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VALIDATION OF THE CONTEMPORARY TECHNIQUES FOR THE PREDICTION OF LOWER THIRD MOLAR IMPACTION

by

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Submitted in partial fulfillment of the requirements

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Abstract

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Although the prediction of lower third molar impaction has been attempted for many years, a prediction service has only recently been made commercially available by Rocky Mountain Data Systems, Inc. It is claimed that their technique (described by Turley and Chaconas in 1975) can predict, ten years in advance, the space available for third molar eruption to ±2.8 mm and, because the third molar eruption is a function of space, eruption can and should be predicted. Although an increasing number of orthodontist employ this service, little independent support for its efficacy is available. Accordingly, an investigation of the accuracy of this technique, as well as that of the two other workers (Leydard and Richardson), was undertaken.

Sixty-two longitudinal cephalometric series, spanning the period from eight years of age to maturity, were selected from the files of the Bolton-Brush Growth Study Center. Each subject had an average of thirteen cephalometric radiographs.

Separate predictions were obtained for both lower third molars by tracing both right and left sides of the mandible, teeth, and occlusal plane for the three techniques. The accuracy of the prediction methods were examined by a variety of statistical tests and the fol-

lowing conclusions were drawn:

(1) Leydard's method was biased toward the prediction of impaction. Of forty-five erupted third molars, only eight were predicted.

(2) Richardson's general observations that steeply angled third molars tend to be impacted and tend to upright less were corroborated by this study. However, Richardson did not present a prediction method per se; therefore, these observations do not constitute a formal validation of a prediction technique.

(3) For Turley's method, the coefficient of triserial correlation between the predicted measurements and the final status of the tooth was of only "moderate" magnitude, averaging .527 for all prediction intervals.

(4) Overall, the Turley method was correct in only 49.5% of the cases. Its accuracy decreased in direct proportion to the length of the prediction interval.

(5) Because with the Turley method several highly undesirable outcomes have a finite probability, the orthodontist probably would choose to "watch and wait," a simpler course of action that probably would have both a higher expected "payoff" and a lesser risk.

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DEDICATED

TO

My wife, Debra, with everlasting love, honor, and respect;

And my parents, Mr. and Mrs. Leo Fink, who made my education, and thus, this paper possible;

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INTRODUCTION

Recently, a computerized scheme designed to forecast the impaction of mandibular third molars has been presented to the dental profession by Rocky Mountain Data Systems (RMDS). This method, developed by Turley and Chaconas (1975), is based on a forecast of the space that will be available to accommocate the third molars at maturity (nineteen years for males; fifteen years for females).

Although this is the first publicized attempt at "computerized" prediction of mandibular third molar impactions, it is not the only method available to orthodontists. Indeed, the feasibility of predicting lower third molar impaction was examined as early as 1936 (Henry and Morant). Leydard (1953) was the first to suggest a prediction formula using the anterior border of the ramus to the distal surface of the lower first molar for a linear measurement of space available for the eruption of the third molar. Margaret Richardson (1975) examined lower third molar impactions by observing the relationship of the axial angulation of the lower third molar to the mandibular plane.

Upon close examination of these two earlier prediction methods, faults can readily be recognized. Leydard's use of the anterior border of the ramus has two inherent problems. Firstly, upon viewing the lateral cephalogram, the image of the anterior border of the ramus crosses the third molar, giving the impression that the third

molar is impacted; in reality, the third molar usually erupts lingual to the anterior border, and what may appear, radiographically, to be an impacted third molar, may actually be a fully erupted tooth (Figure 1). Secondly, accurately tracing the anterior ramal border in the area of the second and third molars is a technically difficult procedure. The molar series often obscures the anterior border, and in many cases it is impossible to locate precisely. Consequently, the anterior border of the ramus is a questionable landmark upon which to base a prediction method.

Richardson's approach appears to be more of an observed relationship rather than a specific prediction technique. No definitive criteria were suggested as to how her observations could be used in forecasting future impactions.

