midpoints, the divergence of the long axes of the teeth from the z plane could be measured. These readings were the angles α for the left and right incisors.

Thus requirements (a), (b) and (c) above were met, and the positions of incisal edges and root apices, relative to the palatal reference datum point (cast zero), could be calculated. The effectiveness of orthodontic treatment in producing movement of the incisal edge and root apex was thus determinable for any stage of treatment for which appropriate casts and radiographs were available.

Results

Changes in tooth position that occurred in a 20 week period during the course of correction of a Class II, Division 2 malocclusion are shown in Figure 7. At the commencement of this particular treatment stage the midlines exhibited displacement to the patient's left; there was a slight diastema between the central incisors; the incisal edge levels were not coincident.

During this treatment period two round archwires (.018" and later .020" diameter) were used in .022" rectangular slots. Both archwires incorporated Warren-type torquing loops; "Alastik" chains with appropriate anchorage

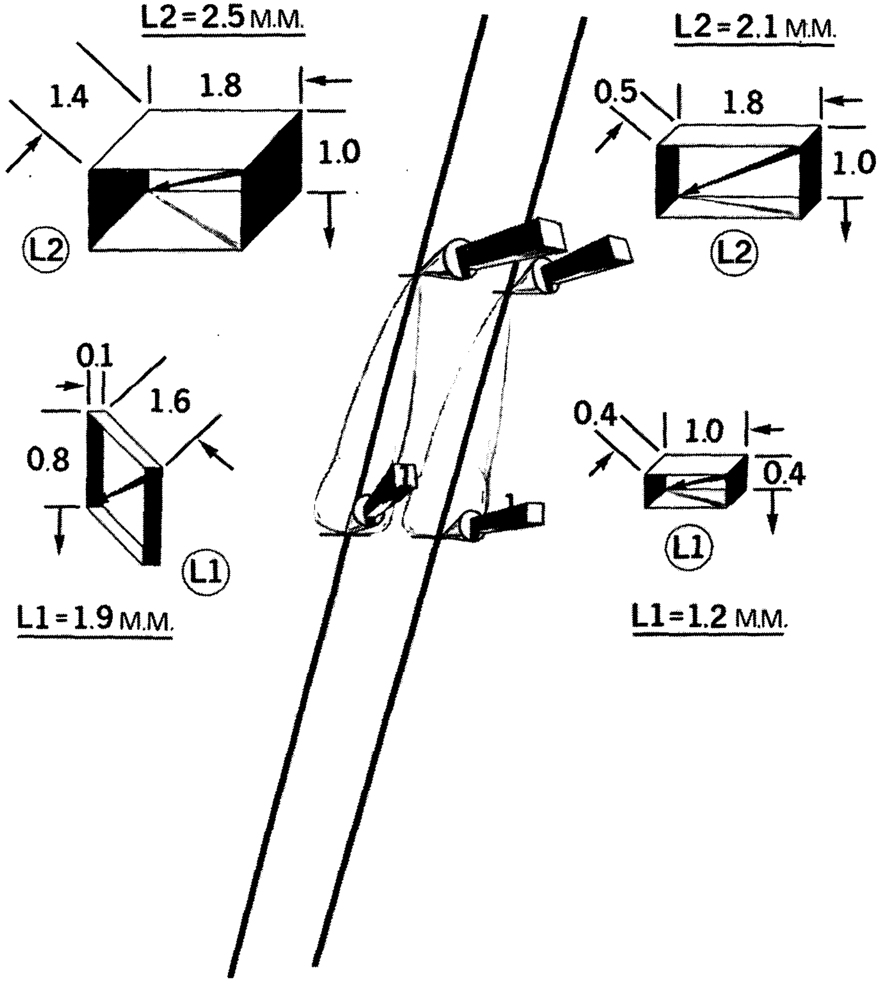

Fig. 7 Diagrammatic representation of root apex and incisal edge movements during one segment of the treatment of a malocclusion. The cone-and-rod arrows at the apices and incisal edges indicate the course and extent of the movements. The boxes show a breakdown into linear components in three planes. It should be remembered that all measurements relate to changes relative to the "cast zero" (see text).

were employed for midline shifting and for space closure.

The three dimensional analysis showed that, relative to the pretreatment positions of incisal edges and root apices, the following movements occurred: there was uniform movement of root apices to the right (1.8 mm); unequal amounts of lingual root apex torque (left 0.5 mm, right 1.4 mm); equal amounts of apical extrusion (1.0 mm); total palatal movement of apex through bone was greater on the right (2.5 mm) than the left (2.1 mm).

Incisal edge movement of the left incisor was much greater (1.0 mm) than the right incisor (0.1 mm) thus closing the diastema but not relocating the midline significantly; the incisal edge of the left central incisor was retracted significantly more (1.6 mm) than the right (0.4 mm); the incisal edges of the two teeth were made more nearly coincident in the horizontal plane by an extrusion of 0.8 mm of the right incisal edge as against an extrusion of 0.4 mm of the left incisal edge.

Summary

A method has been described for analyzing the direction and extent of movement of root apices and midpoints of the incisal edges of maxillary central incisors. The system permits a detailed examination of the effectiveness of any orthodontic technique in relocating maxillary incisors and is particularly useful in determining the efficacy of "torquing" mechanisms.

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