CASE WESTERN RESERVE UNIVERSITY

GRADUATE STUDIES

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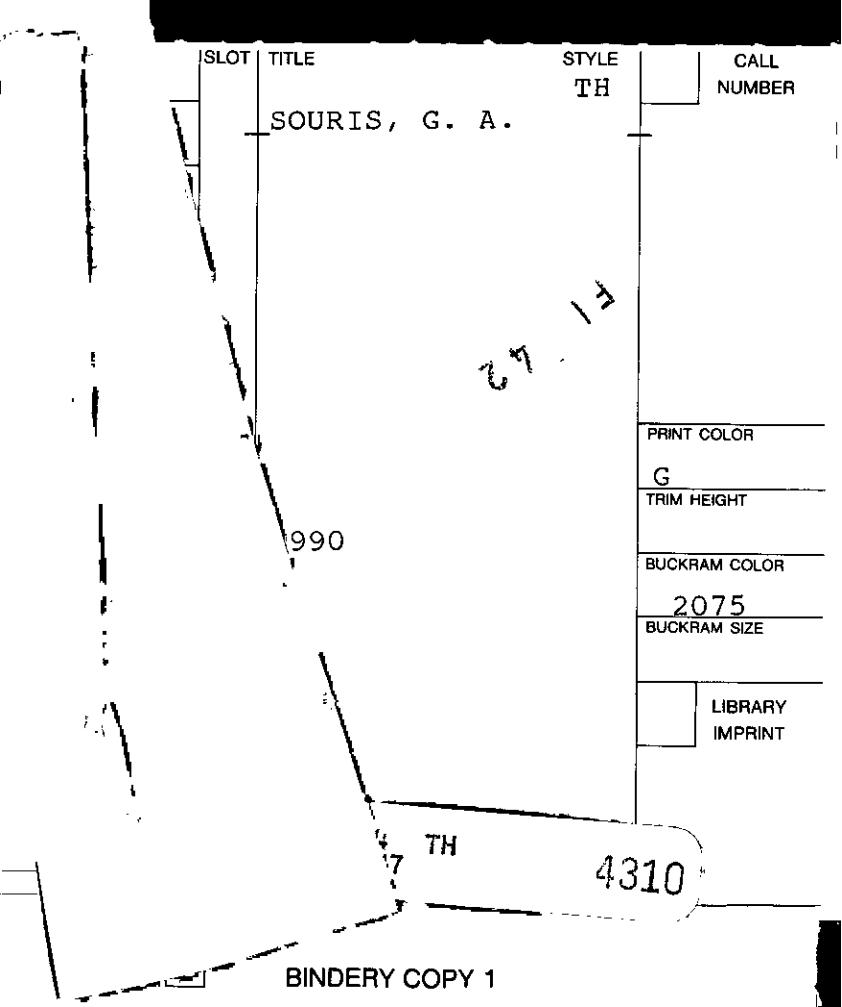
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THIRD MOLAR ERUPTION PREDICTION

A THESIS

Presented to the Faculty of

Case Western Reserve University School of Dentistry

at Cleveland

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE IN DENTISTRY

Department of Orthodontics

by

George Andrew Souris, B.A., D.D.S.

Cleveland, Ohio

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Third Molar Eruption Prediction

Abstract

by

George Andrew Souris, D.D.S.

The purpose of this investigation was to determine the predictive ability of positional changes in the mandibular third molar measured relative to progressive stages of root development. Previous predictive models have focused on linear or angular measurements made relative to chronological age or other components of the craniofacial complex. The present study utilizes angular measurements and ratios developed to account for the angulational uprighting as well as the vertical changes which occur during eruption of the mandibular third molar. Previous literature has demonstrated that these two aspects of mandibular third molar eruption are independent processes, and one movement may occur without the other. The predictive parameters developed in this study address both aspects of mandibular third molar eruption (angulational uprighting and vertical changes relative to the occlusal plane), and they are quantified at the various stages of root development of each tooth ("tooth's age"). This approach allows positional standards to be developed at each stage of root

development, and the predictive ability of these values to be examined. The hypothesis is that mandibular third molars which are adversely effected by craniofacial growth or treatment should demonstrate a less favourable position in the pattern of eruption relative to a tooth at the same stage of root development which is erupting normally and vice verse. The predictive parameters developed in this study were examined independent of the size and shape of other components of the craniofacial complex or the chronological age of the individual.

The sample consisted of 59 individuals divided into five groups: I. Class I skeletal and dental relationship exhibiting erupted mandibular third molars (n=27); II. Class I skeletal and dental relationship exhibiting impacted mandibular third molars (n=16); III. Class II skeletal and dental relationship exhibiting erupted mandibular third molars (n=7); IV. Class II skeletal and dental relationship exhibiting impacted mandibular third molars (n=2); V. Class III skeletal and dental ralationship exhibiting erupted mandibular third molars (n=7). Predictive parameters were developed and examined relative to progressive stages of mandibular third molar root development, and statistically significant differences were noted between impacted and erupted samples. A predictive model was developed utilizing the statistically significant parameters examined, and the

predictability of the model was tested on the original samples utilizing randomized computer selection. An unknown untreated sample consisting of 18 individuals (9 impacted and 9 erupted) was tested for predictability utilizing the logistic regression model developed. In addition, a treated sample consisting of 20 individuals (15 erupted and 5 impacted) was also tested following completion of treatment.

The results demonstrated that changes in angulation and vertical distance from the occlusal plane measured at various stages of mandibular third molar root development were found to be statistically significant parameters in the prediction of impaction or eruption. The dental/skeletal classification of the individual was also found to be statistically significant in terms of prediction of impaction or eruption. The parameters of sex, side of the mandible examined, and distance available (measured from the mesiobuccal cusp tip of the mandibular third molar to the anterior border of the ramus) were not found to be statistically significant parameters.

The logistic regression model developed utilizing the previously mentioned statistically significant parameters was found to demonstrate a high predictability (89.1%) among the original samples examined when tested with randomized computer selection. In addition, the

predictability of the same model was found to be 83% in the unknown untreated sample and 90% in the unkown treated sample.

DEDICATION

I dedicate this Thesis to the members of my family who have demonstrated a great deal of support and encouragement throughout my academic endeavors.

To my mother, Rothanthi, whose love and support have helped me through the many years of education. I thank her for her patience over the years.

To my father, Andrew, who has molded me into the individual I am today. His encouragement and support have helped me reach my academic goals.

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To his wife, Christothoula, whose recent addition to the family has offered another source of love and encouragement.

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My classmates duriong my residency at Case Western Reserve University. Doctors George and Sophie Rozencweig, Doctor Valerie Martone, Doctor Jose Chaques-Asensi, and Doctor Mathew Johnson. You have all touched me deeply and have made my two years of post-graduate studies most memorable and enjoyable. I look forward to our future social and professional encounters both here and abroad.

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I. INTRODUCTION

The potential for impaction or eruption of mandibular third molars in the adolescent patient is a difficult decision often made by the dentist. Because various surgical risks increase with increasing age of the patient, the recommendation for extraction of these teeth at an early developmental state is a common occurrence (Ricketts et.al., 1976). The orthodontic specialist is routinely confronted with the decision as to whether facial growth, with a subsequent increase in arch length, will provide adequate space to allow for a normal eruptive path of the developing third molar.

The potential detrimental effects of maintaining unerupted third molars include cyst formation, pericoronitis, root resorption of the second molar, neoplastic alteration, and numerous others (Laskin, 1969). The surgical risks involved with their extraction include trauma to the bone and soft tissue of the mandible, paresthesia, damage to the adjacent second molar, trismus, post-operative pain, swelling, possible infection, and others (Killey and Kay, 1975). Despite the potential problems, the decision regarding the removal of these teeth is often made in a non-scientific, judgemental manner. A quick glimpse of a series of periapical radiographs or a panoramic x-ray and the

dentist's best clinical assesment as to what these teeth will do are frequently the most sophisticated methods used to determine future eruption or impaction. The developmental variablilty among individuals warrants a more quantitative and scientifically based approach which can allow for more accurate decisions regarding mandibular third molar eruption.

The purpose of this study is to investigate the long-term follow-up of unerupted third molars through the Bolton-Brush archives, and to develop a method for predicting the future impaction or eruption. This predictive method will be based on an aspect which has received very little attention. Although briefly discussed in previous literature, there has been almost no emphasis placed upon the relationship between the eruptive pathway of the mandibular third molar relative to the progressive stages of root development. Considering the variability in chronological timing of third molar development and eruption, the clinical benefit in formulating a predictive method relating positional changes during the eruptive process to various stages of crown-root development could be significant. Such an approach would offer an opportunity to develop a more quantitative method for predicting third molar impaction based on that tooth's own developmental time table. The prediction method would be independent of

appearance or position of the third molar relative to the developmental state of other components of the craniofacial complex and would not be based on the patient's chronological age.

Objectives of the Study

1. Establish parameters to be used for comparison of positional changes in impacted and erupted mandibular third molars.

2. Determine the statistically significant differences in these parameters between impacted and erupted mandibular third molars at various stages of root development.

3. Determine the predictability of these parameters within the selected samples.

4. Establish a predictive method using the appropriate parameters.

5. Test the predictive method on a seperate unknown sample.

II. LITERATURE REVIEW

The eruption pattern of third molars is highly influenced by the growth and remodeling changes occurring in the mandible (Broadbent, 1943; Bjork, 1956). In addition, the development of the mandible plays a significant role in determining the ultimate fate of these teeth (Broadbent, 1943; Bjork, 1956). Enlow (1990) presents a very detailed model of the changes which occur in the mandible during the growth process. He indicates that mandibular development involves more than just resorption along the anterior border followed by deposition on the posterior aspect of the ramus. The remodeling changes involve an entire relocation of the ramus posteriorly to a much greater extent than the width of a single molar. Growth and remodeling occurs in all regions between the anterior and posterior borders of the mandible, and the direction of posterior growth is not merely a straight line connecting those borders. Regional activity within the mandible is very instrumental in the posterior relocation of the ramus. The coronoid process undergoes deposition along its lingual surface, allowing growth in a posterior and superior direction. The result is a posterior relocation of the coronoid process despite the addition of bone on its lingual surface.

This pattern of boney resorption and apposition is an example of the V principle of growth in which a wider part of the mandible undergoes relocation into a more narrow part as the whole V moves toward its wide end. Conversely, the buccal side of the coronoid process exhibits a resorptive boney surface. The remainder of the most superior part of the ramus, including the area just below the sigmoid notch and the superior portion of the condylar neck, grows superiorly by deposition on the lingual osseous plate and resorption on the buccal osseous plate. The portion of the ramus below the coronoid process also has a twisted contour. The buccal surface in this area faces posteriorly toward the direction of growth and therefore is a site of deposition. The lingual surface, however, faces away from the direction of growth and thus exhibits a resorptive field. In addition, a single field of resorption is present on the inferior edge of the mandible at the ramus-corpus junction. This resorptive field eventually leads to formation of the antegonial notch.

In his description of mandibular growth, Enlow considers the posterior edge of the ramus and the condylar head as the two major growth sites of the mandible. The angle of growth which the condyle follows during the upward and backward remodeling is variable and

often depends on whether the individual is a "vertical" or "horizontal" grower. However, the growth of the posterior border of the ramus necessarily keeps pace with any given amount of condylar growth, and together they represent the most active areas of mandibular growth in both linear displacement and amount of bone deposited.

Bjork (1972) also studied mandibular development and tooth eruption through the use of metallic implants. He reported that a general feature of craniofacial growth was a forward rotation of the face. He claimed that this rotation necessitated compensatory adaptation of the path of eruption of the teeth. He noted that the lower dental arch shifted forward on the mandibular base without undergoing any appreciable change in the shape of the dental arch. In addition, the intermolar inclination remained relatively constant as the teeth in both jaws followed the rotation of the face. In another study, Bjork (1968) found that the shape of the basal arch and mandibular angle depended largely on the direction of condylar growth, a feature which exhibited great individual variation.

Behrents (1985) documented continued growth in the aging craniofacial skeleton beyond the age of 17 years. In terms of mandibular change, he noted both the anterior and posterior borders displacing in an inferior direction.

The posterior border also shifted forward in males, while remaining stationary in females. In both sexes, however, the anterior border showed posterior movement, a finding which may have some bearing on the ability of the third molars to erupt. In addition, the length of the body and the ramus increased, and the gonial angle became more acute with time. In summary, the dimensions of the mandible of both sexes increased with time and the ramus area of the mandible exhibited the greatest amount of change. The resultant change in the males was a downward and forward repositioning of the mandible. In the females, however, the increased dimension was accompanied by a greater backward rotation of the mandible causing an increased vertical dimension and no relative anterior movement of the chin. This growth pattern in the mandibular ramus region may suggest a possible need for long term evaluation of third molars prior to their recommendation for surgical removal. However, such a decision should be weighed against any potential surgical or clinical disadvantages and/or risks in maintaining these teeth for an extended period of time.

Despite the complex depository and resorptive processes associated with the growth and development of the mandible, there have been extensive studies documenting the eruptive pathway taken by the third molar in its attempt to reach the occlusal plane. The average

age of crypt formation was found to be eight years by Banks (1934) and Garn et.al. (1962), while Gravely (1965) noticed peak formation at age nine. All three studies considered the upper age limit for third molar genesis to be age 14. Richardson (1980) noted third molar development up to the age of 16 years, although she felt that a delay in third molar development beyond the age of 10 years reduced the possibility by as much as 50 %. Despite the time of onset of development, formation begins in the ramus at a level higher than the occlusal plane, with an eventual descent to a position below the level of the remaining molars (Richardson, E.,1984; Silling, 1973). The formation usually takes place with the occlusal surface of the developing third molar angled mesially to the occlusal plane. This angulation was found to be 40 to 45 degrees by Silling (1973) and 55 degrees by Haaviko et.al. (1978). Richardson (1973) reported an average angle of 38 degrees to the mandibular plane, with values ranging from 11 to 83 degrees.

In order for eruption to occur, there must be a forward migration and a subsequent rotational uprighting of the developing tooth in conjunction with a vertical ascent to the occlusal plane. Henry and Morant (1936) claimed that no uprighting occurs until after the third molar is in close association with the second molar. Broadbent (1943) believed that important changes in the

inclination of the developing third molars take place between the ages of 14 and 16 years, when the roots of these teeth move abruptly forward in the bone. Weinmann and Sicher (1955) implied that such rotational movements occur during the period when the tooth bud is migrating anteriorly. Salzmann (1966) described the forward shift of the third molar roots to correct the anterior crown tilt and permit normal eruption as the mandible increases in length by resorption at the inner angle. Silling's (1973) study confirmed the observations of Henry and Morant (1936), reporting that the change in inclination did not occur until contact was made with the second molar. Richardson (1973) reported an average inclination of 40.78 degrees to the mandibular plane at age 10, with an uprighting change in inclination averaging 11.2 degrees up to the age of 15 years. In another study done by Richardson (1978) involving pre-eruptive movements of the mandibular third molar, it was noted that development at the mesial root must dominate in order for normal uprighting and eruption to occur. In the same study, she suggested that dominant distal root development leads to mesioangular or horizontal impaction. Finally, a seperate study done by Richardson (1984) reported that rotational changes do not occur in the developing third molar until the age of 14 to 16 years.

The frequency of third molar impaction within

different populations has also been investigated by many authors. Though quite variable in sample size and results, it is apparent from these studies that third molar impaction is not an uncommon occurrence. Hellman (1938) studied a random sample of untreated individuals and reported an incidence of 9.5% in males and 23% in females. Bjork et. al. (1956) studied two groups of Scandanavian males, reporting an incidence of 17% in one and 22% in the other. Dachi and Howell (1961) examined 3,874 periapical radiographs of American students aged 20 years and above, and found that third molar impaction had occurred in 17.5% of the patients. A similar frequency was found among Greek students in a study by Haralabakis (1959). Aitasalo et. al. (1972) investigated 4,063 orthopantographic x-rays of an equal sample of males and females ranging in age between 20 and 69 years, and found that third molar impaction had occurred in 10.5% of the cases.