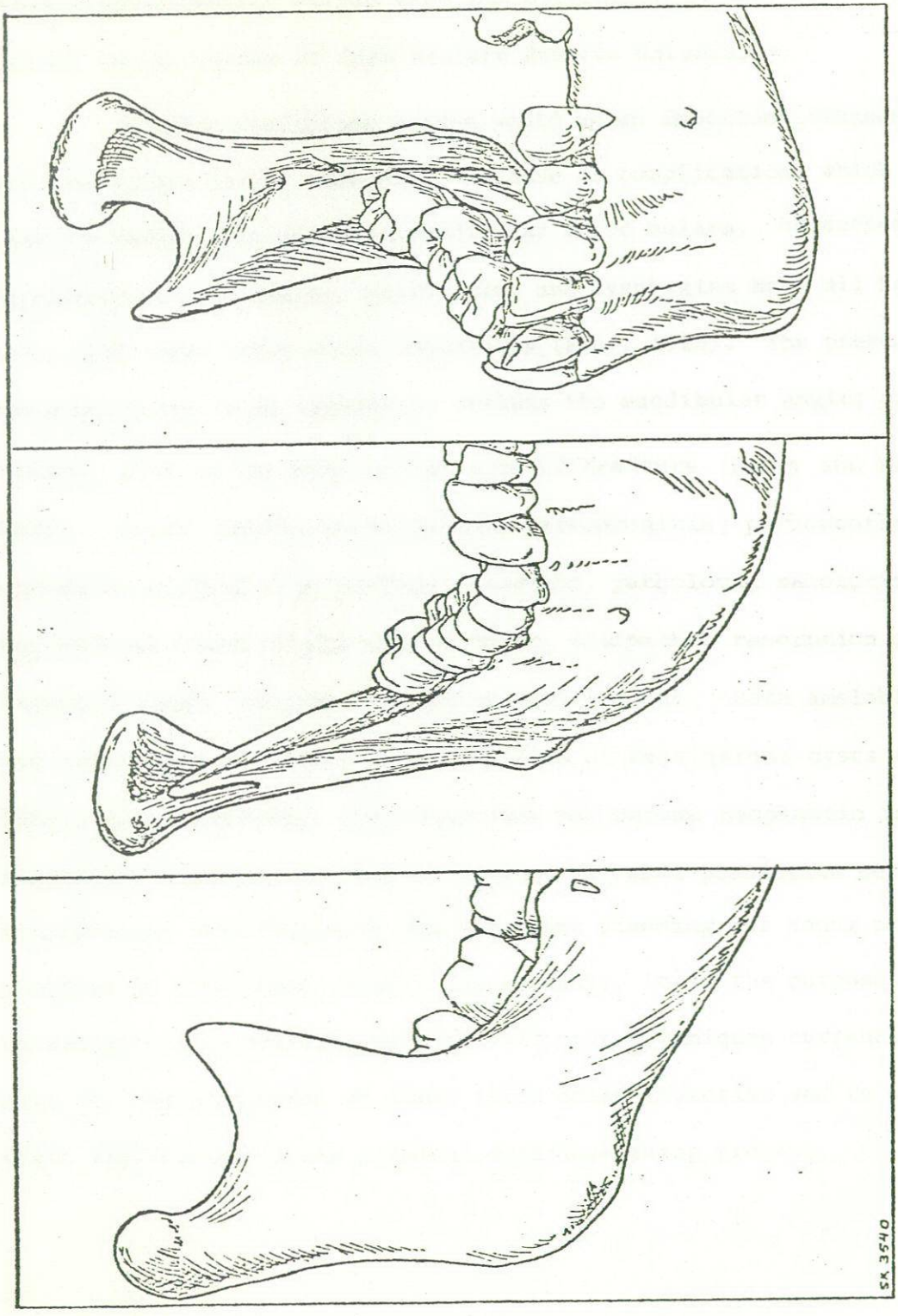
Turley's prediction technique is based upon an easily constructed landmark, and has recently attracted the attention of the orthodontic community, primarily because of its widespread commercial circulation through RMDS.

Curiously enough, an increasing number of orthodontists are taking advantage of this service, in spite of the fact that the only studies substantiating the technique are studies which have been performed by RMDS. Therefore, an independent investigation of the validity of their technique should be undertaken.

An investigation of any prediction scheme would necessarily require the use of a longitudinal series of cephalometric radiographs on subjects who have never been treated orthodontically.

FIGURE 1

THE USUAL ANATOMIC RELATIONSHIP OF THE MANDIBULAR THIRD MOLAR TO THE ANTERIOR BORDER OF THE RAMUS


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Fortunately, this requirement was easily met by obtaining longitudinal cephalometric series from the collection of the Bolton-Brush Growth Study center at Case Western Reserve University.

A valid prediction scheme would be an important diagnostic tool for the entire dental community, because of complications which frequently result from impacted mandibular third molars. Headaches, ocular disturbances, neuralgias, neuritides, and dysphagias have all been associated with lower third molar impactions (Fahy, 1926). The presence of an impacted third molar apparently weakens the mandibular angle; and, with facial trauma, this is the most common site of fracture (Henry and Morant, 1936). Other complications include pericoronitis, periodontitis, caries associated with partial impaction, pathologic resorption of the adjacent root of the second molar, idiopathic resorption of the impacted tooth, and cyst formation (Carr, 1966). Both ameloblastomas and carcinomas may arise from the walls of dentigerous cysts (Carr, 1966), and odontogenic cyst membranes may become neoplastic in the stratified squamous epithelial lining. A valid prediction method, incorporated into diagnoses and treatment planning for young patients, could be of tremendous value. Consequently, it is the purpose of this investigation to evaluate statistically the techniques currently available for the prediction of lower third molar impaction and to discuss their application to the clinical decision-making process.

