Computerized Diagnostic Setups and Simulations

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The successful integration of two-dimensional diagnostic records into a three-dimensional predictive model has been one of the outstanding goals of the dental profession. Brodie,[4,5] Wylie and Elsasser,[12] Vogel,[13] Richardson and Brodie,[9] and Lude[7] have made significant contributions to research in this area. While skeletal variations must be determined from oriented lateral and anteroposterior radiographs or pantographs, dental variations must be assayed from carefully prepared study models.

The purpose of this paper is to present a preliminary report of ongoing research related to the development of a three-dimensional predictive model that will incorporate two-dimensional diagnostic data into a synthesizing and simulating computer program. The present paper will describe the first phase of this research, a two-dimensional mathematical model for representing the major anatomical landmarks on the occlusal surfaces of the postcanine dentition, and some rather primitive computer simulations of orthodontic procedures. OSCOPO is a computer program for the oscilloscopic simulations for correcting, orthodontically, problems in occlusion.

This is a computerized approach to a consideration of the analysis and predictive corrections in orthodontic treatment procedures. It is based on a two-dimensional representation of the upper and lower dentition as photographed from an occlusal (or crown-surface) view. Involved is a computer directed realignment, in the transverse and anteroposterior planes, of the individual units of the dentition in terms of the *esthetic harmony* of the dental arch.

In substance, OSCOPO is the computer method for measuring, analyzing and evaluating the dimensional vectors involved in orthodontic correction. It is a visual method for realigning the dental elements involved in the translation from a malocclusion to a "normal" occlusion in the individual case.

MATERIALS AND METHODS

Certain pits, fissures, and cusp tips are common to the occlusal morphology of any premolar or molar.[3] Moreover, the basic hypotheses of this model assume that these occlusal landmarks of the maxilla and the mandible are highly correlated[6] and that certain selected anatomical landmarks can outline the occlusal, incisal and/or lingual surfaces of the individual components of the dentition. Moreover, these hypotheses suggest that the selected anatomical landmarks can be used to describe the type of occlusion or malocclusion. For example, the relationship of the tip of the protocone (mesiolingual cusp) of the permanent maxillary first molar to the central fossa of the permanent first mandibular molar is an accepted criterion of good occlusion.

The conversion of definable anatomical landmarks on the anterior and posterior teeth of dental casts is accomplished by recording their location as small India ink points.[2] (A Staedler Mars 700 pen with a 0.1 millimeter point is used for this purpose.) The maxillary cast is then mounted on a dental surveyor table

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and adjusted in such a way that the occlusal plane is level. A piece of one-fourth inch plexiglass, on which is inscribed fiducial marks and an orientation line, is placed on the incisal and occlusal surfaces in such a way that the orientation line forms a line of best fit to the median raphe of the maxilla. The distance between the two fiducial marks (a known dimension) is used to correct for small deviations in the size of the photographic image. The anterior segment of the orientation line is adjusted to a mark on the lingual surface of a maxillary incisor which demarcates the most anterior limits of the mandibular central incisors.

The mark delimiting the most anterior limits of the mandibular dentition is determined by fitting the dentitions of the maxillary and mandibular casts together in such a way that the usual occluding relationship for the individual is manifest. The labial surface of the most anterior mandibular central incisor is then extended to and recorded on (using a thin, sharp, straight instrument) the lingual surface of the opposing maxillary central incisor or, in some instances, on the palatal mucosa. The anterior and posterior relationship of the orientation line which forms the best-fit line to the median raphe is recorded on the posterior edge of the maxillary cast and on the labial or incisal surface of the appropriate maxillary central incisor (oftentimes on the incisal aspect of the contact area of the two maxillary central incisors).