Even higher percentages have been reported with studies of orthodontically treated patients. Silling (1973) recalled a group of 50 patients, 18 males and 32 females ranging in age from 18 to 30 years, who had received non-extraction therapy. Lateral cephalometric radiographs and a clinical examination were used to evaluate the position of the third molars. Teeth were judged to be impacted if one or both of the following

conditions existed: 1) severe abnormalities were present that prevented further eruption of the tooth, or 2) such poor response of the overlying and surrounding hard and soft tissues existed that, considering the age of the patient, normal eruption was extremely unlikely. In this sample, Silling noted impaction of one or both mandibular third molars in 67% of the males and 69% of the females. He claimed that holding back or distally tipping the second molars, as commonly used in anchorage preparation, was the cause of increased risk of impaction in such non-extraction cases. Richardson (1975) examined third molar development in 160 orthodontic patients aged 9-11 years over a period of 7 to 10 years through the use of yearly plaster models and lateral cephalometric x-rays. An impacted third molar was defined as one which was prevented from eruption because of its mesioangular relationship with the second molar. They were diagnosed as impacted teeth when subjects were 18 years of age or older, and the third molar had remained in the same relative position for at least 3 years. If each side of the lower arch was considered seperately, the prevelance of impacted mandibular third molars in quadrants treated without extraction was 35%. An additional 20% of the mandibular third molars were extracted during treatment based on a diagnoses of vertical impaction, production of pain and/or swelling, or in an attempt to prevent an

increase in lower incisor crowding.

When discussing the probable impaction of mandibular third molars, there is a general concensus among researchers that lack of adequate space is a primary contributing factor. Broadbent (1943) , in describing the development of mandibular third molars, postulated that retarded mandibular growth was a primary cause leading to impaction. Upon investigation of Stone Age Man's occlusion, Begg (1954) claimed that there is insufficient mesial migration of the dentition in modern man due to lack of attrition, resulting in inadequate space for third molar eruption. Bjork et.al. (1956) implicated three factors in the development of inadequate arch length: a more vertical direction of condylar growth, insufficient increase in mandibular length, and posteriorly directed eruption of the dentition. Ricketts (1972), in partial agreement with Bjork, used his theory of arcial mandibular growth to support the concept that space is made for the normally developing third molar by the forward eruption of teeth rather than resorption along the anterior border of the ramus. In a study involving third molar space, Richardson (1987) concluded that space is gained by both anterior border resorption as well as mesial migration of the dentition, and she found these changes to be random and unpredictable.

The extraction of teeth during orthodontic therapy

and the effect on arch length and third molar eruption has also received a great deal of attention. Kaplan (1975) used records from the Department of Orthodontics at the University of Washington to compare 30 treated cases in which third molars erupted with 20 cases diagnosed as impacted. The erupted group consisted of 18 females and 12 males. The cases were treated with premolar extraction, except for two which were treated non-extraction. The impacted group consisted of 11 females and 9 males, 12 of which were treated non-extraction and 8 with premolar extractions. The mean post-retention age was 26.6 years, and impaction was defined as incomplete eruption of the mandibular third molar due to its position relative to the second molar or the ascending ramus following closure of the root apices. Composite mandibular tracings were obtained from pre-treatment, post-treatment, and post-retention cephalometric radiographs. On each composite, 24 points were digitized and computer analyzed to determine changes in the position of the mandible and its dentition. He concluded that where premolars had been extracted, there was increased mesial molar movement resulting in an increased probability of third molar eruption. In addition, where premolars had been extracted but third molar impaction had occurred, he noted increased vertical condylar growth and a more vertical direction of

mandibular growth. In agreement with Bjork et. al. (1956), Kaplan sighted insufficient resorption along the anterior border of the ramus as the primary factor responsible for an increased risk of third molar impaction. Faubion (1968) examined serial lateral mandibular radiographs of 40 patients, 20 of which were treated with extraction of four first premolars and 20 of which had no teeth removed. The patients were selected alphabetically from the files of a local orthodontist using only the previously stated criteria. The decision on whether to retain or remove the mandibular third molars had been made on the basis of tooth size, changing tooth position, bone structure, and available retromolar space. The mean patient age was 17 years 2 months for the extraction cases and 16 years 11 months for the non-extraction group. In conclusion, Faubion found that 55% of the mandibular third molars were retained in the patients who had premolars extracted, whereas only 15% were retained in the non-extraction group. Fanning (1962) investigated 3,423 white high school and college students ranging in age from 13 to approximately 22 years, 1050 of which were females. A dental history was obtained regarding extraction of erupted or impacted teeth, and in cases of doubt, radiographs were taken as an additional aid in determining the prescence of third molars. These patients were screened as they came

through the dental hygiene clinic, and a third molar was classified as present if any part of the crown had pierced the gingival tissue. The data indicated that 75% of the patients over 20 years of age who had previous extraction of other permanent teeth had erupted third molars, while only 57% showed eruption where no teeth had been removed. Cryer (1967) examined 66 orthodontic cases in which one or both mandibular second molars had been extracted as part of their treatment. Each case had adequate records consisting of a treatment summary, serial record models, and serial lateral cephalometric and intra-oral radiographs. The patients ranged in age from late teens to early twenties. A points system was developed to facilitate comparison of case results which were based on the extraction of mandibular second molars. Each mandibular third molar was scored seperately. The areas evaluated included position of the tooth in all three dimensions, relief of impaction of premolars caused by early loss of deciduous molars, reduction in lower anterior crowding, and need for lower appliance therapy. Upon examination of all four criteria, the data indicated that 35% of all mandibular third molars were judged as demonstrating good results, 40% as fair, and 25% as poor. When looking at mandibular third molar position alone, the points system showed that only 56% of the teeth erupted into a good position when second permanent molars

were extracted between the ages of 12 and 15 years. When extraction of second molars was done following full crown formation of the third molars, this percentage increased to 70%. McBride and Huggins (1969) examined 35 mandibular third molars in 20 patients, 7 male and 13 female, with the average age being 13.5 years. Cephalometric radiographs were taken at 45 degrees from true lateral position to help seperate right from left mandibular third molars, and the sequence of radiographs taken was before extraction, 8-10 months post-extraction, and 20-24 months after extraction of the mandibular second molars. Of the 35 teeth observed, 11 showed an increase in angle to the occlusal plane indicating a less favorable position. The remaining 24 teeth decreased in angulation, indicating a more favorable path of eruption. This study tends to agree with Cryer's work in that extraction of mandibular second molars often allows third molars to move into a more favorable position. Ricketts (1972) examined 25 adult skulls exhibiting normal occlusion with lateral cephalometric radiographs. A hypothesis was proposed that the third molar must lie fifty percent ahead of the external ridge for a fifty percent chance of eruption to exist. To verify this theory, 31 orthodontically treated cases including a variety of malocclusions were examined. These cases tended to verify his hypothesis. In the non-extraction

cases with third molars erupted, the teeth were found to lie ahead of the ridge in 49% of the cases. The extraction cases revealed third molars lying ahead of the ridge in 74% of the cases. Ricketts suggested that a 25% increase in space available for the third molars is created in cases treated with extraction of bicuspids. The data also demonstrated that without extraction 55% of the cases exhibited third molar eruption, whereas 80 to 85% did so when teeth were removed.

Another aspect of mandibular third molar eruption which has not received as thorough a documentation is the rotation and uprighting of the tooth prior to its attempted eruption to the occlusal plane. Richardson (1975) longitudinally examined 270 subjects ranging in age from 9-11 years over a period of 7-10 years with lateral cephalometric x-rays and plaster models taken annually. The study was composed of one group of 45 subjects who had one or two impacted mandibular third molars, and another group of 50 subjects whose mandibular third molars had erupted. An impacted third molar was defined as one which was prevented from erupting due to its mesioangular relationship to the second molar. The diagnoses was made when subjects were age 18 years and over, and the third molar had remained in the same relative position for at least 3 years. Upon examination of the data, she stressed that the developmental

angulation of the third molar to the mandibular plane was found to be much higher in cases of future impaction, and that such impaction can occur in one of three ways: a decrease in the angulation of insufficient amount to permit eruption, no change from the original angulational position, and an increase in angulation to the mandibular plane. She also noted the significantly greater change in angulation exhibited by the erupted groups, and suggested that a steep mesial angulation of the developing third molar offers a much greater chance of future impaction. Richardson also reported that the steeper the initial mesial angulation is, the more likely the tooth is to upright. However, this does not guarantee that it will upright enough to permit its eruption to the occlusal plane. Richardson (1974) also sought to identify several factors associated with early eruption of lower third molars. She examined three groups of subjects selected from the records of a longitudinal study of third molar development. One group consisted of 33 individuals who had early eruption of one or both mandibular third molars. The average age of eruption was 16 years, and in all but two cases, one or two teeth had been extracted from the lower arch. A second group was composed of 23 individuals whose mandibular third molars had not erupted seven years after the beginning of the study and who also had one or two

teeth extracted from the lower arch. The final group contained 20 individuals whose mandibular third molars were not erupted after seven years of observation and no teeth had been removed from the lower arch. Upon analysis of numerous variables of growth and third molar eruption, she reported that a small initial degree of angulation, a large amount of change in this angulation, a large amount of growth of the mandible, and extraction of a tooth in the corresponding buccal segment all showed a significant correlation with the occurrence of early eruption. In yet another study, Richardson (1970) attempted to correlate the tooth's early developmental position to various dimensions of the jaws and teeth. She analyzed the records of 162 children ranging in age between 8 and 13.7 years, with an average of 11.1 years. They were selected based on the ability to measure appropriate space conditions on the models, and the presence of sufficient calcification of at least one mandibular third molar to enable a measurement of its angulation to the occlusal and mandibular planes on a lateral cephalometric radiograph. Various measurements such as length of the mandible, gonial angle, space between second and third molars, and width of the third molar were closely examined and correlated to the tooth's initial degree of angulation. The study was performed under the assumption that impaction is based to a large

extent on inadequate space due to insufficient or inappropriate growth which may manifest itself at an early stage of tooth development. Despite great variability, the data suggested that the degree of angulation at this early developmental stage is virtually independent of the size and shape of the mandible.

A number of predictive methods have been developed regarding third molar impaction, each focusing on a separate aspect of the tooth's pattern of eruption. Early work in this area was done by Ledyard (1953) who used lateral jaw radiographs. In this study, the patient's jaw was held at an angle against a headrest on which a cassette was placed, and the x-rays where then directed perpendicular to the side being radiographed. All the patients were selected from the files of a local orthodontist, and 375 tracings were made of both right and left lateral jaw radiographs. Measurements were made along the occlusal plane from the mesial of the mandibular first molar to the anterior border of the ramus. He found that the increase in this distance between the ages of 14 years and an average of the ages from 16 to 20 years was 2.3 mm. He suggested that these measurements can be used in a predictive manner. A Third Molar Space Index was developed by Henry and Morant (1936) which expressed the mesiodistal width of the third molar at its widest diameter as a percentage of the space

available from the distal of the second molar to the ramus on a bimolar radiograph. They examined 187 tracings, dividing the sample into three categories: 1) subjects aged 17-19 years, 2) subjects aged 20-21 years, and 3) subjects aged 22 years and over. Upon analysis of the data, they found that if this index exceeded 120 in a person at maturity, then impaction could be predicted. As previously discussed, Ricketts (1972) suggested that if 50 % of the developing third molar lies ahead of the external oblique ridge at maturity, then there is a 50 % chance of eruption. He also claimed that a measurement of less than 25 mm made from a cephalometric landmark he called Xi point (representing the geometric center of the ramus) to the distal of the second molar was indicative of a poor prognosis for eruption. In a related study done at Loma Linda University, Jacobsen (1984) examined lateral cephalometric and panoramic radiographs of 130 orthodontically treated patients ranging in age from 9 to 13.8 years. The patients were observed for 6 to 10 years to determine the fate of the third molars. Various linear measurements were made from maxillary and mandibular molars to Xi point, the pterygoid vertical, and the coronoid notch. Analysis of the data revealed that the distance from Xi point to the distal of the maxillary second molar was the best predictor of third molar eruption probability. Clinically, if Xi point to

distal of maxillary second molar was 21 mm, there was a 60% chance of third molar eruption. The predictability increased with increasing distance. The analysis was able to predict 75.8% of the impaction cases and 69.9% of the eruption cases. Finally, facial type and the presence or absence of premolar extractions had no significant effect on the eruption of third molar. Turley (1974), using 75 orthodontically treated cases, evaluated several methods of measuring space available for the eruption of mandibular third molars. He found the most useful to be the distance from Xi point to the distal of the second molar measured at maturity. He then used these measurements to develop a chart of probabilities of impaction, third molar eruption into proper occlusion, and third molar eruption into poor occlusion. The calculated mean values were approximately 21mm of available space for impacted third molars, 25 mm of space for third molars erupted into marginal occlusion, and 30 mm of space for third molars erupted into proper occlusion. Schulhof (1976) used computerized growth forecasting methods as a means of predicting this distance at maturity. He claimed that he could diagnose future impactions as early as nine years of age. In a previously mentioned study, Margaret Richardson (1975) also supported the popular theory of adequate growth creating space in that she reported a significantly

greater mandibular growth in cases of third molar eruption versus impaction. However, in another study she could find no correlation between the angulational changes in position of the developing third molar and linear growth changes in the mandible (Richardson, 1973). She examined the longitudinal records of 46 children who had no teeth extracted from the mandibular arch and who had been observed over a period of five years. Records included models and four cephalometric radiographs: 90 degree left lateral, postero-anterior view, and 60 degree right and left laterals. Each subject had six sets of records which had been taken on a yearly basis. Measurements were made of the positional changes associated with the mandibular third molar during its eruption and compared to the growth changes which occurred in the mandible. She concluded, unlike the findings of Bjork, Broadbent, and others, that there is not a simple relationship of growth permitting third molar eruption, but that rotational changes must occur which are independent of any changes in available space occurring distal to the second molars (Richardson, 1973). In an attempt to further test this hypothesis of adequate growth as a predictive tool, Richardson speculated that it should be possible to demonstrate differences in relative size and shape of the mandible and teeth in subjects with impacted third molars versus those in which

they erupted. She further suggested that it should be possible to predict whether or not a developing third molar will erupt using measurements of certain mandibular dimensions. Examining the same sample groups mentioned in the discussion of a previous article (Richardson, 1975), she compared various mandibular measuremnets made on lateral cephalometic radiographs. Even though the results indicated that the impacted group demonstrated a Class II skeletal relationship with a shorter, narrower, more acutely angled mandible, these differences only became significant past the age of 18 years, precluding their possible use as early predictive measurements (Richardson, 1977). The previously mentioned studies discussing the developmental pattern of third molars also indirectly suggest the ineffectiveness of linear space measurements as a predictive tool due to a crypt position which is independent of boney landmarks such as the anterior border of the ramus which are often used for measurement. A different approach to the problem was proposed by Olive and Basford (1981), who suggested that the ratio between the inter-second molar width and the inter-ramal width, as measured from a frontal cephalometric radiograph, is an important predictive factor. They examined 30 volunteers at the University of Queensland Dental School and formed two groups, one consisting of 15 adults whose mandibular third molars

were both fully erupted and in good position, and another consisting of 15 adults whose third molars were radiographically confirmed as being mesioangularly impacted. Frontal radiographs were taken of each subject with the occlusal plane horizontal and the teeth in centric occlusion. The occlusal plane was defined as the line passing through the distobuccal cusps of the mandibular second molars on each side. The intersection of this line with the margin of the image of the coronoid processes was used to represent the anterior border of the ramus at the level of the occlusal plane. The distance between these two points on the right and left side was defined as the inter-ramal width. The inter-second molar width was defined as the distance between the most lateral points on the mandibular second molar crowns. The comparative data indicated that inter-ramal/ inter-molar width ratio was a significant factor in the impaction of mnadibular third molars. In another study using frontal cephalometric projections, Svendsen et. al. (1985) analyzed the eruptive path of the mandibular third molar in an attempt to identify any trends offering some predictive value. The cases investigated were drawn from a group of subjects who had been used in a longitudinal study of craniofacial growth. Records were taken annually with an average of six films per series, the first being taken at an average age of 14.8 years.