REVIEW OF THE LITERATURE

Eruption of the Mandibular Third Molar

Although the path of eruption of the mandibular third molar is similar to that of the other permanent molars, the time of initial formation of the third molar has a much greater range of variability. For ease of comparison, the development and clinical eruption of the third molar has been separated into nine stages of clacification and movement, as shown in Table I (Garn et al., 1962).

The mean time of appearance of the third molar follicle, in males and females, is at 8.7 and 8.6 years, respectively (Garn et al., 1962). It has been observed radiographically as early as five years of age, but usually does not appear after the fourteeth year (Banks, 1934). Initially, the epithelial bud lies on the surface of the ramus, but then begins to invaginate into the bone as development commences (Richardson, 1970; Silling, 1973). According to the standards of Garn et al., 1962), a mean time of cusp clacification begins in males and females at 9.4 and 9.6 years, respectively. The plane of the occlusal surface, upon calcification, is positioned upward and forward at an angle of 40° to 45° to the occlusal plane (Silling, 1973). The bud varies in its horizontal location, lying from 0 mm. to 7 mm. (mean of 1.2 mm.) distal to the second molar (Richardson, 1970).

At this time, several processes are taking place simultaneously.

TABLE I

SEX DIFFERENCE, PERCENTILES AND VARIABILITY
IN THIRD MOLAR DEVELOPMENT

Stage of Development	Median Age (Years)		N	Combined-Sex Percentiles			"Variability[2]"
	Boys	Girls		15	50[1]	85	
1. Small Follicle	8.7	8.6	70	7.7	8.6	10.2	15
2. Full Follicle	9.2	9.1	90	8.1	9.1	10.2	12
3. Cusp Calcification	9.4	9.6	140	8.3	9.4	10.8	14
4. Crown Completion	13.6	14.2	79	12.4	13.9	16.0	13
5. Root Formation	14.4	15.0	66	13.3	14.8	16.7	12
6. Half Root	16.7	17.2	95	15.4	16.9	17.9	8
7. Alveolar Eruption	16.9	17.1	94	15.9	17.0	17.9	6
8. Cusp Level	17.9	17.8	39	17.2	17.8		14
9. Apical Completion	20.2	19.9	37	17.7	20.0		13

[1]Median

[2]Calculated as the difference between the 15th and 85th percentiles divided by twice the median.

After Garn et al. (1962).

The third molar, starting in the ramus, migrates downward and forward, while the anterior border of the ramus resorbs (Brodie, 1942; Silling, 1973). Consequently, it is soon located within the body of the mandible in close proximity to the second molar. Meanwhile, the alveolar process is rapidly growing in vertical height. The third molar erupts upward at a faster rate than the bone is growing, so that eventually the tooth surpasses the level of the alveolar crest and mucosa, and erupts clinically into the plane of occlusion (Brodie, 1942).

The vertical correction of the axial tilt of the third molar during development has been investigated, and the reported results have been conflicting. As the third molar bud migrates forward, the upward and forward orientation of the occlusal surface usually remains unchanged. Broadbent (1943) and Weinman and Sicher (1955) showed radiographically that rotational movement occurred during the process of forward movement toward the second molar. Silling (1973 showed radiographically that only after the third molar bud came into close proximity to the second molar, did a change in axial orientation take place. A normal relation to the occlusal plane was then achieved to allow eruption to proceed normally.

Vertical eruption of the tooth does not begin until root formation has begun (Moyers, 1973). Nolla's (1960) stages of tooth calcification indicate that the crown is complete at stage 6, and one third of the root is completed by stage 7. Thus, vertical eruption of the tooth begins somewhere between stages 6 and 7. According to Garn's standards for lower third molars, the average

crown completion time is 13.6 and 14.2 years for males and females, respectively. The mean time of root formation is 14.4 and 15.0 years in males and females, respectively. Clinical eruption was seen around 17.9 years for males and 17.8 years for females, and mean apical closure was completed at 20.2 and 19.9 years for males and females, respectively.

Incidence of Mandibular Third Molar Impaction

Bjork et al. (1956) found, in twenty-year-old, Swedish males, at least one mandibular third molar impacted in 18.8% of 133 subjects with complete dentitions, and that 15.5% of the lower third molars were impacted in 110 subjects with incomplete dentitions (Table II).