The image of the fiducial marks, the orientation line, and the anatomical landmarks (India ink marks) are then recorded on a photographic plate using a 4 × 5 Crown Graphic camera. The camera, with duplicates of the orientation line and fiducial marks recorded on the ground glass view screen, is adjusted in such a way that an approximate 1:1 relationship of the image photographed and the photographic image is achieved, but the final dimensions are adjusted to the known fiducial parameter. The dentition of the mandibular cast is again fitted to the dentition of the maxillary cast so that the subject's usual occluding relationship exists while the occlusal plane of the maxillary dentition is still level and mounted on the surveying table of the dental surveyor. Perpendiculars projecting from the anterior and posterior marks representing the extensions of the midsagittal plane are erected (using the vertical arm of the surveyor) and are recorded at a convenient place on the labial surface of a mandibular incisor and on the posterior surface of the mandibular cast. In this way the line representing the best-fit line of the median raphe of the maxillary cast is transferred to the mandibular cast. Thus, the anteroposterior and lateral relationships of the maxillary and mandibular anatomical landmarks are preserved. The mandibular cast is then adjusted and photographed in the same manner described for the maxillary cast.

The anatomical landmarks of the maxillary and mandibular dentitions are recorded as X and Y (Cartesian) coordinates. These coordinates are recorded on Hollerith cards using the Image Plane Digitizer, an auxiliary data processor control console, and an IBM 526 summary card punch. The Cartesian coordinates from the data cards are then recorded on a magnetic tape. The instructions provided by OSCOPO convert the two independent coordinate systems of the maxillary and mandibular dentition into a common coordinate system, and cause the representation of these anatomical landmarks and/or outlines of the occlusal and lingual surfaces to appear on the screen of an oscilloscope in the usual occluding relationship of the patient (Fig. 1a).

The image of a posterior tooth consists of: (1) points that describe anatomical landmarks, and (2) a series of