Subjects consisted of 23 males and 8 females representing a group of 41 erupted mandibular third molars and 18 horizontally or mesioangularly impacted third molars. The inclination of the third molars was measured annually from the time of complete crown calcification until the inclination was stable. The results demonstrated that the eruption pattern for impacted versus erupted teeth was markedly different, with reliable prediction becoming possible at the time of appearance of the bifurcation. Haaviko et.al. (1978) attempted to use the molar's intial angulation to the second molar and the gonial angle as a predictive tool. They investigated 80 cases which were randomly selected from a larger set of orthopantomograms of normally healthy children, the only criteria being that the children had all their teeth and that development of the mandibular third molars was at about the stage of crown completion. Another group of 30 orthodontic patients with two mandibular premolar extractions was selected using the latter criteria. The first orthopantomogram was taken at an average age of 13.5 years at approximately the stage of crown completion. The second was taken at an average age of 19.5 years, a time when the third molar could be expected to have developed and possibly erupted. The data showed no predictive correlation between the initial and follow up angulation of the third molar to the gonial angle or

the angulation of the second molar. A study by Bjork and Svendsen (1988) investigated the influence of late third molar mineralization and early physical maturity on normal eruption of maxillary and mandibular third molars in both sexes. A group of 91 subjects, 36 females and 55 males, were included in the study, and longitudinal yearly records were available from before puberty until 25 years of age. All first and second molars had to be present throughout the period of investigation and approximately 75% of the indivduals had undergone some kind of orthodontic treatment with or without premolar extractions. The age at mineralization was determined from orthopantomograms, and physical maturity was recorded as the age of union of the distal epiphysis of the radius as seen on the hand-wrist radiograph. The study concluded that late third molar mineralization in combination with early physical maturity were important contributing factors to be considered when evaluating potential impaction.

The objective of this study is to examine new potential avenues for the prediction of third molar impaction in the hope of eliminating much of the speculative clinical judgement often applied in determining the ultimate fate of these teeth. An attempt will be made at establishing a predictive relationship between the eruptive pathway of the mandibular third

molar and its progressive crown and root development. Positional and angulational changes will be correlated to different stages of root development in anticipation of establishing a set of normative values to which other developing third molars can be compared. In reviewing previous literature, it is apparent that any attempts at prediction of impaction must involve a developmental time table of that particular tooth and not that of the remaining dentition and its boney counterparts. Chronological age, though often cited as as important factor in a clinical determination of potential impaction, has no significant value in such predictive attempts due to the variability in timing of growth and tooth development. In this study, a comparison will be made between impacted and erupted third molars in order to establish significant differences in the position of the developing third molar relative to its progressive stages of root formation. These differences will then be tested for their predictive value on an unknown sample in which longitudinal progression of third molar development has been documented radiographically to the point of impaction or eruption. The formulation of such a predictive method will take into account the developmental rate of each individual tooth, a factor which is essential to any predictive attempt.

In determining these positional and angulational

changes, however, equal consideration must be given to both increases in arch length as well as rotational correction of the tooth. It is apparent from previous literature that third molar uprighting occurs independent of any growth and subsequent increases in available space. Therefore, this study will take into account not only the tooth's ability to reach the occlusal plane based on the presence of sufficient space, but also the necessary angulational changes which must precede it.

III. Methods and Materials

1. Sample Selection

The subjects for this study were selected from the Bolton-Brush Growth Study Center at Case Western Reserve University in Cleveland, Ohio. Longitudinal lateral cephalometric radiographs were used for examination of appropriate parameters (Table I). Individuals were divided into 5 groups: I. Class I skeletal and dental relationship with erupted mandibular third molar(s) (n=27); II. Class I skeletal and dental relationship with impacted mandibular third molar(s) (n=16); III. Class II dental and skeletal relationship with erupted mandibular third molar(s) (n=7); IV. Class II dental and skeletal relationship with impacted third molar(s) (n=2); V. Class III dental and skeletal relationship with erupted mandibular third molar(s) (n=7). No subjects could be found exhibiting a Class III dental and skeletal pattern with impacted third molars. Subjects were selected for the appropriate sample groups using the following criteria: 1) availability of longitudinal lateral cephalometric radiographs demonstrating mandibular third molar development to the point of eruption or impaction, 2) no missing teeth, and 3) no orthodontic treatment. Eruption was defined as a third molar whose mesiobuccal cusp tip had reached the level of the

occlusal plane on the lateral cephalometric radiograph. When possible, its position in the arch was confirmed with available dental models. Impaction was defined when a third molar was prevented from eruption due to its mesioangular relationship with the second molar. This was diagnosed when subjects were aged 18 years and over and third molar root formation was complete or the tooth had maintained or worsened its position relative to the occlusal plane over a period of at least three years. These criteria are similar to those used by Richardson in the majority of her studies (1973, 1974, 1975, 1977).

Each group was further subdivided into male and female, and a distinction was made between right and left sides for each individual. A frequency distribution for each variable is shown in Table II. Group I exhibited 14 males ranging in age from 10 years 11 months to 24 years 7 months, and 12 females ranging in age from 12 years to 33 years 1 month. Group II contained 9 males ranging in age from 13 years to 25 years 2 months, and 7 females ranging in age from 11 years 11 months to 24 years 1 month. Group III was made up of 2 males ranging in age from 14 years to 18 years 7 months, and 5 females ranging in age from 10 years 11 months to 22 years 2 months. Group IV exhibited 2 males ranging in age from 12 years 11 months to 24 years 8 months. Finally, Group V contained 6 males ranging in age from 12 years 11 months

to 19 years 4 months, and one female followed from age 13 years to age 20 years 3 months (Table III).

The lateral cephalometric radiographs were obtained using the Broadbent-Bolton cephalometer and a source-object distance of 5 feet.

2. Data Collection

Using .003 inch frosted matte acetate, several points and planes were identified on each cephalometric radiograph for each individual third molar. The right and left third molars were traced seperately, and only those teeth for which appropriate landmarks could be identified were included in the sample. In addition, not every radiograph in each longitudinal series appropriately exhibited the necessary landmarks for both right and left sides.

The points and planes which were plotted for each third molar are shown in Figures 1. and 2. Point A (Figure 1.) was defined as the mesiobuccal cusp tip of the third molar. Point B was designated as the mesial cementoenamel junction of the developing tooth. Point C was identified as the distobuccal cusp tip, and point D defined the distal cementoenamel junction. Point E delineated the most distal point of root completion. Point F was designated as the mesial cementoenamel junction of the second molar. Points G through J were

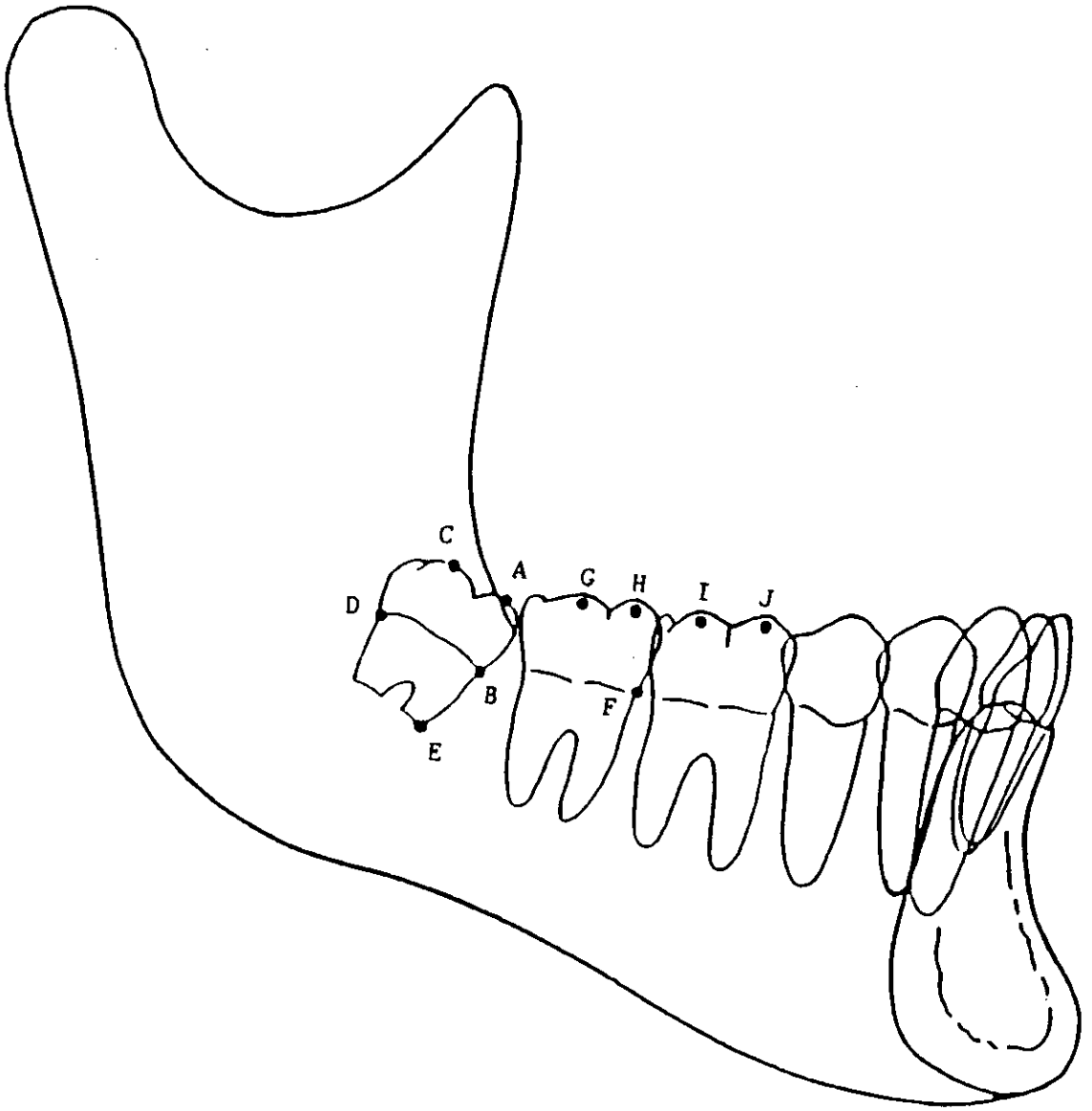


Figure 1. Illustration of the ten dental landmarks identified on each cephalometric radiograph.

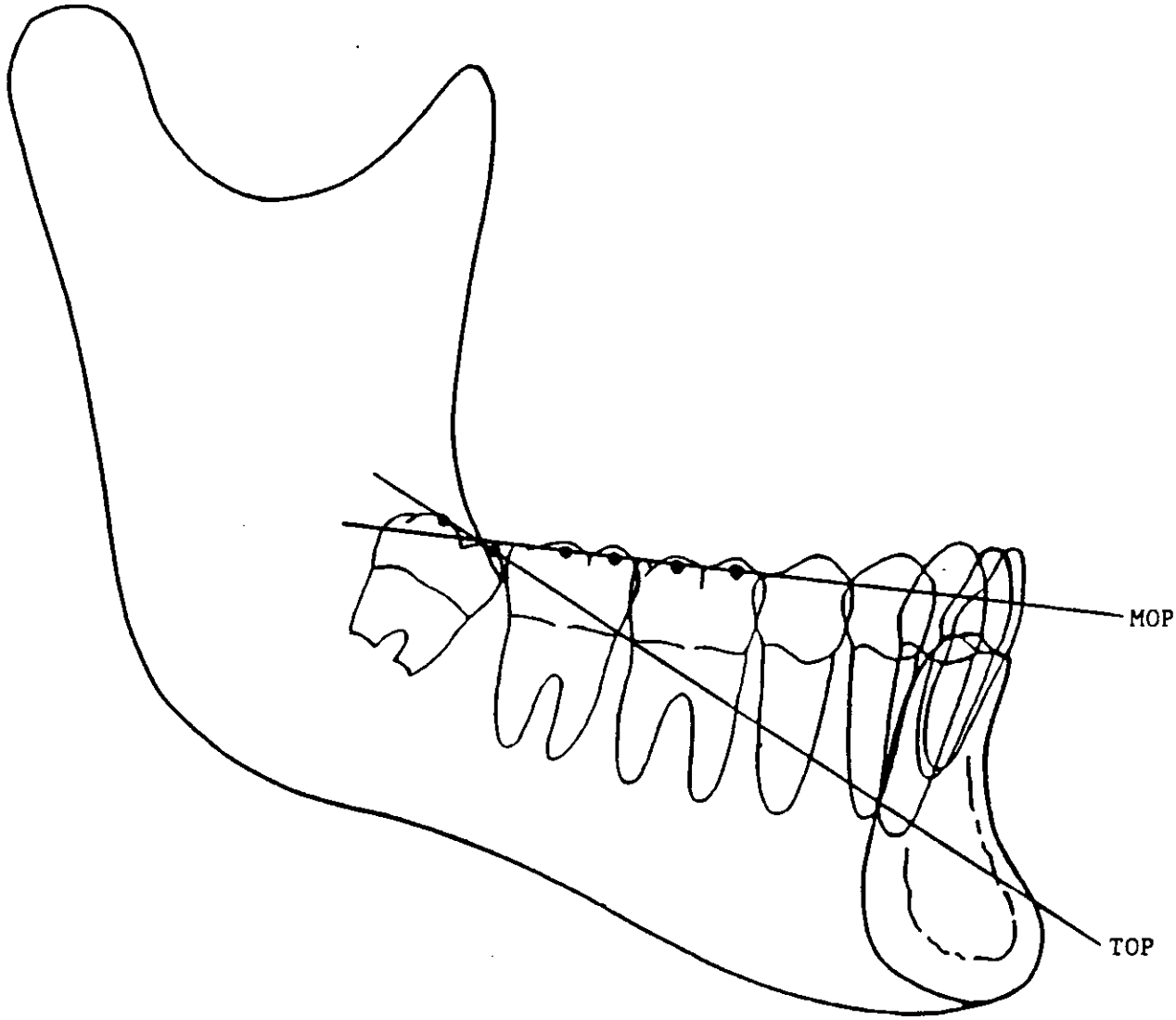


Figure 2. Illustration of the two planes identified for each individual tooth.

used to identify the mandibular occlusal plane (MOP). A line connecting the mesial and distobuccal cusp tips of each third molar was also used to delineate that tooth's own occlusal plane (TOP) (Figure 2.).