The difference in incidence of impaction between the complete and incomplete dentitions may be due to the presence of an edentulous space. In cases with an incomplete dentition, there is usually a mesial shift of the posterior teeth toward the edentulous space. This shift creates additional distal arch space for the lower third molar to erupt.

Dachi and Howell (1961) found that of 1,192 subjects reviewed, 17.5% had at least one lower third molar impacted. Morris and Jerman (1971) showed a much greater incidence of third molar impaction. Of 5,6000 19.5 year-old male recruits, U. S. Air Force, 22.3% had all four third molars impacted, 11.5% had three impacted third molars, 17.9% had two impacted third molars, and 14.0% had one third molar impacted. Based upon these figures, two out of

TABLE II

INCIDENCE OF MANDIBULAR THIRD MOLAR IMPACTION

Impaction	Complete Dentition (133 Cases)	Incomplete Dentition (110 Cases)	Total (243 Cases)
Both Sides	17 (12.8%)	8 (7.3%)	25 (10.3%)
One Side	8 (6.0%)	9 (8.2%)	17 (7.0%)
Total	25 (18.8%)	17 (15.5%)	42 (17.3%)

After Bjork (1956).

three (65.6%) 19.5-year-old men in the United States can be assurred to have one to four impacted third molars. This investigation was based on men who had not reached the average eruption age for the lower third molar, which age, according to Silling (1973), was 20.5±2.3 years. Furthermore, what might appear in two-dimensional radiographs as an impacted third molar, may actually be a tooth that is free of contact buccolingually from the second molar, and that, in time, will erupt.

Bilateral impactions do occur more frequently than unilateral impactions; whether a significant difference exists still remains for future studies to determine. Hellman (1936) found no difference between the frequencies of bilateral and unilateral impactions. However, this conclusion was based upon a very small sample. Daschi and Howell (1961) also found no significant difference in a study of 308 subjects: 16.9% had bilateral impactions and 13.0% had unilateral impactions. Conversely, Bjork (1956) did find a significant difference in a group of 133 cases with complete dentition: a 12.8% displayed bilateral impactions, while 6.0% showed unilateral impactions.

Hellman (1936) found a significant sex difference associated with third molar impactions. 20.8% of 172 20.75-year-old females and 9.5% of 261 20.5-year-old males had third molar impactions. Hellman explained this difference as a function of mandibular growth, since in the female, growth of the mandible has usually ceased when the third molar is ready to erupt, while in the male mandibular growth may continue during the eruption of the tooth. A larger

sample would make these statistics much more convincing, but also more controversial, inasmuch as Daschi and Howell (1961) found no sex difference in a sample consisting of 532 males and 660 females.

Crowding Due to Third Molars

Many clinical orthodontists have long believed that the impacted third molar is a major cause of crowding of the lower anterior dentition. In support of this view, many studies have shown that subjects with congenitally missing third molars had significantly less anterior crowding as compared to individuals having impacted or erupted third molars (Bergstrom and Jensen, 1961; Keene, 1964; Sheneman, 1969). It has been assumed that the mesial force produced by the impacted molars is transmitted through the posterior teeth, causing the mandibular anterior teeth to become malaligned.

Laskin (1969) pointed out, however, that if a mesial force were transmitted from an improperly erupting molar, this force would cause a corresponding forward shift of all posterior teeth in order to be physically transmitted to the incisors. Moreover, he postulated that the most likely place for disruption of tooth contact would be in the canine region. Laskin concluded that because the relationship of the upper and lower posterior teeth did not significantly change, and that the crowding was usually seen in the mandibular incisor area, he disputed the charge that the third molars were the direct cause of anterior dental crowding.

The effect of the third molar on the lower anterior dental alignment has usually been evaluated by comparing subjects with

third molars present to subjects with third molars congenitally missing. Selmar-Olsen (1937) examined sixty-three mandibles of different races having unilateral congenital absence of the lower third molars, and he observed significant crowding. He believed that with vigorous mastication, the external muscles, cheeks, and lips have the effect of directing the crowns of the lower incisors lingually, with a corresponding labial movement of the roots. In addition, he suggested that hyperfunction of the orbicularis oris or hypofunction of the tongue will cause crowding of the lower incisors.

Vego (1961) showed that arch length decreases, through anterior crowding, on the average of 2.5 mm. with lower third molars present, as compared to a 1.7 mm. decrease when third molars were congenitally missing. He attributed this difference to the presence or absence of the third molars.