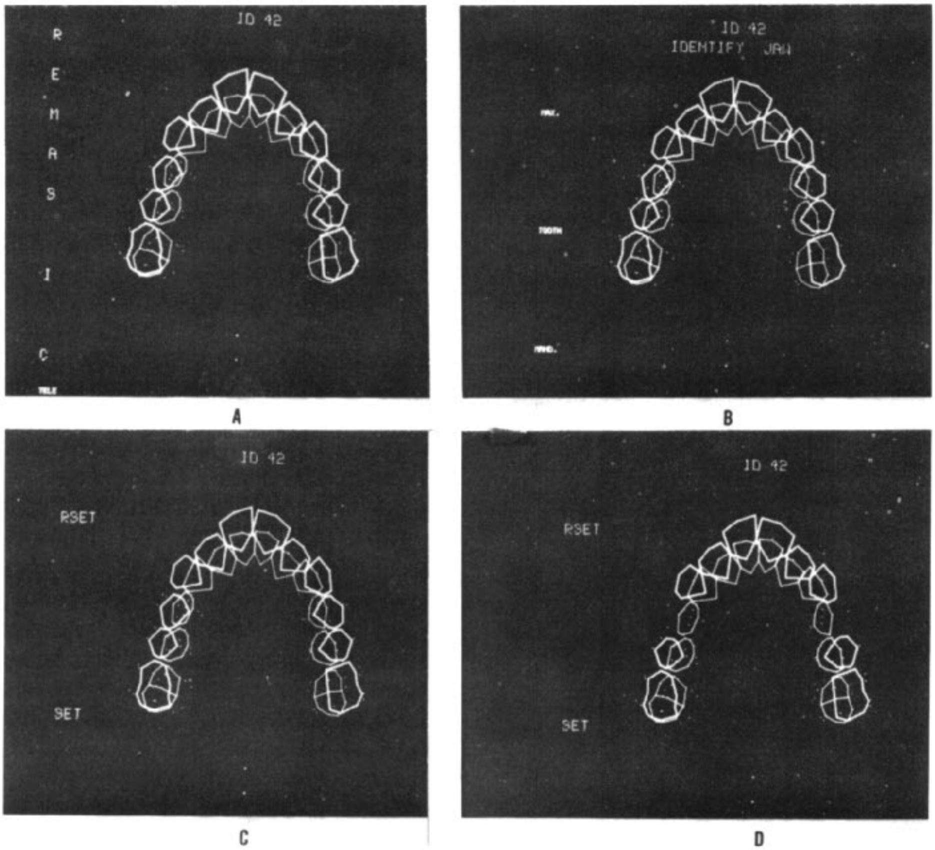

Fig. 1 (a) The "top view" or occluding view of the outlines of the maxillary and mandibular dentitions. The outlines of greater intensity are related to the maxillary dentition. The lingual and incisal surfaces of the anterior teeth are outlined by vectors connecting six points; the occlusal surfaces of the posterior teeth are outlined by a variable number of points representing the anatomical landmarks on the periphery of the occlusal surfaces. At the top is the identifying number of the cast. On the left side are code letters controlled by the penlight: R—controls rotational simulations; E—erasure or "extraction" simulations; M—translational simulations; A—causes erased images to reappear in their original position; S—causes the entire system of newly generated coordinates related to the teeth to be recorded on magnetic tape; I—reinitialized the display to conform to the original input data; and C—causes the magnitude and direction of the last simulated movement in degrees rotated or millimeters moved to be typed on the teletype. The code word "Tele" transfers control from the penlight to the teletype.

(b) When activated by the penlight, the code word "tooth" allows the operator to identify the appropriate tooth or tooth group in the proper arch. This procedure of identification is necessary before simulations of erasure or movement can be accomplished. The units of the entire maxilla or mandible may be identified by activating the code words "max." or "mand." respectively.

(c) The code word "SET" when activated by the penlight permits the computer to act in the preselected mode of simulation, i.e., rotation translation or erasure, on the tooth or tooth group previously identified. "RSET" permits corrections in identification or, if the computer is in the mode for translation, it allows an immediate transfer to the rotational mode.

(d) The extraction, "erasure", of two maxillary first premolars.

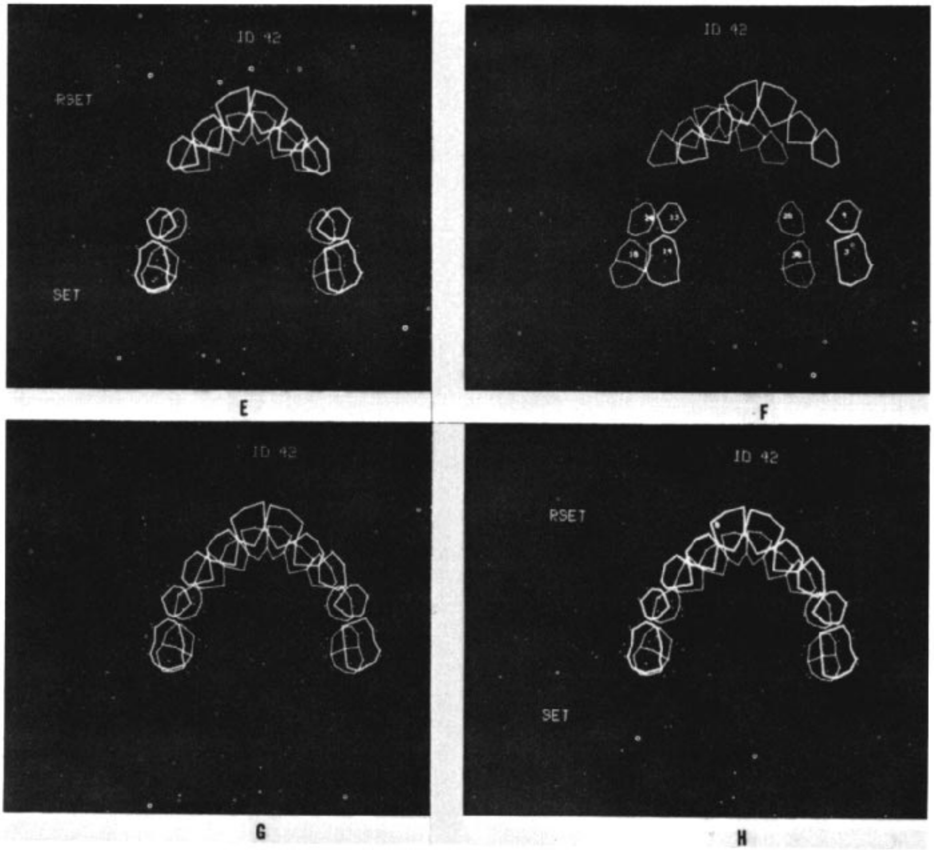

Fig. 1 (continued) (e) The extraction, "erasure", of two mandibular first premolars.