The measurements, angles, and ratios used are shown in Figures 3., 4., and 5. A unique ratio was used to identify the progressive stages of third molar root development, and this number was given the title "developmental index" (DI) (Figure 3.). This value was obtained by first drawing a line connecting both mesial and distal cementoenamel junctions (point B to point D). A perpendicular to this line was then drawn through the mesiobuccal cusp tip of the third molar (point A). The intersection of these two lines was defined as point K. The ratio was then established by dividing the length (in mm) of the developing root (points K to E) by the length of the crown (points K to A). The mesiobuccal cusp tip was selected as the dental landmark to follow during eruption because it is this cusp which must be allowed to rotate and erupt in order for the tooth to successfully reach the occlusal plane. This ratio began at zero, indicating crown completion with no root formation, and became progressively larger as root development proceeded. This index was established in order to relate certain aspects of each tooth's pattern of eruption to its progressive stages of root development. The

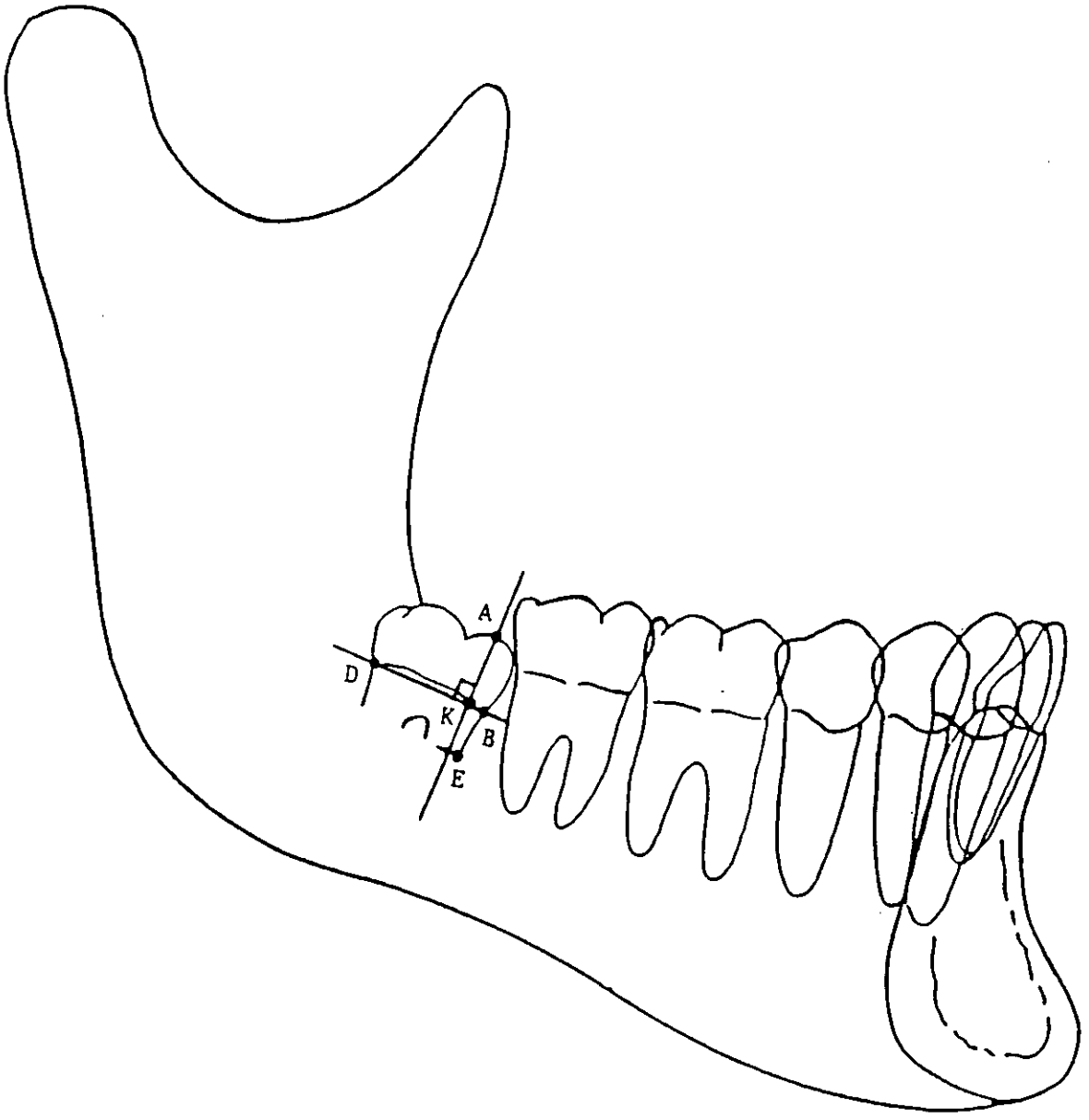


Figure 3. Illustration of the developmental index (DI). The appropriate points and planes used to develop this ratio are clearly indicated: KE/KA.

values were collected seperately for each individual tooth and were then grouped into seven categories: 1) 0-.25 ; 2) .26-.50 ; 3) .51-.75 ; 4) .76-1.00 ; 5) 1.01-1.25 ; 6) 1.26-1.50 ; 7) 1.51-1.75. The organization of these categories allowed for the identification of significant trends between impacted versus erupted teeth and also demonstrated the effectiveness of the predictive factors in question at various stages of root development. In addition, these categories were large enough to help account for difficulty in visualization of the appropriate landmarks resulting in examiner tracing error. Except at the category margins, slight errors in visualization and tracing would still place a tooth's developmental index within the same level, an aspect which could be clinically useful in accounting for intra-examiner variability.

The first predictive factor which was tested is shown in Figure 4. This unique value was classified as the "eruption distance ratio" (EDR). This ratio was established by first drawing a line perpendicular to the mandibular occlusal plane passing through the mesiobuccal cusp tip of the third molar (point A). The intersection of these two lines was defined as point L. A second perpendicular was drawn passing through the mesial cementoenamel junction of the second molar (point F). The intersection of this line with the MOP was identified

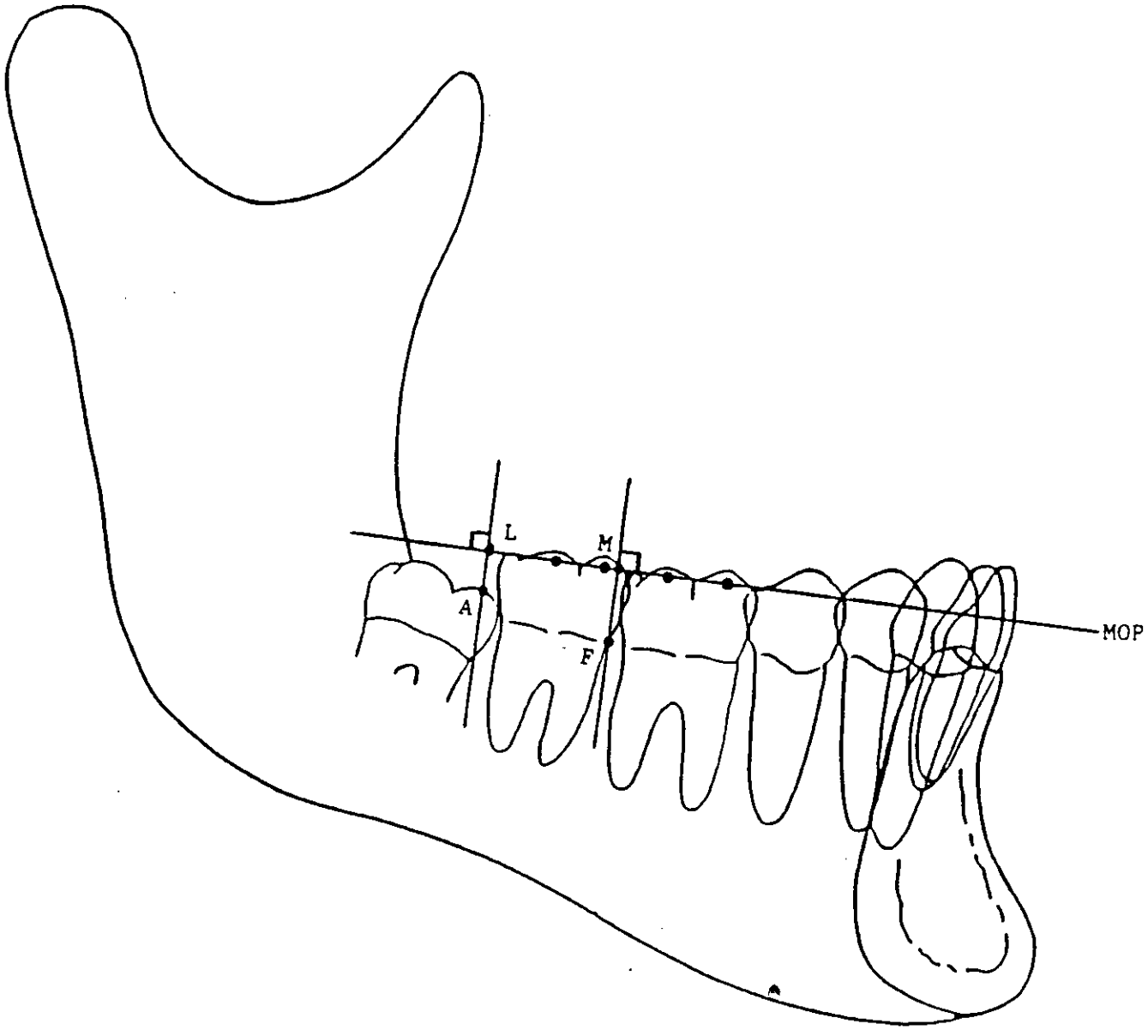


Figure 4. Illustration of the eruption distance ratio (EDR). The appropriate landmarks and planes are clearly identified. The desired ratio is calculated using the formula: AL/FM.

as point M. The distance (in mm) of the mesiobuccal cusp tip from the occlusal plane (points A to L) was then divided by the distance of the second molar cementoenamel junction from the occlusal plane (points F to M). This ratio became smaller as the cusp tip approached the MOP. A value of zero indicated eruption to the level of the MOP. This value was established in order to document the changes in distance to the MOP which occurred as the tooth was or was not allowed to erupt during its progressive stages of root development. It again allowed for the identification of any significant differences between impacted versus erupted teeth and the establishment of any predictive value to this ratio at different stages of root development. The use of a ratio helped compensate for examiner tracing error in location and reproducability of the MOP, but more importantly, it allowed for variation in tooth size and anatomy between subjects. Figure 5. demonstrates a situation in which a direct measurement of mesiobuccal cusp tip to MOP (points A to L) would produce highly variable results between subjects. When viewed from the standpoint of tooth development, however, these two subjects seem to hold an identical vertical position relative to the second molar crown with regards to their present state of eruption. The addition of second molar crown height apparently helped compensate for such anatomical variation.

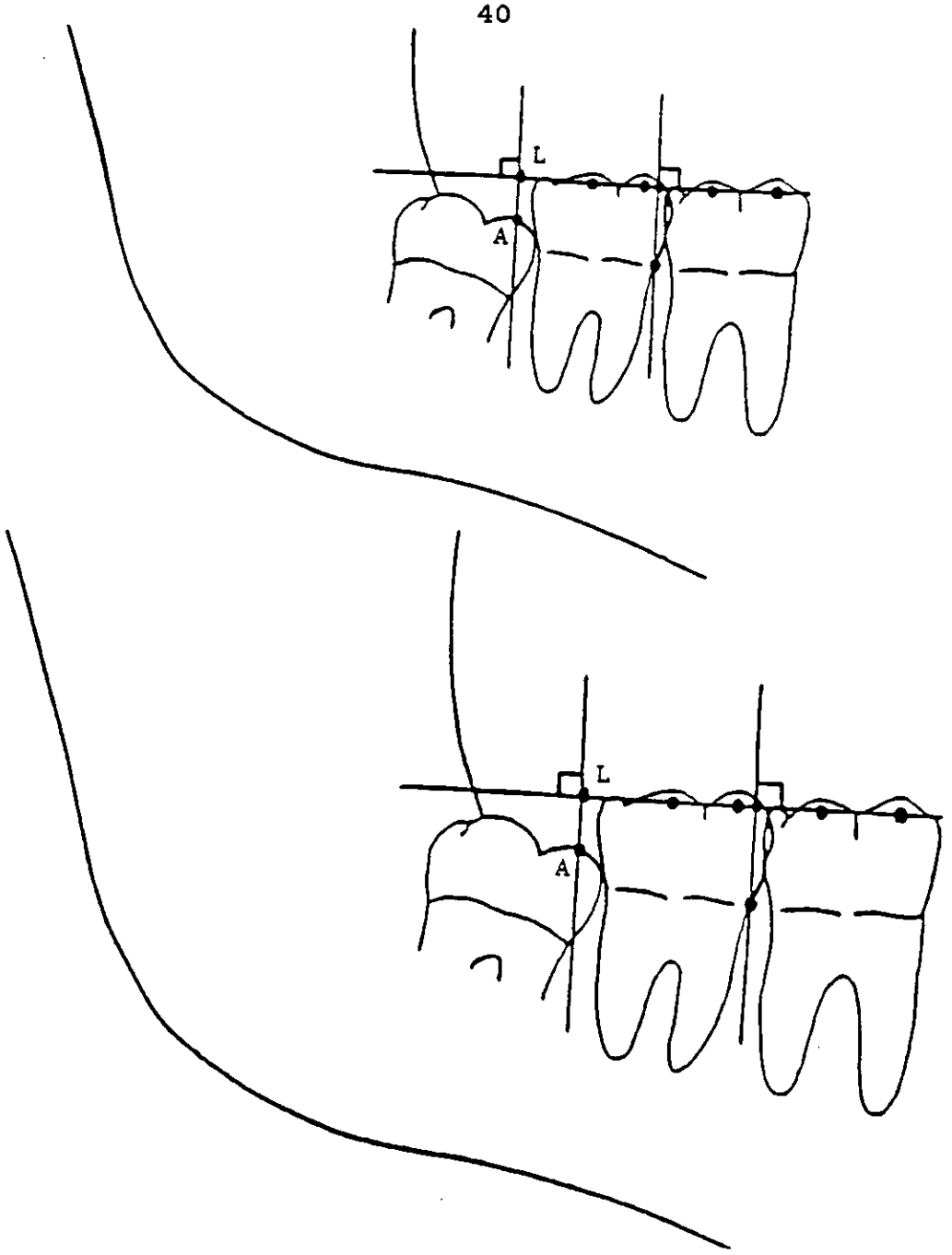


Figure 5. Illustration of anatomical variation which could produce highly variable measurements of mesiobuccal cusp tip to MOP (points A to L) despite a similar position of eruption relative to the second molar. The addition of second molar crown height (points F to M) helped overcome such variation.

The second predictive factor which was examined is demonstrated in Figure 6. The two planes used for this angular measurement were the MOP and the occlusal plane of each individual tooth (TOP). The internal angle (in degrees) between these two planes was designated as the angle to the occlusal plane (AOP) for each tooth, a measurement used in many previous studies. The purpose of this measurement is to document the appropriate angulational changes which must take place as part of the normal third molar eruption pattern. The addition of this value to any measurements of eruption distance or available space is essential in any predictive method. As demonstrated by Richardson (1973), the development of adequate space for eruption is of no consequence if appropriate angulational changes do not preceed it. Statistically significant differences between impacted and erupted teeth were to be documented, and the predictive value of this measurement was to be noted at the different developmental indices previously mentioned. The addition of this factor allowed the prediction method being tested to account for both aspects of third molar eruption, the presence of sufficient space as well as the rotational changes which must accompany it. It is apparent from previous literature that both of these developmental changes must be addressed simultaneously in order to allow for a more accurate and consistent method

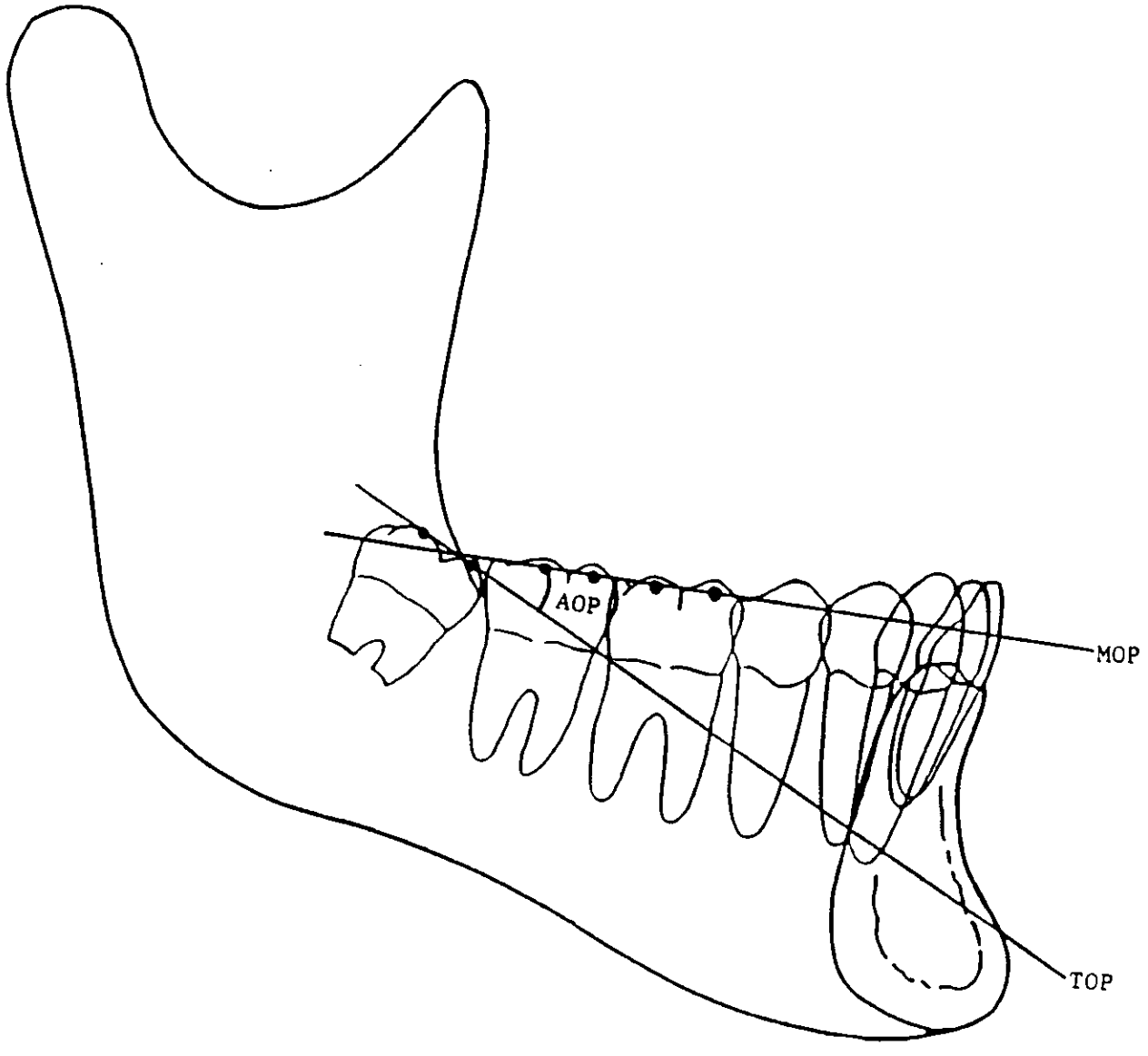


Figure 6. Illustration of the angle to the occlusal plane (AOP) and the appropriate planes used in its measurement.

of prediction.