Shanley (1962) divided forty-four subjects into three groups: (1) bilaterally impacted, (2) bilaterally erupted, and (3) congenitally absent third molars. In his study, no statistically significant difference was seen among the three groups with respect to lower anterior crowding. Shanley concluded that the third molar exerts little, if any, influence on the alignment or procumbency of the mandibular anterior teeth.

Fuder (1969) showed that the lower first molar (and all teeth mesial to it)was farther forward relative to point B, and the lower incisor more procumbent in subjects with only third molar crown formation completed when compared to subjects with congenitally

missing third molars. Thus, with the teeth farther forward on the mandibular base, the incisors would be more procumbent, and crowding would result due to their less stable position. Inasmuch as no root formation has begun (thus, presumably no mesial force due to eruption), the third molar crown could not significantly influence the antero-posterior position of the teeth mesial to it. Fuder concluded that the mandibular third molar was not a direct cause of the lower incisor crowding which often coincides with third molar development.

Mandibular crowding, after orthodontic treatment has been completed, may be due to several factors; among others:

(1) lingual uprighting of the lower anterior teeth, as has been shown to occur with increasing age (Bjork, 1956);

(2) teeth expanded beyond an acceptable angle to basal bone, resulting in the powerful facial musculature moving the teeth back over basal bone; and

(3) the slow rate of readjustment of the free marginal fibers in the periodontal ligament, which may cause the teeth to revert partially or fully to their original positions (Reitan, 1959).

(4) because mandibular growth continues on longer than maxillary growth, the lower anterior incisors may become malaligned due to the pressure exerted by the forward growth of the lower (contained) arch against the restricting maxillary arch.

It would appear from the studies mentioned above that the impacted third molar has little or no influence on mandibular anterior dental crowding.

Etiology of Impaction

Early studies on malocclusion and impaction generally focused

on the importance of environment, while often overlooking the role of heredity (Morehouse, 1930, D'Alise, 1930; Nodine, 1943). Begg (1939) believed that the mesio-distal attrition of teeth due to the chewing of coarse, fibrous food allowed the posterior teeth to migrate forward, creating space for the third molars to erupt. Due to the refined consistency of the modern diet, little mesial migration can take place, and the chance of third molar impaction has increased.

Brun (1942) felt that the area from the distal surface of the last occluding tooth to the anterior border of the ramus absorbed the greater part of the force expended by the internal pterygoid and masseter muscles. He hypothesized that pressure from these muscles, due to the force of mastication, affected the growth and development of this area, and that because of refined foods, the force exerted by these muscles is greatly diminished. Brun concluded that the amount of growth would also be diminished, and that the impaction of the third molars would result. To advocate such a line of thought supposes that bone can grow interstitially, and bone, as we all know, grows by apposition, once calcification takes place (Weinman and Sicher, 1955).

Archer (1975) has cited many other possible sources of impaction: (1) primary displacement of the tooth germ, (2) ankylosis, (3) systemic disturbances, including cleiodocranial dysostosis, (4) malposition of the adjacent tooth and pressure from the adjacent tooth, (5) abnormal density of overlying bone, (6) chronic inflammation, with a resultant increase in the density of the overlying mucous membrane, (7) acquired diseases with associated necrosis due

to infection or abcesses, and (8) inflammatory changes in bone due to exanthematous diseases.

Another suspected cause of third molar impactions is orthodontic treatment. Mechanics that move the buccal segments distally may increase the chance of third molar impaction (Rice, 1940). Eruption of maxillary second molars is influenced by posterior movement of maxillary first molars, which is demonstrated by buccal eruption of second molars into crossbite. Rice concluded that similar distal forces may be directed against the developing third molars. Silling (1973) believes there is a good possibility that orthodontic treatment, which holds back the lower molars or actively tips them distally, may cause the crown of the third molar to rotate into an abnormal position, and thus, increase the chances of impaction.

The effect of premolar extractions on third molar eruption has been investigated, with conflicting results. McCoy (1965) was of the opinion that third molar impactions occurred in the majority of orthodontic cases, even with four premolars extracted. This was only a clinical impression; no statistical evaluation was performed. Faubion (1968) showed that almost four times as many mandibular third molars erupted satisfactorily in patients with premolar extractions. 55% of the third molars were retained in patients with four premolars extracted, whereas only 15% were retained in the non-extraction group.

Attention has shifted from the role environment plays in the etiology of third molar impactions, to the influence of heredity.

Hellman (1938) believed that impactions might be a local manifestation of a general condition. He measured the age, height, and weight of subjects with four molars erupted, and subjects with three of four impacted third molars. On the average, the group with molar impactions was one year younger, lighter in weight, and taller. In facial and cranial dimensions, every subject in the impacted group was smaller in facial height, width, and depth. Hellman concluded from this that impaction of third molars was not a special occurrence, but rather, is a part of a generalized condition.