(f) The identification of all maxillary and mandibular molars and premolars prior to translating them into the space created by the extracted premolars. Note that all teeth are identified by numbers according to the Universal system of dental nomenclature. The entire maxilla is translated so that the identifying numbers are more easily visualized.

(g) When the code word "SET" is activated, the "tracking cross" appears. The "tracking cross" follows the movement of the penlight causing the identified group of teeth to translate according to the path of the cross. X and Y coordinates are typed on the teletype to effect translations with this particular device. Note that the posterior teeth have moved *en masse* to a new position.

(h) The identification of tooth number 9, the left maxillary central incisor prior to rotating.

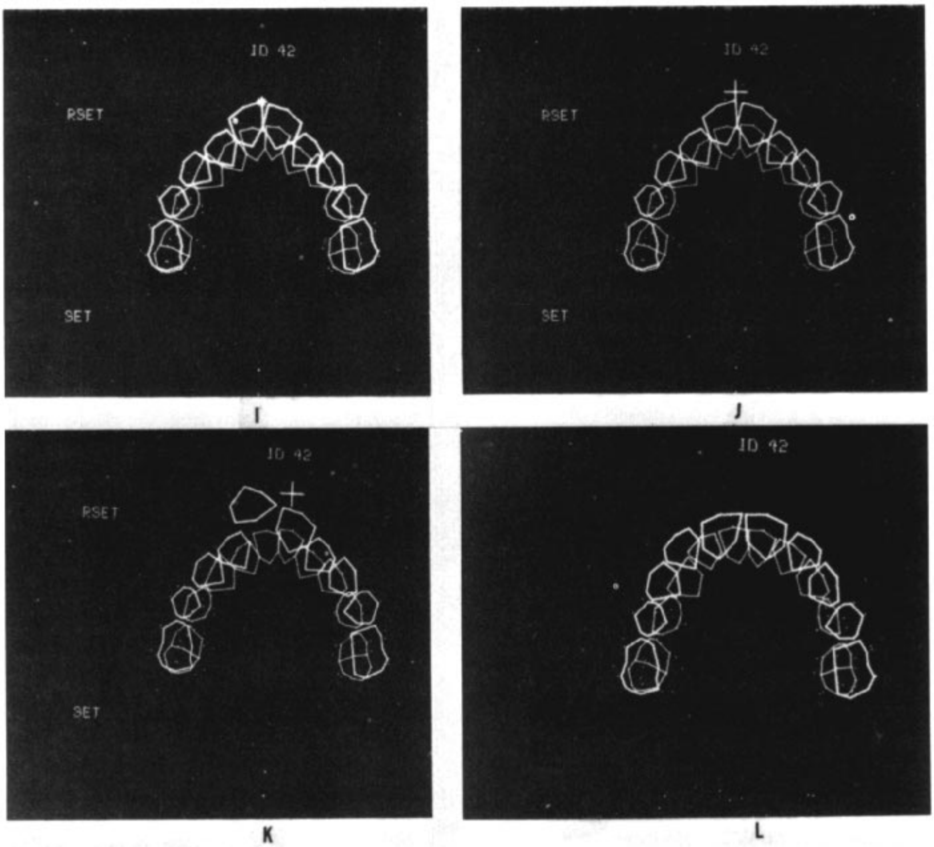

Fig. 1 (continued) (i) The fixation of the axis of rotation on the left maxillary central incisor. The asterisk appears after the activation of the code word "SET". The asterisk is positioned with the penlight at the desired point of rotation.

(j) The activation of the code word "SET" causes the "tracking cross" to appear which will follow the path of the penlight causing the target teeth to rotate in the direction and magnitude of the "tracking cross."