A final factor which was examined involves a measurement of available space (Figure 7.). This measurement was similar to that of Henry and Morant (1936) but was measured from the point of intersection of a line drawn perpendicular to the MOP through the mesiobuccal cusp tip of the third molar (point L). The distance from this point to the intersection of the MOP with the ramus (identified as point N) was measured in millimeters. This unique distance was designated as the "ramus distance" (RD) and was used as a means of testing the predictive value of measurements of available space made to the anterior border of the ramus. It was not considered an integral part of the predictive method being tested, however, as previous literature (Bjork et.al., 1956; Broadbent, 1943) indicates that the position of the third molar during development and eruption is posterior and lingual to the anterior border of the ramus (Figure 8.). Therefore, the distance mesial to this border is not necessarily an accurate indicator of the space available for eruption. In addition, the anterior border of the ramus is an area exhibiting a great deal of remodeling and resorption, and therefore demonstrates great variability during the process of growth and development. Finally, any direct linear measurement made on a cephalometric radiograph

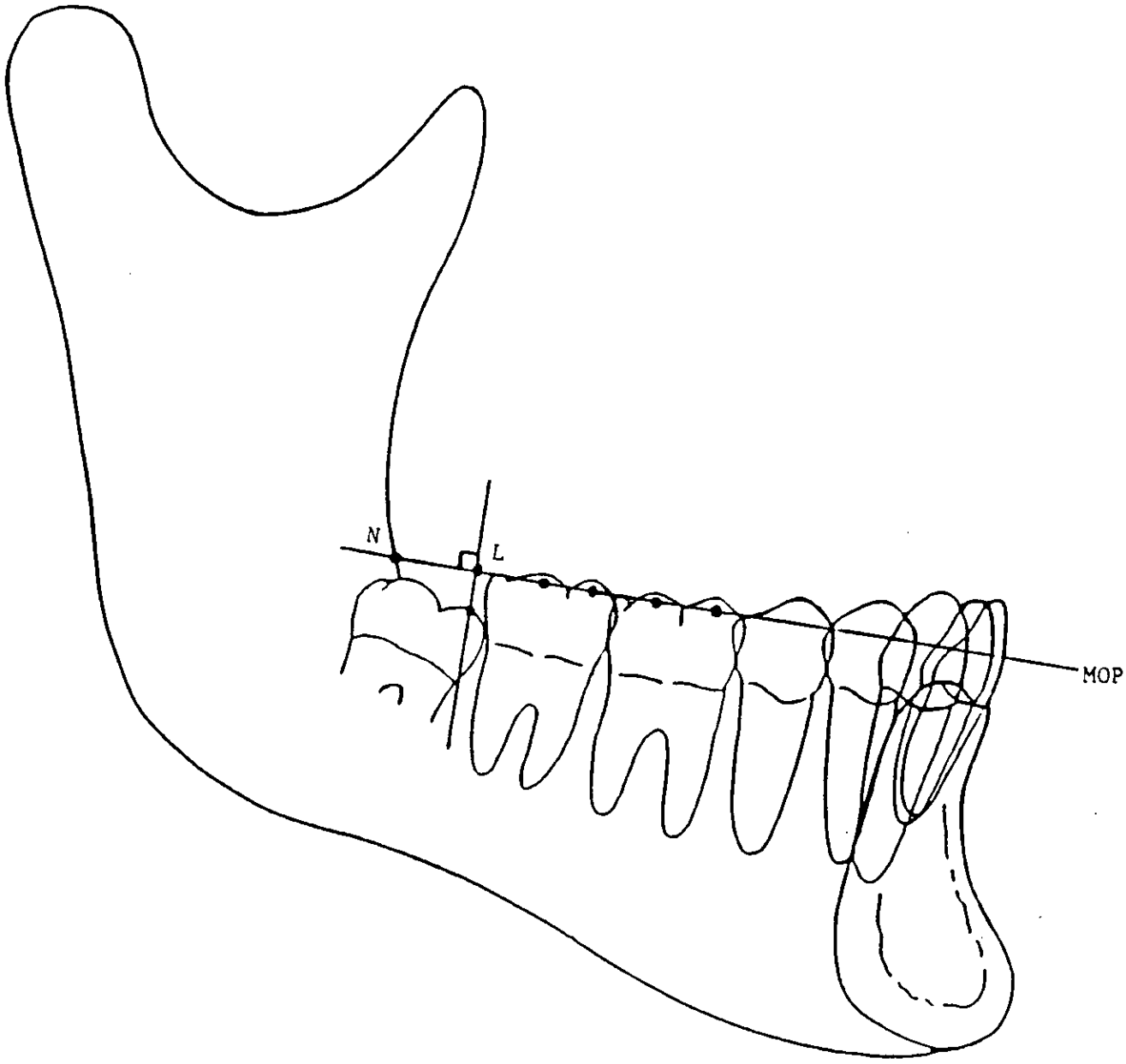


Figure 7. Illustration of the ramus distance (RD) as measured from the mesiobuccal cusp tip to the ramus (points L to N).

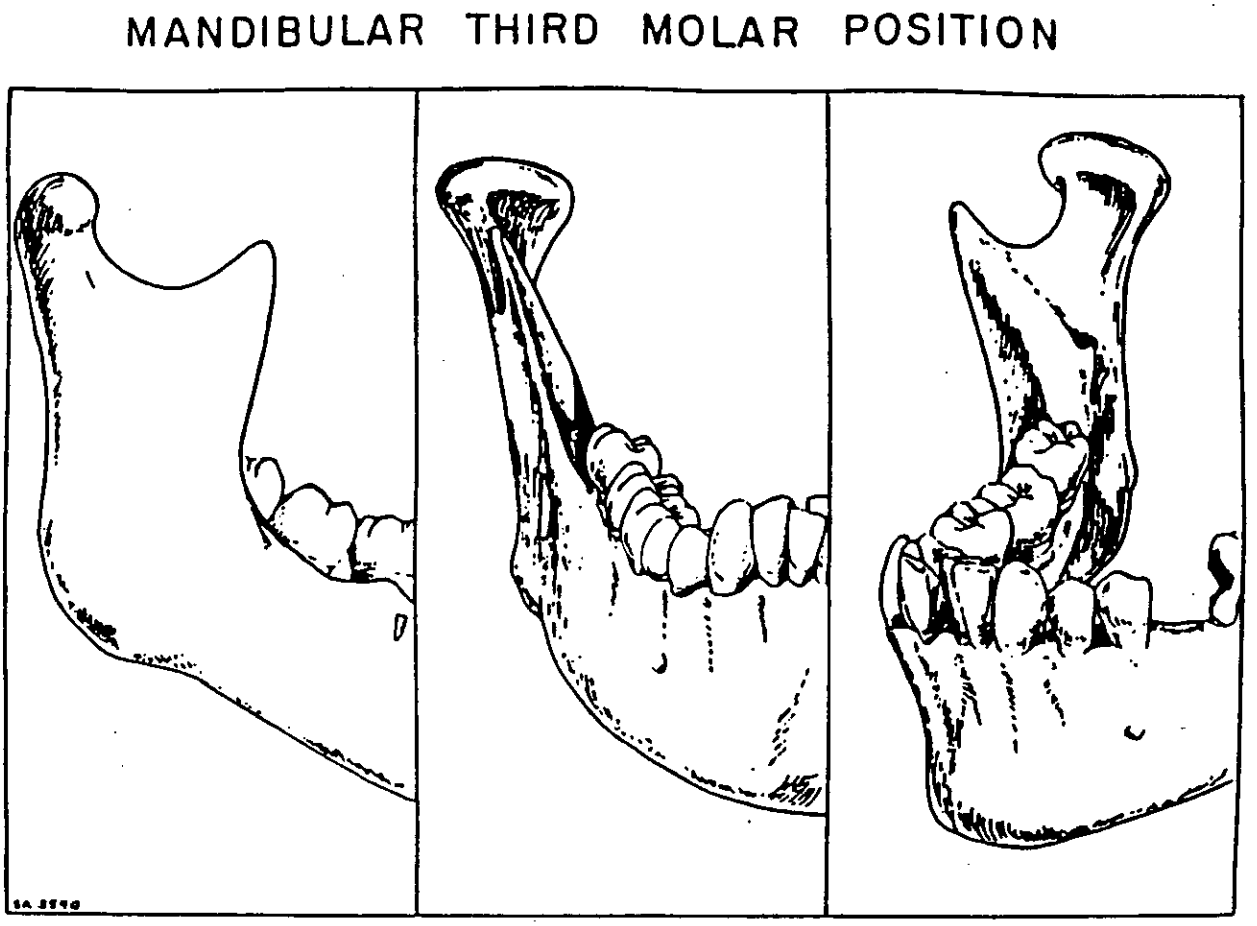


Figure 8. Illustration of the posterior and lingual position of the mandibular third molar relative to the anterior border of the ramus (Illusrtation courtesy of the Bolton-Brush Growth Study Center).

does not take into account normal anatomic variations in size and shape. As a result, though tested statistically for any significant value, this measurement was not included as a key element to the predictive method being tested.

3. Data Manipulation

Following collection of the data and calculation of the appropriate values, the information was entered for computer analysis and formulation of the appropriate statistical model. Of the 59 patients included, 38 had measurements entered for both right and left sides (Table II). By comparison of the mean values of the right side to those of the left side at the various levels of developmental index (pg. 37) it was found with a 95% confidence level that there is no side effect for the measurements of angle to occlusal plane (AOP), eruption distance ratio (EDR), and ramus distance (RD). Therefore, a single mean was calculated for each developmental index (DI) combining right and left sides in each of the 38 individuals.

The method used to relate the occurrence of impaction or eruption to the seven levels of DI was the hierarchial model of multiple logistic regression (Ware and Wu, 1979). This model allowed the risk at each DI to act independently on all measurements made prior to that

DI. The model used was actually a standard multiple regression model except that the number of independent variables avried over each DI, and the parameters had to be estimated seperately for all levels.

The logistic regression model used for this study can be written as:

$$\text{probability (outcome = eruption)} = \frac{1}{1+(2.718)^{-z}}$$

where z is the linear combination:

$$z = b0 + b1\ X1 + b2\ X2 + \ldots + bn\ Xn$$

The probability of outcome = impaction can be estimated as:

probability (outcome = impaction) =

1- probability (outcome = eruption)

If the estimated probability of the outcome = eruption is less than .5, a prediction is made that the event will not occur. If the probability is greater than .5, it is predicted that the event will occur. In the unlikely event that the probability is exactly .5, a prediction can be made in either direction.

In logistic regression, the parameters of the model are estimated using the maximum likelihood method. The coefficients (bn) that make the observed results most "likely" are selected. Since the logistic regression model is non-linear, an iterative algorithm is necessary for parameter estimation and rapid convergence. The

logistic model can be written in terms of the log of the ratio of the probability that outcome = eruption to the probability that outcome = impaction:

$$\log \frac{\text{prob (outcome = eruption)}}{\text{prob (outcome = impaction)}} = b0 + b1\ X1 + \ldots + bnXn$$

The original data had 449 observations from the various individuals. After combining the right and left sides into one mean value, there were 261 observations. Based on these observations, the model was explored with the statistical software SSPS/PC+ logistic regression procedure. By using a stepwise selection technique which is based on a strategy that very few calculations determine the best variable to be added to the model at any given step, a logistic regression model was built as:

z = 15.37 - .14 (AOP) - 7.86 (EDR) + 4.02 (DI = level 1) + 3.56 (DI = level 2) + 3.32 (DI = level 3) + 2.17 (DI = level 4) + 1.17 (DI = level 5) + .56 (DI = level 6) - 8.73 (Class I) - 8.76 (Class II)

The model begins with only the constant 15.37. At each step, the variable with the smallest significance level for the score statistic, provided it is less than the chosen cutoff value (.5), is entered into the model. The likelihood-ratio (LR) test is then used for removing variables from a model. All variables in the model are examined to see if they meet removal criteria (0.10). The algorithm stops when no more variables can be entered

or removed. The above model includes only the variables angle to occlusal plane (AOP), eruption distance ratio (EDR), developmental index (DI), and dental/skeletal classification. The remaining variables (sex, side, ramus distance) were eliminated from the model as useful predictors of outcome using the stepwise analysis previously mentioned.

To determine how well the logistic model performs, the goodness of fit was assessed using two seperate methods:

1) Examination of the probability of the observed results given the parameter estimates, which is known as the "likelihood".

A good model is one which results in a high likelihood of the observed results. Statistically, this translates into a small value of -2 times the log of the likelihood (-2LL). If the model fits perfectly, the likelihood is 1, and the -2LL is zero. Under the null hypothesis that the model fits perfectly, -2LL has a Chi-Square distribution with N-p degrees of freedom, where N is the number of cases and p is the number of parameters estimated. The -2LL for the above model was 138.5 with 250 degrees of freedom. The large observed significance level indicated that this model does not differ significantly from the "perfect" model.

2) Comparison of the model predictions to the

observed outcome using a classification table for outcome:

		Predicted Impacted	Erupted	Total
Observed	Impacted	52	17	69
	Erupted	14	178	192
	Total	66	195	261

Overall percent predicted correctly: 88.1%

Sensitivity: 92.7%

Specificity: 75.4%

False positive rate: 8.7%

False negative rate: 21.2%

The sensitivity is the proportion of true positives that were predicted to be positive. The specificity is the proportion of true negatives that were predicted to be negative. False positive rate is the proportion of predicted positives that were actually negative. False negative rate is the proportion of predicted negatives that were actually positive.

A variety of statistics are used for identifying points for which the model does not fit well, points that exert a strong influence on the coefficient estimates, and variables that are highly related to each other. The statistics used include deviance values, normalized residuals, leverage values, and differences in beta (DFBETA). Following testing of the data with these statistical methods, 6 observations with high residual

values were removed.

Upon deletion of the 6 unusual observations, a new multiple regression model was built:

$$z = 10.15 - .17\,(AOP) - 8.95\,(EDR) + 2.45\,(DI=1) + 1.6\,(DI=2) + 1.34\,(DI=3) - 1.05\,(DI=5) - 1.21\,(DI=6) + 1.67\,(DI=7) + .23\,(Class\ II) + 8.63\,(Class\ III)$$

To determine how well the above model performs, the same two methods of assessing goodness of fit of the model were used:

1) Examining the probability of the observed results.

The -2LL for the new model was 121.77 with 246 degrees of freedom. The large observed significance level indicated that this model does not differ significantly from the "perfect" model.