Bjork et al. (1956) felt that lower third molar impactions were due to four factors. The first, and most important, was the direction of condylar growth. They associated a vertical vector of condylar growth with inadequate resorption at the anterior border of the ramus. The second factor was an insufficient increase in the length of the mandible in proportion to the amount of condylar growth. The third factor was the direction of tooth eruption, since a backward eruptive pattern of teeth will decrease the length of the alveolar arch resulting in a decrease in space for the third molar. The fourth factor concerned the maturation of the third molar. Bjork showed that impactions are associated with retarded mineralization of the third molar, and perhaps a generalized retardation of dental development. In addition, Bjork and his associates found that third molar space, the distance between the distal surface of the second molar and the anterior border of the ramus on a level with the occlusal line of the mandibular arch, is larger in subjects with fully erupted third molars than in subjects with third molars

unerupted, but in normal position. It was concluded that the eruption of the third molar influenced the "resorptive rebuilding" of the retromolar area to allow eruption of the tooth. In twelve out of seventeen cases with bilateral impactions, the mandible was shorter in length at twelve and twenty years of age when compared to mandibles with erupted third molars (Bjork et al., 1956).

Current studies support the view that insufficient space in the retromolar area is a direct cause of mandibular third molar impactions (Bjork et al., 1956; Leydard, 1953, Turley and Chaconas, 1975). It is for this reason that prediction schemes focus around this main point (Henry and Morant, 1936; Leydard, 1953; Turley and Chaconas, 1975).

Prediction of Lower Third Molar Impaction

The accurate prediction of lower third molar impaction would enable the orthodontist to prescribe removal of the third molar at a time as early as eight years when surgery might be less traumatic to the patient, and, in turn, complications due to lower third molar impaction and extraction would be avoided later in life.

Henry and Morant (1936) were the first in the dental literature to suggest removal of third molars based on a prediction technique. They were also the first to recognize that a measurement of available space in the retromolar area should be the focal point of a prediction technique. Their so-called "third molar space index" incorporates a measure of the retromolar area: "the maximum breadth of the outline of the third molar as a percentage of the distance

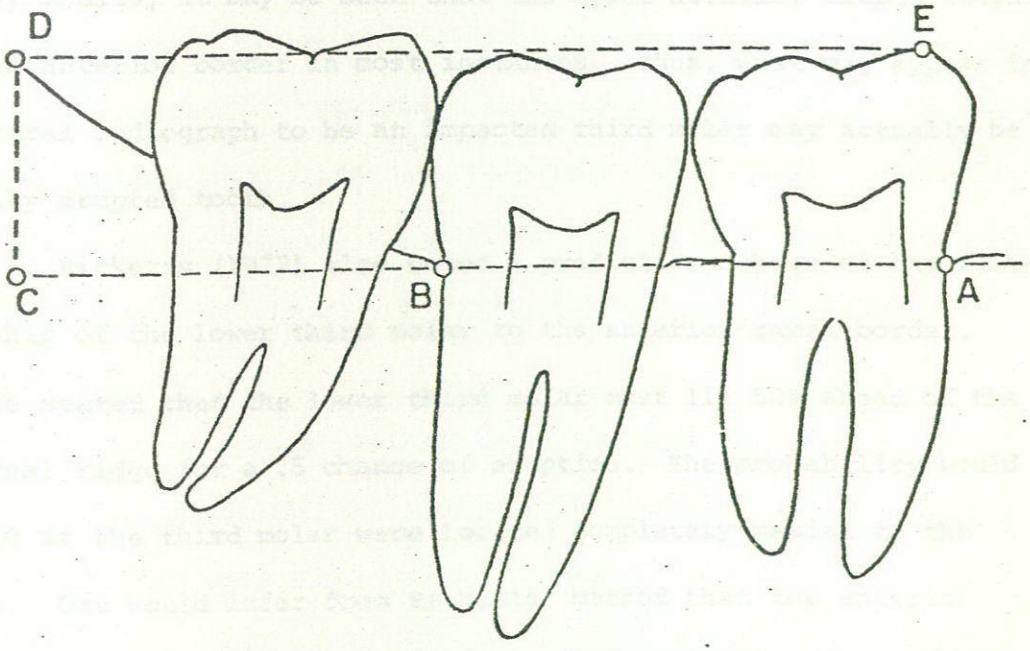
between the second molar and ramus." The smaller the index, the greater the space for the third molar, and vice versa. Mandibles with normally erupted third molars showed indices ranging from 43 to 90; third molars that were excessively erupted showed values that ranged from 93 to 107. Ramal impactions ranged from 90 to 142, and mesio-oblique impactions ranged from 81 to 160. These values were based on a sample consisting of 187 dental and medical students at age twenty-two.