(k) An exaggerated rotational movement of the maxillary left central incisor about the point of rotation.

(l) The "top view" of the maxillary and mandibular dentition after simulated extractions, rotations and translations. These simulations have involved a majority of the teeth and are presumed to mimic certain orthodontic procedures. See text for limitations and compare with Figure 1a.

connected vectors which outline the occlusal surface of the tooth as projected to the occlusal plane. The image of an anterior tooth consists of a series of vectors connecting points that outline the incisal surface, points that describe the maximum mesiodistal diameter, and a point that describes the most gingival extent of the lingual surface (Fig. 1a).

Standard rotational and translational formulae were incorporated into OSCOPO to cause these simulations.

Results

OSCOPO, then, gives a "top view" of the tooth images of the mandibular and maxillary dental casts as projected to the occlusal plane while recording the patient's usual occluding relationship. Other portions of the program permit translational, rotational, or erasure simulations of the image of a tooth or group of teeth changing the occlusal pattern as originally seen on the dental cast or oscilloscope. These changes can be effected by providing particular information through three operational modes: (1) the *control mode,* (2) the *identification mode,* and (3) the *incremental mode.*

The teletype and the penlight are used to transmit the necessary information controlling the operational modes. The penlight is the more versatile input device. Coded information in the form of letters and words is provided on the left side of the oscilloscope (Fig. 1a). The activation of the penlight over one of these code images causes the computer to recognize that particular set of coded instructions. In order to manipulate an image on the oscilloscope the computer must initially be in the control mode.

The control mode is used to accomplish the following: (1) to reinitialize the display ("I", Figure 1a), restoring the original display to the screen without registering any previous manipulations; (2) to save ("S", Figure 1a) the display data on a magnetic tape so that it can be utilized at another time for the purpose of redisplaying, observation, making photographs or to determine the amount of change in the location of any anatomical landmarks; (3) to obtain a type-out ("C", Figure 1a) recording the magnitude and/or direction of the last manipulation; (4) to command the computer to erase an image ("E", Figure 1a); (5) to cause erased images to reappear ("A", Figure 1a); and (6) to inform the computer that one desired to translate ("M", Figure 1a) or rotate ("R", Figure 1a) an image. "Tele," when activated, transfers control to the teletype.

To manipulate a tooth image or a group of tooth images the computer must be transferred from the *control mode* to the *identification mode.* Then it is necessary to identify the tooth or the teeth needed for the manipulation procedure. (See Figures 1b, f, and h). This is accomplished by pointing the penlight directly over a point on a tooth or by typing in the tooth number on the teletype. The tooth number immediately appears on the screen of the oscilloscope indicating that the tooth has been identified by the computer. (See Figures 1f and h). If a tooth is mistakenly identified, one may correct the situation by activating the code word "RSET" (Figures 1c, d, e, h, i, j, and k). All of the tooth images of the maxilla or mandible may be identified by activating the code words "max" or "mand" which also appear on the screen, Figure 1b. Once the identifications are completed, control may also be transferred to the increment mode by activating the code word "SET" (Figures 1c, d, e, h, i, j and k).

The *increment mode* controls the magnitude and direction for the movement of the identified tooth or tooth group. Using the penlight one may translate a tooth or group of teeth by "pushing" a "tracking cross," that appears on the screen after the activation of the code word "SET" with the penlight, Figures 1g and i. The image will therefore undergo the same magnitude and direction of movement as the tracking cross. The teletype may also be used for this manipulation simply by typing in the X-Y analytical coordinates of the translation. One may manipulate by rotation by initially identifying the object tooth or tooth group, after which the axis of rotation is fixed, Figure 1j. This is accomplished by placing the "asterisk" that appears on the screen after giving the rotational and identification commands. The penlight is useful for placing this asterisk at the desired point of rotation, then by activating the code word "SET" the "tracking cross" appears which will follow the course of the penlight causing the identified tooth or tooth group to undergo the same angular displacement about the rotation axis as does the "tracking cross," Figures 1i and 1j. OSCOPO provides the operator with the capability of alternating the use of these two types of movements, i.e., translation or rotation. For example, if one had completed a rotational manipulation and desired to translate, one need only to activate the code word "RSET" to change from a rotational type of manipulation to one of translation or vice versa. To return to the control mode one needs only to activate the control word "SET".