2) Comparing the model predictions to the observed outcome by the classification table for outcome:

		Predicted		
		Impacted	Erupted	Total
Observed	Impacted	52	13	65
	Erupted	15	177	192
	Total	67	190	257

Overall percentage predicted correctly: 89.1%

Sensitivity: 92.2%

Specificity: 80.0%

False positive rate: 6.8%

False negative rate: 22.4%

Other logistic regression models were examined by removing varying combinations of unusual observations and using alternate statistical methods. However, the above model had the smallest -2LL value and the highest overall predicted percentage and was therefore selected as the best fitting model.

In order to determine the stage of root development at which this model is most useful in prediction of outcome, the predictive ability of each level of DI was examined. The total percentage predicted correctly by the model was determined following the exclusion of observations made at each individual level of DI:

	Total percentage predicted correctly
All levels of DI included	89.1%
Exclude DI=1	92.6%
Exclude DI=2	90.5%
Exclude DI=3	88.7%
Exclude DI=4	87.6%
Exclude DI=5	87.5%
Exclude DI=6	87.8%
Exclude DI=7	89.0%

The model was also tested on an unknown sample consisting of both untreated and orthodontically treated individuals. Unlike the original sample, treated

individuals were included in the unknown sample in order to test the hypothesis that any orthodontic treatment effecting the eruptive pathway of the mandibular third molar during its progressive root development should manifest itself in the predictive measurements made upon completion of treatment. Treatment mechanics negatively effecting the tooth during root development may tend to worsen the position when compared to a normally erupting third molar at the same stage of root development. The opposite may hold true for treatment creating a more favorable environment for third molar eruption. A similar predictability between treated and untreated individuals would support the concept that any changes effecting tooth devolopment and eruption, whether induced by treatment or growth, should be reflected in the predictive measurements.

The unknown test sample was selected from the files of the Bolton-Brush Growth Study Center and contained individuals who exhibited longitudinal records to the point of impaction or eruption of one or both mandibular third molars. The individuals were evaluated using longitudinal cephalometric radiographs and models when possible. Third molars were considered erupted when the mesiobuccal cusp tip reached the level of the occlusal plane. Impaction was defined when a third molar was prevented from erupting due to its mesioangular

relationship with the second molar. This was dignosed past 20 years of age following completion of root formation. The test sample consisted of 10 untreated Class I individuals, 8 untreated Class II individuals, 9 treated Class I individuals, 10 treated Class II individuals, and 1 treated Class III individual (Table IV). The untreated sample contained 9 individuals identified as having at least one erupted mandibular third molar and 9 individuals classified as having at least one impacted mandibular third molar according to the previously mentioned criteria. The treated sample was composed of 5 individuals with at least one mandibular third molar considered impacted and 15 individuals exhibiting at least one erupted mandibular third molar.

In untreated individuals, all but two cephalometric radiographs were selected having a minimum developmental index of .51 (level 3). An attempt was made to select radiographs demonstrating a relatively even distribution of the developmental indices examined (levels 3 through 7). The radiographs were selected based on the presence of appropriate landmarks required to determine the necessary measurements. The initial radiograph was then traced, and the DI, the AOP, the EDR, and the dental/skeletal classification were appropriately entered into the statistical model (pg. 51). An example of how the model was used is clearly demonstrated:

Class II untreated ; DI = .60 (level 3) ; AOP = 30 ; EDR = .57

$$z = 10.15 - .17\,(AOP) - 8.95\,(EDR) + 2.45\,(DI=\text{level } 1) + 1.6\,(DI=\text{level } 2) + 1.34\,(DI=\text{level } 3) - 1.05\,(DI=\text{level } 5) - 1.21\,(DI=\text{level } 6) + 1.67\,(DI=\text{level } 7) + .23\,(\text{Class II}) + 8.63\,(\text{Class III})$$

$$z = 10.15 - .17\,(30) - 8.95\,(.57) + 1.34 + .23$$

$$z = 1.52$$

Notice that all other constants are eliminated from the model except for that associated with the appropriate level of DI. Similarly, only the constant representing the appropriate dental/skeletal classification is maintained. If the DI falls within level 4 or the individual has a Class I dental/skeletal pattern, no constant is added since none exists for these two categories. The model then becomes a simple mathematical calculation.

The probability of eruption is determined as follows:

$$\text{probability (outcome = eruption)} = \frac{1}{1+(2.718)^{-z}}$$

$$= \frac{1}{1+(2.718)^{-(1.52)}}$$

$$= .82$$

This value indicates that the probability of eruption is 82% while that for impaction is only 18%.

Table IV demonstrates the dental/skeletal classification (treated and untreated), the DI, the AOP, the EDR, the probability of outcome = eruption, the predicted outcome, and the actual outcome for each individual tested.

A probability of 70% (.70) was selected as the minimum value considered clinically acceptable in making a prediction of impaction or eruption. In the above example, a prediction of eruption was made. When the probability was less than 70%, another cephalometric radiograph taken a minimum of 6 months later was examined. The time period between progressive radiographs is also indicated in Table IV. The equation was then recalculated and a prediction was made if the probability of impaction or eruption was at least 70%. In one individual (Bolton file # 1074), no clinically acceptable change in probability was noted in three progressive radiographs, therefore a prediction was made based upon the directional trend noted in the calculated values (Table IV). The predicted outcome of each tooth examined was compared to the actual outcome as determined from a cephalometric radiograph exhibiting the appropriate criteria for classification of impaction or eruption. A classification table for outcome was then constructed for the untreated sample demonstrating the various calculations utilized in the computer generated classification table:

		Predicted Impacted	Erupted	Total
Observed	Impacted	7	2	9
	Erupted	1	8	9
	Total	8	10	18

Overall percent predicted correctly: 83%

Sensitivity: 89%

Specificity: 78%

False positive rate: 20%

False negative rate: 13%

Note that in the above sample two of the third molars were predicted at a developmental index of less than .51, contrary to the method suggested in the statistical analysis of the original sample. This was done in order to determine the effect on the overall predictability. Both of these teeth were among the 3 teeth predicted incorrectly, and a prediction made at the next longitudinal radiograph (DI > .50) would have been correct in both cases. The overall predictability excluding these two observations becomes 94%. This data confirms the previous findings stating that this predictive model should be confined to mandibular third molars exhibiting a developmental index of at least .51.

The same methodology was used in testing the treated sample. This portion of the unknown sample consisted of individuals treated with fixed appliances of various

types and durations. The cephalometric radiographs selected were limited to those exhibiting third molars with a minimal DI of .51 (level 3). All radiographs examined were taken following completion of treatment. Table V demonstrates the chronological age of the treated individuals at the various developmental indices examined. The indices are listed in order of increasing dimension to allow for a comparison of chronological age between individuals at the same level of mandibular third molar root development. A classification table for outcome was constructed for the unknown treated sample:

		Predicted		
		Impacted	Erupted	Total
Observed	Impacted	4	1	5
	Erupted	1	14	15
	Total	5	15	20

Overall percent predicted correctly: 90%

Sensitivity: 93%

Specificity: 80%

False positive rate: 7%

False negative rate: 20%

The treated and untreated samples were combined and a final classification table for outcome was constructed demonstrating the overall predictability in the unknown test sample used for this study:

		Predicted Impacted	Erupted	Total
Observed	Impacted	11	3	14
	Erupted	2	22	24
	Total	13	25	38

Overall percent predicted correctly: 87%

Sensitivity: 92%

Specificity: 79%

False positive rate: 12%

False negative rate: 15%

The size of the combined error in locating, superimposing, and measuring the changes in the various landmarks was calculated using the following formula:

$$\text{SE measurement} = \sqrt{\frac{\sum d^2}{2n}}$$

Landmarks were identified and measurements were made on lateral cephalometric radiographs of ten distinct mandibular third molars examined on two independent occasions (one week time interval). The combined error did not exceed .07 for the developmental index, .05 for the eruption distance ratio, 4 degrees for the angle to occlusal plane, and 1.0 mm for the ramus distance.

IV. Results

Numerous varaibles were examined within the sample population investigated. The frequency table (Table II) exhibiting thaes variables demonstrates a relatively even distribution of male (57.6%) and female (42.4%) as well as right (49.1%) and left (50.9%) observations. The overall sample contains a much higher percentage of impacted mandibular third molar observations (69.5%) as opposed to erupted mandibular third molar observations (30.5%). In addition, the sample is composed of a much larger number of Class I individuals (n=43) relative to Class II (n=9) and Class III (n=7) individuals. The age distribution of the individuals examined in the various sample categories is shown in Table III. The wide range of chronological ages is evident in the data. The uneven distribution among certain variables is due to the lack of availability of data.

The means and standard deviations of the Individual's age, the angle to occlusal plane (AOP), the eruption distance ratio (EDR), and the ramus distance (RD) were examined when the developmental index (DI) was measured as zero (crown completion with no root formation). The results (Table VI) demonstrated a slightly smaller mean age (13.49 years) for erupted third molars when compared to those which impacted

(15.32 years), although the values were not significantly different. The values for AOP showed a similar pattern, that for erupted teeth (27.02 degrees) being slightly smaller than that for impacted teeth (32.63 degrees). The EDR exhibited a mean value of .70 for erupted third molars and .82 for the impacted sample. Finally, the RD value was 4.67 mm for cases of eruption and 5.55 mm in cases of impaction.

The same values were calculated for the erupted sample of mandibular third molars which were defined as having complete root formation, and the results are shown in Table VII. The mean and standard deviation of the DI was calculated for these teeth as well, and was found to be 1.33 +/- .33.

The logistic regression model which was developed eliminated a number of the tested parameters as useful predictors, maintaining only the AOP, the EDR, the DI, and the dental/skeletal classification. It was found that the other parameters investigated (sex; side; ramus distance) were not statistically significant in terms of predicting outcome. This allowed for the unification of all data up to the level of dental/skeletal classification, and the development of appropriate means and standard deviations for the identification of significant trends and differences. Table VIII compares the means and standard deviations of the AOP at the

various levels of DI (pg. 37) between impacted and erupted mandibular third molars. The differences are shown for each dental/ skeletal classification, although unavailability of adequate data for Class II and Class III impacted samples does not allow for identification of existing trends. Investigation of the mean values for the AOP in Class I impacted mandibular third molars demonstrates a progressive increase in angulation with increased root development (increasing DI). Conversely, Class I erupted mandibular third molars exhibit a progressive decrease in the AOP as the DI becomes larger. The overlap between standard deviations of impacted and erupted samples within each level of developmental index decreases with increasing root development (increasing DI). At the fourth level (.76-1.00), there is no overlap of standard deviations between the impacted and erupted samples.

The mean values for the AOP in Class II and Class III erupted samples show similar trends, the angular measurements decreasing with increasing DI. When compared to the Class I erupted sample, the Class II sample exhibits mean values for the AOP which are slightly lower in all categories of developmental index except level 4 (.76-1.00) and level 6 (1.26-1.50). However, the differences in the AOP between these samples at each level of DI are quite small. The Class III

sample exhibits mean values for the AOP which are slightly higher in all categories of DI except level 5 (1.01-1.25). Again, these differences are numerically rather minimal.

The means and standard deviations of the eruption distance ratio (EDR) for the impacted and erupted samples in each dental/skeletal classification are shown in Table IX. The Class I erupted sample exhibits a progressive decrease in EDR with increasing root development (increasing DI). The Class I impacted sample demonstrates a slight increase in EDR later in root development (level 4 and 5). When comparing the two samples, the overlap of standard deviations between impacted and erupted teeth disappears at the fourth level of DI (.75-1.00), a finding identical to that seen in the measurements of AOP. Again, insufficient data did not allow any comparison between impacted and erupted samples within Class II and Class III dental/skeletal relationships. When compared to the Class I erupted sample, the Class II erupted sample shows a minimal decrease in the EDR at level 2 (.26-.50) and level 5 (1.01-1.25) of the DI. In addition, the mean EDR at level 4 (.76-1.00) shows a slight increase. The Class III erupted sample also shows a slight decrease in mean EDR at level 2 and level 5 of the DI. The differences between the dental/skeletal classifications with regards

to the mean values of EDR in the erupted samples are very minimal.

The ranges of values for the AOP and EDR at each level of DI are also shown in Tables X, XI, and XII. Table X exhibits the range of observed angles (AOP) and ratios (EDR) for Class I impacted and erupted samples. The ranges of values for the AOP and EDR in erupted and impacted Class II samples are shown in Table XI. The Class III erupted sample demonstrated ranges in the value of AOP and EDR shown in Table XII.

The logistic regression model developed involved the parameters of AOP, DI, EDR, and dental/skeletal classification. Using these parameters, the computer tested the predictability of this model by randomly selecting observations from the pool of data and making a prediction of outcome. The classification table of outcome (pg. 51) demonstrates the actual results as compared to those predicted by the computer. The overall predictability of the model was found to be 89.1%. Of th 192 observations of erupted teeth, 92.2% (177) were correctly predicted as erupted (sensitivity). There was an 80% success rate at correctly predicting impaction of those teeth which actually became impacted (specificity). Of the 190 teeth predicted to erupt, 6.8% (13) actually became impacted. Finally, 22.4% (15) of the 67 teeth predicted to impact actually erupted.

The contribution of individual parameters to the predictability of the overall model was tested by eliminating those parameters and re-evaluating the predictability. Upon examination of the means and standard deviations of the AOP and EDR values (Tables VIII and IX), it is apparent that the differences between the impacted and erupted mandibular third molars are much smaller at very early levels of DI (levels 1 and 2). This finding is suggestive of the lack of statistically significant differences between impacted and erupted mandibular third molars early in development. To determine how these early levels of DI effect the predictability, each level was individually eliminated from the model and the predictability re-evaluated (pg. 52). Upon elimination of level 1 (0-.25), the predictability increased to 92.6%, and the elimination of level 2 (.26-.50) resulted in a predictability of 90% This finding suggests that the lack of adequate differences between impacted and erupted teeth at these levels negatively effects the model, decreasing its predictive ability. As each of the remaining levels of DI were individually eliminated, the overall predictability was found to decrease. These results suggest that the predictabiltiy is positively effected by the inclusion of these levels of DI due to the prescence of adequate statistically significant variation between

impacted and erupted teeth. The model designed is therefore most effective at prediction beginning at a developmental index of .51 (level 3), the earlier developmental indices causing a decrease in predictability.

The predictive model was also tested on an unknown sample consisting of Class I and II untreated individuals as well as Class I, II, and III treated individuals (Table IV). Table V demonstrates the large variability in chronological age of the individuals at the various developmental indices examined in the treated sample. The results for the untreated sample are shown in a classification table of outcome depicted on page 57. The overall predictability was found to be 83%, but when the two observations made prior to a DI of .51 are eliminated, the predictability jumps to 94%, a value which is very close to that found by the computer (89.1%). The sensitivity was found to be 89% and the specificity was calculated as 78%. The false positive rate was 20%, while the false negative rate became 13%. The classification table of outcome for the treated sample is shown on page 58. The overall predictability of this sample was found to be 90% with the inclusion of only mandibular third molars exhibiting a DI of greater than .50. This value is also very close to the computer generated predictability. The sensitivity of this sample

was found to be 93%, and the specificity was calculated as 80%. The false positive rate was 7%, and the false negative rate was found to be 20%. Combining these two samples produced the final classification table of outcome demonstrated on page 59. The combined overall predictability was calculated as 87%. The sensitivity was found to be 92%, and the specificity was 79%. The false positive rate was 12%, and the false negative was calculated as 15%.

V. Discussion

The data collected in this study demonstrates a relatively even distribution of male (57.6%) and female (42.4%) as well as right (49.1%) and left (50.9%) observations. The distribution of erupted (69.5%) and impacted (30.5%) observations, however, is weighted more heavily towards the erupted sample. The logistic regression model selected eliminated the variables of sex and side examined as significant predictors of mandibular third molar impaction or eruption, and this result can be accepted with reasonable confidence due to the equal sample distribution. Upon examination of dental/skeletal classification, however, the sample shows a strong bias towards Class I individuals (n=43), the Class II (n=9) and the Class III (n=7) samples being very limited. The observations made on the mandibular third molars of Class II and Class III individuals are not an adequate statistical representation of those dental/skeletal classifications. Although the statistical model selected incorporated dental/skeletal classification as a significant predictive variable, it must be pointed out that an adequate statistical sampling of Class II and Class III individuals is needed in order to reach a more definitive conclusion regarding the predictive value of these parameters. It is possible that a more evenly

distributed sample may result in elimination of these variables as significant predictors in this statistical model.