Although Henry and Morant spoke of this analysis as a prediction technique, there was no actual prediction formula developed. The third molar space index is only a measure of the severity of impaction at maturity; it is not a prediction formula. Moreover, all the measurements were performed on variably magnified periapical films. To locate accurately where the mesial surface of the first molar and distal surface of the second molar meet the alveolar crest in the construction of the third molar space would be technically difficult (Figure 2).

Leydard (1953) was the first to suggest a prediction formula, per se. He demonstrated that very little growth occurs in the area between the lower first molar and the anterior border of the ramus after fourteen years of age and reported that, at maturity, the average size of this dimension was 21 mm. Under the assumption that the average person will ultimately attain 21 mm. in length from the distal surface of the first molar to the anterior border of the ramus, he measured the combined mesiodistal diameters of the second and third molars and, if the combined diameters were greater than

FIGURE 2

CONSTRUCTION OF THE THIRD MOLAR SPACE B-C
(after Henry and Morant, 1936)



21 mm., he concluded that the third molar would be impacted. This method can be employed at any age after third molar crown completion and, in premolar extraction cases, an estimate of expected mesial drift can be added to the projected available space in the retromolar area.

Unfortunately, the relation of the anterior border of the ramus to the third molar may be of questionable significance. As viewed in the lateral cephalometric radiograph, the anterior border often appears to obstruct the third molar from full eruption, but in dry skulls, it may be seen that the molar actually erupts lingual to the anterior border in most instances. Thus, what may appear in a lateral radiograph to be an impacted third molar may actually be a fully erupted tooth.

Ricketts (1972) also based a prediction scheme on the relationship of the lower third molar to the anterior ramal border, and he stated that the lower third molar must lie 50% ahead of the external ridge for a .5 chance of eruption. The probability would be 1.0 if the third molar were located completely mesial to the ridge. One would infer from Ricketts' method that the anterior border would obstruct the third molar from eruption, when actually, as stated before, the tooth erupts lingual to it. Moreover, this prediction can only be used in the young adult patient, when the third molar is nearing its final position. Prediction at early ages, when the third molar is located high in the ramus, would appear not to be possible with this method.

Margaret Richardson (1975) examined the problem of predicting

impaction from the standpoint of the angular relationship of the mandibular third molar to the mandibular plane. She measured the angle formed by the occlusal surface to the mandibular plane at two stages: (1) as soon as the occlusal surface calcified, and (2) when the third molar assumed its final position. Richardson found that, on the average, there was a significantly greater initial angle of the third molar to the mandibular plane in stage one for the impacted group as compared to the erupted group. Also, there was a significantly greater change in angulation of the mandibular third molar in the erupted group. She concluded that a steeply angled developing third molar had a better than average chance of becoming impacted.

Richardson's study dealt with observations rather than with the development of a prediction technique. She spoke in generalizations, such as "steeply angled" and "better than average chance," and no characterization of what constitutes "steeply angled" was offered.

A fourth prediction technique has recently been reported by Turley and Chaconas (1975). Their study was based on sixty orthodontic patients whose third molars proved to be either impacted, erupted and in function, or erupted but not in function. They stated that the distance from the distal surface of the second molar to "Xi point" is the crucial measurement for prediction of third molar impaction. Xi point is a constructed landmark which is said to closely correspond to the position of the lingula on the medial surface of the mandibular ramus (Ricketts, 1972). If, at maturity, this distance (Xi point to distal of second molar) is

20 mm., eruption of the third molar has a low probability. At 25 mm., the case is considered to be "borderline" (third molars that are erupted, but not in functional occlusion, fell into this category), and if the measurement is 30 mm., the third molar has an excellent prognosis (Ricketts et al., 1975).

To predict impaction at an earlier age, the distance Xi point to the distal of the second molar is projected to maturity by way of the following prediction equation (Schulhof, 1976):

1.6 x N x cos θ + leeway space = growth for N years, where

N = number of years,

θ = angle formed by the functional occlusal plane and Xi point to pogonion,

1.6 = average growth in millimeters per year, and

leeway space = 1.6 mm.

For females, the formula is purported to predict to age fifteen; for males, to age nineteen.

Of the prediction techniques available to orthodontists, Turley's is perhaps the most popular. It is said to predict the amount of growth from Xi point to the distal surface of the second molar to ±2.8 mm. (Data Bits, RMDS). It also has the advantage of using Xi point, a landmark that is not obscured by any other superimposed structures, and is easily located on any cephalometric radiograph.