Discussion

OSCOPO represents a synthesis from prior research efforts[1,10,11] in an attempt to adequately evaluate the size and shape[8] of the individual dental units.[2,3] It is to be a component of a future and larger program that will incorporate skeletal and myofunctional variations as related to occlusion or malocclusion. The present model crudely and primitively moves, by translation and rotation, individual tooth units into relationships that tend to be esthetically ideal. OSCOPO expresses no consideration to the question of stability or the individual's biological limits of movement. This consideration must come with continued experimentation.

While OSCOPO, in its present form, actually simulates rotational movements, the translatory movements seen on the oscilloscope are not the same as those observed in the biological state. A tooth is a three-dimensional object, and when it is moved one must discriminate between a movement that is achieved as a total "bodily movement" and one that is the consequence of a "tipping movement." OSCOPO does not have the potential for discriminating between these two types of movements, nor can it distinguish between apicoincisal (occlusal) or tilting movements. It does, however, represent graphically the end result of movement procedures in the two defined planes of space.

One might argue that many of the same effects achieved by OSCOPO may also be reproduced through standard techniques where the teeth are removed from the cast and waxed into a new position (perhaps prior to making a new cast). The latter technique suffers from a loss of tooth structure and because accurate measurements can not be made within or between the dental arches. OSCOPO maintains the original data and the "Save" command allows the instantaneous storage of newly generated information for later use. In this respect, this model becomes a powerful tool for teaching in that different tooth positions pertaining to the same case can be observed or compared at any time by using photographs or by on-line transmissions.

A modified version of OSCOPO can

use the great potential of the computer in determining, statistically, the range of variation for a particular "type" of occlusion. For example, consider the tremendous range of variation that exists in one "type" of malocclusion (Angle Class II, Division 1). The analysis of the spatial deviations observed between specific anatomical landmarks located on the occlusal surfaces of mandibular and maxillary dentitions would redefine, possibly using more acceptable criteria, normal occlusion and/or malocclusion.

OSCOPO exemplifies a way of managing a large body of diagnostic data in a variety of ways. More importantly, the relationship of each tooth to any of the other teeth in the dentition can be quantitatively assayed in terms of linear or areal dimensions. Thus, the quantitative comparison of tooth material becomes a reality as does the appraisal of the tooth-arch dimension relationships. These relationships, evaluated in this manner, will probably be of greater biological significance than many of the constructed assays.

The writer envisions that OSCOPO will become a part of a larger and more sophisticated computer program that will incorporate a variety of diagnostic data obtained from oriented radiographs, dental casts, pressure readings, and muscle function. The incorporation of such data into a mathematical model will permit, ultimately, the prediction of the expected growth processes from the initial observation (T_1) to a future point in time (T_2). Such a predictive model will be of utmost importance to the clinician because these programs will permit an almost instantaneous analysis of the pertinent morphological features, say at maturity, with and/or without orthodontic intervention. The incorporated statistical model will permit the analysis of the morphological features at any age level with a stated level of probability. More importantly, this tool will advance interceptive orthodontics and permit the initiation of treatment procedures (where indicated) at the earliest effective age. Further, this model may elucidate the treatment procedure that will yield the maximum result, in terms of esthetics, function, and stability, in the minimum time.

While the long range goals *vide supra* may seem farfetched, there are immediate clinical applications for this tool. For example, this model is sufficiently accurate and sensitive to resolve the controversy related to the use of light wire, as opposed to heavy wire, and the relative efficiency of each in effecting tooth movement. Heavy wire imparts a firm pressure upon the tooth or teeth over a short period of time. In contrast, light wire imparts delicate forces on to the tooth or teeth over a relatively long time period. This problem may be resolved quickly and in the very near future.

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