The wide range of chronological ages examined is shown in Table III. Although the research did not focus directly on chronological age, some generalizations can be made relative to the various stages of third molar root development. It was noted that a tremendous variability in chronological age of the individual existed among teeth with the same level of root development (same DI). There was very little consistency found between the age of the individual and the level of third molar root development. These observations confirm the hypothesis that chronological age is not a good predictor due to the great anatomic variation which exists in the timing of development. The use of the developmental time table of each individual third molar (DI) allows for a much more meaningful comparison.

A comparison of the variables examined was made between impacted and erupted mandibular third molars at two particular levels of tooth development. The means and standard deviations of age, angle to occlusal plane (AOP), eruption distance ratio(EDR), and ramus distance(RD) were examined at the developmental index of zero (crown completion with no root formation) for impacted and erupted teeth. The mean age of individuals

with erupted teeth exhibiting complete crown mineralization (13.49 years) was found to be slightly lower than that for impacted teeth at the same stage of development (15.32 years). This result tends to be in agreement with the study done by Bjork and Svendsen (1988) stating that late third molar mineralization is one factor contributing to mandibular third molar impaction. The AOP was found to be smaller at this level of development for erupted teeth (27.02 degrees) when compared to impacted teeth (32.63 degrees). This finding is in agreement with Richardson's work (1977) stating that the mesial inclination of mandibular third molars at an early stage of development is higher in cases of impaction. The AOP is one of the significant parameters used to develop the predictive method developed in this study, and this difference in angulation between impacted and erupted teeth is an early indicator of its predictive potential. The mean EDR was also smaller for erupted teeth (.70) as opposed to impacted teeth (.82). This unique ratio is another significant variable in the development of this predictive method, and this early difference is an indicator of the potential predictive value of this measurement.

The same values were determined for erupted mandibular third molars which were defined as having complete root formation. The significant value examined

in this sample was the mean DI upon root completion which was found to be 1.33 +/- .13. This measurement is important in determining the point of mandibular third molar development at which the predictive method being tested becomes significantly useful. The results indicated a good predictability early in tooth development (DI>.50). Since the mean DI upon root completion of erupted mandibular third molars was found to be 1.33, the predictive method examined is clinically useful during a relatively early stage of root development.

Upon investigation of several logistic regression models, the values developed for this predictive method (DI, AOP, EDR) were consistently entered and maintained in the models as useful predictors. The parameters of sex and ramus distance were eliminated in every model examined. In addition, it was found that no side effects existed between right and left sided data, allowing a unification of these values. The elimination of ramus distance as a useful predictor is in agreement with the previously stated hypothesis that this type of linear measurement is not a useful predictor of potential mandibular third molar impaction. The posterior and lingual development of the mandibular third molar relative to the anterior border of the ramus (Figure 8.) is one factor associated with the lack of reliability of

this measurement. Also, the presence of significant anterior border remodeling coupled with the existence of mandibular anatomic variation were two additional factors implicated in the lack of predictive value of any linear measurement made to the anterior border of the ramus. The data allowed elimination of the ramus distance from the predictive method which was ultimately developed due to the lack of statistically significant predictability when using this parameter. The elimination of sex and side examined as useful predictors of mandibular third molar impaction or eruption was also supported by the data. The lack of predictive value of these parameters is speculated as resulting from the use of the developmental index (DI) in this predictive method. The DI allows measurements to be made relative to the stage of root development of each mandibular third molar. It allows the predictability of certain measurements to be determined using the developmental age of the tooth and not the biologic age of the individual. It is hypothesized that any characteristics of growth and development which effect the path of eruption of the mandibular third molar will reflect themselves in the predictive measurements made during the progressive stages of root development. Changes negatively effecting the path of eruption would be expected to worsen the position of that tooth relative to a normally erupting

third molar at the same stage of root development. The opposite effects would be expected from growth changes which positively effect the path of eruption. Consequently, the parameters of sex and side examined become less significant when viewed from the standpoint of the "tooth's age" as opposed to the chronologic age of the individual.

The parameter of dental/skeletal classification could not be eliminated as a significant predictive factor in the statistical model selected. As a result, the data could not be combined at this level of classification. The predictive method developed therefore includes a classification of Class I, Class II, or Class III dental/skeletal pattern. It was hypothesized prior to examination of the data that this parameter would also be insignificant in terms of prediction due to the same reasons previously mentioned with regards to sex and side examined. Although the data indicates that these three categories cannot be statistically combined to yield one mean value, the differences between the means and standard deviations of the predictive values for these classifications is very small (Tables VIII and IX). Further investigation is required in order to determine whether these small differences would be altered if a more adequate representation of individuals exhibiting Class II and

Class III dental/skeletal patterns were examined. Lack of sufficient observations in these two categories was due to unavailability of data.

The inclusion of the angle to occlusal plane (AOP) as a useful predictor in this model is in agreement with Richardson's work (1975) stating that mandibular third molar angulation is a significant factor in helping determine eventual eruption or potential impaction of that tooth. The eruption distance ratio (EDR) developed to help document the distance of the mesiobuccal cusp tip from the mandibular occlusal plane was also found to be a statistically significant predictor of impaction or eruption. Each of the above parameters were selected in order to account for both aspects of mandibular third molar eruption, the presence of sufficient space and the appropriate angulational changes which must preceed it. It was hypothesized that both parameters are necessary in order to develop a consistent predictive method since each aspect of mandibular third molar eruption is an independent variable (Richardson, 1973). These values were maintained as useful predictive variables in all statistical models which were examined.

The AOP was examined for the various levels of developmental index (DI) in each dental/skeletal classification. The mean AOP for Class I erupted mandibular third molars became progressively smaller

while that for Class I impacted mandibular third molars became larger. The differences between the two also became progressively larger with all overlap between the standard deviations disappearing by the DI of .76. These findings demonstrate the lack of sufficient uprighting by those mandibular third molars which did not erupt. The differences between impacted and erupted teeth are much smaller early in development, the lack of adequate rotational uprighting becoming much more significant later in development of the roots. The statistically significant differences in the AOP between impacted and erupted mandibular third molars was found to have a very useful predictive value.

The AOP for Class II and Class III erupted samples showed trends similar to those of the Class I sample. The angulation became smaller with progressive stages of root development (increasing DI). When compared to the Class I sample, the Class II mean values for the AOP were slightly lower at all values of DI except two. These differences were small, and any conclusions reached are based upon a limited sampling of Class II individuals (n=9). The Class III sample exhibited mean values for the AOP which were slightly higher at all levels of DI except one. This dental/skeletal classification also exhibited a very limited number of individuals (n=7). The Class II and Class III impacted samples did not have

adequate observations to draw any statistically significant conclusions. Again, further research is required in these categories due to insufficient availability of data.

The means and standard deviations for the eruption distance ratio (EDR) at each level of DI were also compared between dental/skeletal classifications. The Class I erupted sample showed a progressive decrease in EDR with increasing DI, while the Class I impacted sample showed a slight increase in EDR at levels 4 and 5 (.76-1.00; 1.01-1.25) of the DI. The differences between the two samples became progressively larger with all overlap between the standard deviations disappearing by the DI of .76 (level 4). The impacted sample exhibited a lack of vertical positional changes in the mesiobuccal cusp tip resulting in an increase in distance from the mandibular occlusal plane in the later stages of root development. This parameter was statistically found to have a very useful predictive value. In combination with the value of AOP, this parameter was very consistent in predicting mandibular third molar impaction or eruption.

The Class II and Class III erupted samples showed identical trends and minimal differences in mean EDR at all levels of DI when compared to the Class I erupted sample. Insufficient data did not allow any statistically significant conclusions to be drawn

regarding Class II and Class III impacted samples. The differences between dental/skeletal classificatiions which do exist are very minimal, and further examination is required to reach additional conclusions.

The logistic regression model developed to determine the probability of outcome was used to produce a computer generated predictability using random selections from the samples examined. The overall predictability was found to be 89.1%, a value which is clinically significant as a diagnostic tool. This high predictability demonstrates the value of the parameters examined when evaluated from the standpoint of the various stages of root development of the mandibular third molar. This finding confirms the hypothesis that documentation of the angulational and positional changes of the mandibular third molar can be very useful in helping predict impaction or eruption when using the developmental time table of the indivdual tooth. It is hypothesized that any changes in craniofacial growth effecting the path of eruption of the mandibular third molars should manifest themselves in the predictive parameters examined at the various stages of root development.

The contribution of individual parameters to the predictability of the overall model was also examined. It was found that the first two levels of DI (0-.25; .26-.50) decreased the overall predictability of the model.

Although the decrease in predictability was relatively small and the overall predictability remained quite high, it must be noted that the most effective predictive ability of this model begins at level 3 of the DI (.51 and above). Richardson (1977) concluded that it is not possible to predict third molar impaction or eruption at an early age of 10 to 11 years using measurements indicating available space or size and shape of the mandible. She noted that differences between impacted and erupted samples are insignificant early in development, becoming progressively larger with increased growth. The results in this study support the conclusion that positional differences between impacted and erupted mandibular third molars are much smaller at an early stage of root development as well, agreeing with Richardson's findings in terms of early mandibular development. The variation between the means and standard deviations of the angle to occlusal plane and the eruption distance ratio (Tables VIII and IX) also reflect the lack of differences between impacted and erupted mandibular third molars in the early stages of root development. It is at level 3 of the developmental index (.51-.75) that differences between the two samples begin to become more significant. It was therefore concluded that this predictive model is best used on mandibular third molars exhibiting a developmental index

of at least .51 (level 3).

The predictive model was also tested on an unknown sample of treated and untreated individuals representing each of the three dental/skeletal classifications (Table IV). The chronological age of each individual at the various levels of developmental index (DI) is shown in Table V. The data indicates a great range in the age of individuals exhibiting mandibular third molars at approximately the same stage of root development. This finding is in agreement with the previously mentioned data regarding the original samples examined (pg. 69). The data therefore supports the hypothesis that chronological age is not a good criterion to be used in the evaluation of third molar development and eruption. The large disparity in age between individuals exhibiting mandibular third molars at the same stage of root development indicates that chronological age is not a reliable parameter to be used in prediction. A more careful examination of the chronological age of the individuals at the various levels of DI is required in order to thoroughly document the large variability which exists.

The overall predictability of the unknown untreated sample was found to be 83% (pg. 57). This predictability, however, included two incorrect predictions based on observations made at a

developmental index of less than .51. Upon elimination of these two observations, the predictability becomes 94%. In addition, a prediction made on the subsequent radiograph at the appropriate level of DI (level 3) as previously discussed would have produced a correct prediction in both instances. These observations were included in order to test the effect of predictions made at a DI of less than .51. The findings support the original data stating that prediction prior to level 3 of the DI (.51-.75) has a detrimental effect on the overall predictability of the model due to insignificant differences between impacted and erupted mandibular third molars at an early stage of root development. It is interesting to note that the overall predictability of the model without these two observations (94%) is very similar to the computer generated predictability (89.1%).

A significant value to note upon examination of the classification tables for outcome is the number of mandibular third molars predicted to impact which ultimately erupted. It is this value which is most clinically significant in terms of patient management. A premature prediction of impaction results in unnecessary surgery for the individual, whereas an incorrect prediction of eruption merely delays the surgical procedure. Therefore, it is an incorrect prediction of impaction which the clinician must be most concerned

with. In the original sample examined, 15 of the 257 observations made (6%) were incorrectly classified as mandibular third molars which would ultimately become impacted (pg. 51). In the untreated unknown sample (pg. 57), only 1 of the 18 observations (6%) was incorrectly predicted as an impaction in which the tooth did ultimately erupt.

Upon examination of the treated unknown sample (pg. 58), the overall predictability was found to be 90%. This sample only included observations made on mandibular third molars having a DI falling in the range of level 3 (.51-.75). The similarity to the overall computer generated predictability (89.1%) is again apparent. In addition, only 1 of the 20 observations (5%) was incorrectly predicted as an impaction in which the tooth ultimately erupted. Combining the treated and untreated unknown samples yielded an overall predictability of 87%. It must be pointed out that elimination of the two untreated observations made prior to level 3 of the DI would produce an overall predictability of 92% which is also very close to the computer generated predictability. Of the 38 total predictions made, only 2 (6%) were incorrectly classified as teeth which would ultimately become impacted.

A detailed investigation and statistical analysis of the data indicates that the predictive model described in

this study has useful clinical significance as a dignostic tool which can assist the dental practitioner in making a judgement regarding the potential for impaction or eruption of mandibular third molars. The statistical model developed offers a simple mathematical equation which can be used to produce a probability of outcome which can assist in the decision regarding the surgical extraction of mandibular third molars. The model incorporates a unique concept, focusing on the developmental state of the tooth and not that of the individual. This unique focus in combination with the non-linear predictive parameters developed most likely accounts for the good predictability demonstrated by the model.

The model also allows for clinical judgement to be used regarding the decision as to what level of probability is considered acceptable in making a prediction. The criterion used in this study was a 70% probability of impaction or eruption. Any value below this was not considered clinically acceptable, and another cephalometric radiograph was examined at a minimum interval of 6 months. It is recommended that the the clinical acceptability of each calculated probability be evaluated by each individual according to the clinical circumstances with which he or she is presented. Higher minimally acceptable probabilities would most

likely produce even higher predictabilities, but this is left to the discretion of the practitioner. It is also recommended that no prediction be made prior to adequate root development of the mandibular third molar which would place the tooth in level 3 (.51-.75) of the developmental index. If adequate root development is not present or the calculated probability is not considered clinically acceptable to make a prediction, it is recommended that another radiograph be taken a minimum of 6 months later. This time period can be adjusted to meet each individual practitioner's needs, but 6 months is considered a minimal time for useful changes to occur in the development of the tooth.

The predictive model was also tested on an unkwown treated sample following completion of treatment. It was hypothesized that any treatment mechanics effecting the mandibular third molar during its progressive stages of development would place that tooth in a more or less favourable position upon completion of treatment relative to an untreated tooth at the same stage of root development. Although a high predictability was found upon examination of a treated sample following completion of treatment, further investigation is required to establish more definitive conclusions. A larger sample separated by treatment modality and exhibiting a more even distribution of impacted and erupted mandibular

third molars would be very helpful in reaching additional conclusions regarding clinical applicability of the model in treated individuals.

It should be pointed out that any predictions made with this model are based on a two dimensional analysis, and no prediction can be made regarding the final buccal-lingual position of the tooth. Other prediction methods using frontal cephalometric radiographs (Svendsen et. al., 1985) can be used to assist in buccal-lingual evaluation. In addition, the model is limited by the ability of the examiner to clearly distinguish the points and planes required to calculate the appropriate values. It is recommended that 60 degree rotated cephalometric radiographs be taken if needed to assist in the seperation of right and left mandibular third molars (Richardson, 1977).

Further investigation is required to determine the possibiltiy of application of this model to other types of radiographs. The reliability of the model using panoramic or periapical radiographs is a topic which could ultimately produce clinically useful information. Tait and Williams (1978) stated that distortion of the projected angles measured on a radiograph become appreciable only when the plane of the film is angulated greater than 10 degrees to the side of the mandible being examined. This finding could help compensate for

distortion error resulting from malpositioning of periapical radiographs or malalignment of the head during panoramic radiography. The ratios included in the predictive model could help compensate for radiographic distortion of any linear measurements. Further investigation is required, however, in order to determine whether the predictive parameters examined in this study are reliable enough to produce consistent predictability using other types of radiographs.

The untreated unknown sample was also examined by an orthodontist with 33 years of clinical experience in private practice and a part-time faculty position in the Case Western Reserve University Department of Orthodontics. The identical cephalometric radiographs (9 impacted; 9 erupted) examined for prediction utilizing the model developed in this study were given to this individual for visual examination. The chronological age of the individual at the time of the radiograph was also given. A visual examination of the tooth in question was completed, and a prediction was made regarding potential eruption or impaction of the tooth. The overall predictability was found to be 61% (11 out of 18 predicted correctly). This individual stated that he frequently recommends extraction of mandibular third molars in his practice. The results indicated a lower predictability than that for the model developed in this

study (83%), but consideration should be given to the clinical bias of the individual when interpreting these results. In addition, clinical experience in the management of mandibular third molars could also produce highly varaible results among individuals.

VI. Conclusions

1. The values of the angle to occlusal plane and the eruption distance ratio measured at various stages of mandibular third molar root development (developmental index) were found to be statistically significant parameters in the prediction of impaction or eruption.

2. The dental/skeletal classification (Class I, Class II, and Class III) of the individual examined was found to be statistically significant in terms of mandibular third molar eruption prediction.

3. The parameters of sex, side of the mandible examined, and ramus distance were not found to be statistically significant in terms of prediction of impaction or eruption of mandibular third molars.

4. The chronological age among individuals at the same stage of mandibular third molar root development was found to be highly variable.

5. The chronological age of individuals exhibiting erupted mandibular third molars at the stage of complete crown calcification (no root formation) was found to be less than that of individuals demonstrating impacted

mandibular third molars at the same stage of development.

6. The angle to occlusal plane and the eruption distance ratio measured upon completion of crown calcification (no root formation) were found to be smaller in erupted mandibular third molars when compared to impacted mandibular third molars at the same stage of development.

7. The mean value of the angle to occlusal plane became progressively smaller with increasing root development in the sample of erupted mandibular third molars.

8. The mean value of the angle to occlusal plane became progressively larger with increasing root development in the sample of impacted mandibular third molars.

9. The differences in the means of the angle to occlusal plane between impacted and erupted mandibular third molars became progressively larger with increasing root development.

10. The mean value for the eruption distance ratio became progressively smaller with increasing root development in the erupted sample of mandibular third molars.

11. The mean value for the eruption distance ratio in the sample of impacted mandibular third molars showed a slight decrease later in root development.

12. The differences in the means of the eruption distance ratio between impacted and erupted mandibular third molars became progressively larger with increasing root development.

13. The predictive model developed included the parameters of developmental index (DI), angle to occlusal plane (AOP), eruption distance ratio (EDR), and dental/skeletal classification:

$$z = 10.15 - .17\,(AOP) - 8.95\,(EDR) + 2.45\,(DI=level\ 1) + 1.6\,(DI=level\ 2) + 1.34\,(DI=level\ 3) - 1.05\,(DI=level\ 5) - 1.21\,(DI=level\ 6) + 1.67\,(DI=level\ 7) + .23\,(Class\ II) + 8.63\,(Class\ III)$$

$$\text{Probability (outcome = eruption)} = \frac{1}{1 + (2.718)^{-z}}$$

14. The predictive model tested was found to be most efficient when used beginning at level 3 of the developmental (.51-.75). Predictions made prior to this level of root development were found to decrease the overall predictability of the model.

15. The computer generated predictability of impaction or eruption was found to be 89.1% through random selection from the original samples examined.

16. The overall predictability of the model tested in an unknown untreated sample consisting of 18 individuals (9 with erupted and 9 with impacted mandibular third molars) was found to be 83%.

17. The overall predictability of the model tested in a sample treated with fixed appliances and consisting of 20 individuals (15 with erupted and 5 with impacted mandibular third molars) was found to be 90%.

Table I. Categorical listing of the file numbers of the individuals examined in the original sample. All information was gathered from the Bolton-Brush Growth Study Center at Case Western Reserve University in Cleveland, Ohio.

	Class I		Class II		Class III	
Erupted	1024	1158	1157	2327	1224	3143
	1047	1908	2328	2768	144	277
	2058	2627	3144	3381	3341	3349
	2720	2798	3289		3377	
	2893	2478				
	2242	2425				
	2471	2516				
	3156	3197				
	3367	3477				
	3408	3533				
	3546	3634				
	3130	945				
	2574	3159				
	3517					
Impacted	1192	112	3357	3403		
	153	422				
	1123	1530				
	2792	2815				
	3149	3234				
	2702	1883				
	3714	2517				
	3355	2216				

Table II. Frequency table for discrete variables.

Outcome	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Impaction	18	30.5	18	30.5
Eruption	41	69.5	59	100.0

Class	Frequency	Percent	Cumulative Frequency	Cumulative Percent
I	43	72.9	43	72.9
II	9	15.2	52	88.1
III	7	11.9	59	100.0

Sex	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Female	25	42.4	25	42.4
Male	34	57.6	59	100.0

Side	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Right	10	16.9	10	16.9
Left	11	18.6	21	35.6
Right and Left	38	64.4	59	100.0

Table III. Chronological age ranges of individuals for each longitudinal series of cepholometric radiographs examined in each sample grouping (ages listed in years-months).

	Class I Erupted	Class I Impacted	Class II Erupted	Class II Impacted	Class III Erupted
Male	12-0 to 19-0	15-0 to 18-0	14-0 to 18-0	15-4 to 20-2	15-2 to 19-2
	14-1 to 19-10	13-0 to 18-2	14-0 to 18-7	12-11 to 24-8	13-3 to 18-4
	13-0 to 20-0	16-11 to 19-4			13-11 to 18-3
	15-5 to 21-5	14-2 to 18-2			13-0 to 19-4
	12-0 to 16-11	14-11 to 19-0			14-0 to 18-6
	12-11 to 19-0	15-5 to 18-0			12-11 to 17-1
	10-11 to 17-0	15-2 to 20-0			
	14-0 to 19-0	14-6 to 20-6			
	13-0 to 17-11	15-0 to 25-2			
	13-0 to 20-10				
	13-8 to 17-6				
	12-11 to 17-0				

continued

Table III. Continued

	Class I Erupted	Class I Impacted	Class II Erupted	Class II Impacted	ClassIII Erupted
Male	14-0 to 18-0				
	14-11 to 24-7				
	13-11 to 17-10				
Female	13-11 to 20-2	18-0 to 21-1	13-1 to 20-1		13-0 to 20-3
	13-7 to 18-11	13-0 to 19-1	14-11 to 20-1		
	12-1 to 17-0	17-11 to 24-1	15-10 to 18-0		
	16-0 to 19-0	15-1 to 20-0	15-0 to 22-2		
	14-8 to 18-2	14-0 to 23-3	10-11 to 20-2		
	13-2 to 18-2	17-11 to 23-1			
	12-0 to 19-0	11-11 to 19-11			
	15-0 to 21-0				
	12-0 to 19-1				
	11-11 to 18-0				
	14-0 to 33-1				
	14-0 to 20-0				

Table IV. Listing of the untreated and treated unknown samples tested with the predictive model. Included are the Bolton file number, dental/skeletal classification with treatment status (UTR-untreated; TR-treated), developmental index (DI), angle to occlusal plane in degrees (AOP), eruption distance ratio (EDR), probability of outcome=eruption (Prob), prediction made (E-eruption; I-impaction), and actual outcome.

Bolton #	Class/ TR-UTR	DI	AOP	EDR	Prob (E)	Pred	Actual
3092	Class I-UTR	.77	18.5	.40	.97	E	E
2733	Class I-UTR	.67	27	.57	.86	E	E
3319	Class I-UTR	.69	34	.36	.92	E	E
3483	Class I-UTR	.79	45	.62	.05	I	I
2972	Class I-UTR	.49	31	.54	.84	E	I
3315	Class I-UTR	.64	14	.50	.99	E	E
2656	Class I-UTR	.57	23	.36	.99	E	E
3438	Class I-UTR	.63	32	.92	.10	I	I
945	Class I-UTR	.76	33	.53	.44	---	---
(6 months later)		.88	28	.50	.71	E	E
2747	Class I-UTR	.76	51	.46	.07	I	I
2094	Class II-UTR	.52	39	.73	.19	I	I
3177	Class II-UTR	.60	30	.57	.82	E	E
3362	Class II-UTR	.81	24	.31	.97	E	E
1074	Class II-UTR	.51	31	.67	.51	---	---
(1 year later)		.70	32	.67	.57	---	---
(1 year later)		.82	38	.42	.54	I	E
2423	Class II-UTR	.67	47	.83	.02	I	I
259	Class II-UTR	.47	20	.57	.97	E	I
3471	Class II-UTR	.73	40	1.17	.01	I	I
1167	Class II-UTR	.81	38	.77	.05	I	I
3140	Class I-TR	.63	30.5	.30	.97	E	E
1038	Class I-TR	.58	34	1.00	.04	I	I
3369	Class I-TR	.53	32	.55	.76	E	E
159	Class I-TR	.83	25	.54	.74	E	I
3425	Class I-TR	.59	32	.83	.20	I	E

continued

Table IV. Continued

Bolton #	Class/ TR-UTR	DI	AOP	EDR	Prob (E)	Pred	Actual
2959	Class I-TR	.75	35	.90	.02	I	I
3208	Class I-TR	.65	27	.18	.99	E	E
1005	Class I-TR	.63	28	.58	.82	E	E
1840	Class I-TR	.86	29	.23	.96	E	E
2569	Class II-TR	.88	18	.67	.79	E	E
2809	Class II-TR	.53	26	.69	.75	E	E
1214	Class II-TR	.77	32	.92	.04	I	I
4491	Class II-TR	.65	15	.15	.99	E	E
1129	Class II-TR	.63	21	.29	.99	E	E
1087	Class II-TR	.75	25	.69	.49	---	---
(1 year/3 months)		.94	34	.86	.04	I	I
2027	Class II-TR	.68	30	.43	.94	E	E
2732	Class II-TR	.76	19	.67	.76	E	E
2896	Class II-TR	.80	14	.83	.64	---	---
(1 year later)		1.00	13	.41	.99	E	E
1025	Class II-TR	.73	19.5	.58	.96	E	E
2900	Class III-TR	.75	25	.42	.99	E	E

Table V. Chronological ages of the individuals in the unknown treated sample at the various developmental indices examined (ages listed in years-months).

Bolton #	Developmental Index	Chronological Age
2809	.53	15-11
3369	.53	22-2
1038	.58	19-6
3425	.59	16-11
1129	.63	15-11
3140	.63	17-11
1005	.63	18-7
4491	.65	16-11
3208	.65	17-6
2027	.68	16-0
1025	.73	15-9
1087	.75	19-9
2959	.75	16-8
2900	.75	18-1
2732	.76	16-5
1214	.77	18-2
2896	.80	18-6
159	.83	16-3
1840	.86	19-0
2569	.88	15-6
1087	.94	20-4
2896	1.00	19-7

Table VI. Means and standard deviations of chronological age, angle to occlussal plane (AOP), eruption distance ratio (EDR), and ramus distance (RD) upon completion of crown calcification with no root formation (developmental index = 0).

	Outcome			
	Impaction (n=19)		Eruption (n=57)	
Variable	Mean	Std	Mean	Std
Age (years)	15.32	1.69	13.49	1.16
AOP (degrees)	32.68	9.10	27.02	7.22
EDR	0.82	0.13	0.70	0.16
RD	5.55	1.35	4.67	1.45

Table VII. Means and standard deviations of chronological age, angle to occlusal plane (AOP), eruption distance ratio (EDR), ramus distance (RD), and developmental index (DI) upon completion of root formation.

	Outcome	
	Eruption (n=44)	
Variable	Mean	Std
Age (years)	19.85	3.40
AOP (degrees)	7.10	5.78
EDR	0.01	0.05
RD	8.13	1.72
DI	1.33	0.13

Table VIII. Means and standard deviations of the angle to occlusal plane (in degrees) at each level of developmental index (DI) classified according to outcome and dental/skeletal classification. Level 1: DI = 0-.25; level 2: DI = .26-.50; level 3: DI = .51-.75; level 4 DI = .76-1.00; level 5: DI = 1.01-1.25; level 6: DI = 1.26-1.50; level 7: DI = 1.51-1.75.

Class I

Outcome		Developmental Index 1	2	3	4	5	6	7
Impaction	Mean	32.0	33.4	36.3	39.1	46.1	--	--
	Std	6.8	4.7	7.5	11.2	24.6	--	--
Eruption	Mean	26.8	25.1	24.3	19.5	12.2	6.8	9.3
	Std	7.0	4.5	6.6	5.8	8.1	5.4	2.9

Class II

Outcome		Developmental Index 1	2	3	4	5	6	7
Impaction	Mean	19.0	22.0	--	--	--	47.5	--
	Std	--	0.0	--	--	--	12.0	--
Eruption	Mean	22.8	21.3	21.2	20.1	11.6	7.5	--
	Std	9.2	8.9	7.6	7.5	4.1	0.7	--

continued

Table VIII. Continued

Class III Outcome		Developmental Index 1	2	3	4	5	6	7
Impaction	Mean	--	--	--	--	--	--	--
	Std	--	--	--	--	--	--	--
Eruption	Mean	27.9	26.4	25.0	22.8	11.6	9.0	--
	Std	5.2	2.5	6.0	3.9	5.2	7.9	--

Table IX. Means and standard deviations of the eruption distance ratio at the various levels of developmental index classified according to outcome and dental/skeletal classification (see Table VIII for range of developmental indices included in each level).

Class I Outcome		Developmental Index 1	2	3	4	5	6	7
Impaction	Mean	0.8	0.8	0.8	0.9	0.9	--	--
	Std	0.1	0.1	0.2	0.3	0.6	--	--
Eruption	Mean	0.7	0.7	0.5	0.3	0.1	0.0	0.0
	Std	0.2	0.1	0.2	0.2	0.1	0.0	0.0

Class II Outcome		Developmental Index 1	2	3	4	5	6	7
Impaction	Mean	0.8	0.8	--	--	--	0.9	--
	Std	--	0.0	--	--	--	0.1	--
Eruption	Mean	0.7	0.6	0.5	0.4	0.0	0.0	--
	Std	0.2	0.1	0.1	0.1	0.1	0.0	--

continued

Table IX. Continued

Class III Outcome		Developmental Index 1	2	3	4	5	6	7
Impaction	Mean	--	--	--	--	--	--	--
	Std	--	--	--	--	--	--	--
Eruption	Mean	0.7	0.6	0.5	0.3	0.0	0.0	--
	Std	0.2	0.1	0.1	0.1	0.0	0.0	--

Table X. Ranges of values for the angle to occlusal plane (AOP) and eruption distance ratio (EDR) at the various levels of developmental index in Class I individuals classified according to outcome (see Table VIII for range of developmental indices associated with each level).

Developmental Index Level	AOP		EDR	
	Impaction	Ertuption	Impaction	Eruption
1	24-46.5	4-37.5	.70-1.03	.45-1.09
2	22-40	19-32.5	.64-1.07	.38-.87
3	24.5-50.5	11.8-38	.57-1.24	.18-.86
4	20-60.5	11-32	.61-1.64	0-.66
5	33-90	1.5-27.5	.54-2.0	0-.36
6	---	0-16.5	---	0-.08
7	---	6-11.8	---	0

Table XI. Ranges of values for the angle to occlusal plane (AOP) and eruption distance ratio (EDR) at the various levels of developmental index in Class II individuals classified according to outcome (see Table VIII for the range of developmental indices associated with each level).

Developmental Index Level	AOP		EDR	
	Impaction	Eruption	Impaction	Eruption
1	19	14-39.5	.8	.42-.89
2	22	11-33	.81	.36-.69
3	---	12-30.5	---	.47-.61
4	---	13-34	---	.09-.69
5	---	6-15.3	---	0-.14
6	39-56	7-8	.77-.94	0
7	---	---	---	---

Table XII. Ranges of values for the angle to occlusal plane (AOP) and eruption distance ratio (EDR) at the various levels of developmental index in Class III individuals classified according to outcome (see Table VIII for ranges of developmental indices associated with each level).

Developmental Index Level	AOP		EDR	
	Impaction	Eruption	Impaction	Eruption
1	---	23-36.5	---	.51-.92
2	---	23-30	---	.46-.81
3	---	21-37	---	.38-.64
4	---	18.5-29.5	---	.16-.50
5	---	7-20	---	0
6	---	0-17	---	0
7	---	---	---	---

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