In view of the fact that this prediction technique has captured the attention and interest of the orthodontic community, it will, therefore, be the purpose of the present investigation to

characterize independently the accuracy of Turley's prediction method on a large sample over varying prediction intervals, and to compare the results with those previously published by RMDS (1975). In addition to this, Richardson's and Leydard's prediction techniques will also be evaluated.

MATERIALS AND METHODS

Sample

Serial lateral cephalometric radiographs for sixty-two individuals were selected from the files of the Bolton-Brush growth study according to the following criteria: (1) the availability of serial records from eight to eighteen years or older, (2) presence of a full complement of teeth, including the third molars, and (3) no history of orthodontic treatment. On the average, each series consisted of thirteen cephalograms.

Technical Details

The lateral cephalograms used in this study were obtained with a Broadbent-Bolton cephalometer, using a source-object distance of sixty inches. For each of the various prediction methods, right and left sides were traced separately in different colors on .003-inch frosted matte acetate. The Bolton-Broadbent Orientator was used on the corresponding posteroanterior cephalometric radiographs to identify the right and left sides. Linear measurements obtained through the use of dial vernier calipers (modified Helios dial calipers, catalogue No. 382, Dental Corporation of America, Washington, D. C.) were rounded to the nearest tenth of a millimeter. Angular measurements obtained through the use of a Baume protractor (catalogue No. 701-402, Unitek Corporation, Monrovia California), were rounded to the nearest five-tenths of a degree. For each of the various prediction methods, right and left sides were traced separately in different colors on .003-inch, frosted matte acetate. Any third molar that remained in the same position

for at least three years, in subjects eighteen years or older, was considered to be impacted (Richardson, 1975).

Landmarks and Measurements

Leydard's Method (Figure 3)

The basic tracing consisted of: (1) outlines of three molars and two premolars, (2) the anterior and posterior ramal outlines, (3) the functional occlusal plane (a line drawn through the cusps of the first and second premolars and the first molar), and (4) a line perpendicular to the occlusal plane, passing through the height of contour of the distal surface of the lower first molar. The average length of the retromolar area, according to Leydard, was 21 mm. The mesiodistal diameters of the second and third molars were measured, and a comparison made between the amount of tooth structure and the estimate of the available space (21 mm.). Impaction of the third molar would be predicted, if the mesiodistal diameters of the second and third molars were greater than 21 mm.

Richardson's Method (Figure 4)

The basic tracing consisted of: (1) the outline of the mandibular third molar, (2) the posterior ramal outline, (3) the inferior border of the mandible, including the symphysis, (4) the mandibular plane (menton to gonion), and (5) a line from the cusp tips of the lower third molar to the mandibular plane.

Two tracings were made for each case. The initial tracing was done at the time of calcification of the occlusal surface of

FIGURE 3

THE CONSTRUCTION OF THE
RETROMOLAR DIMENSION
(after Leydard, 1953)

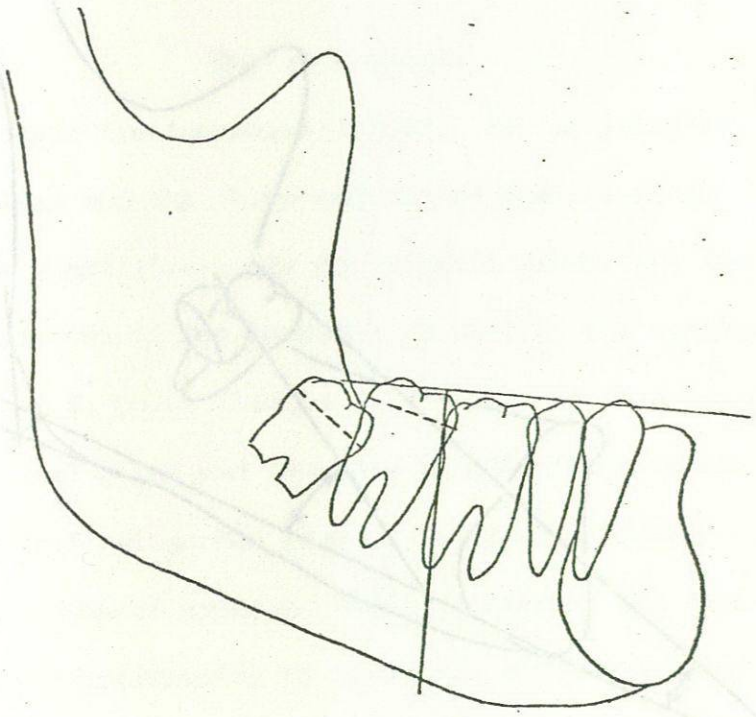
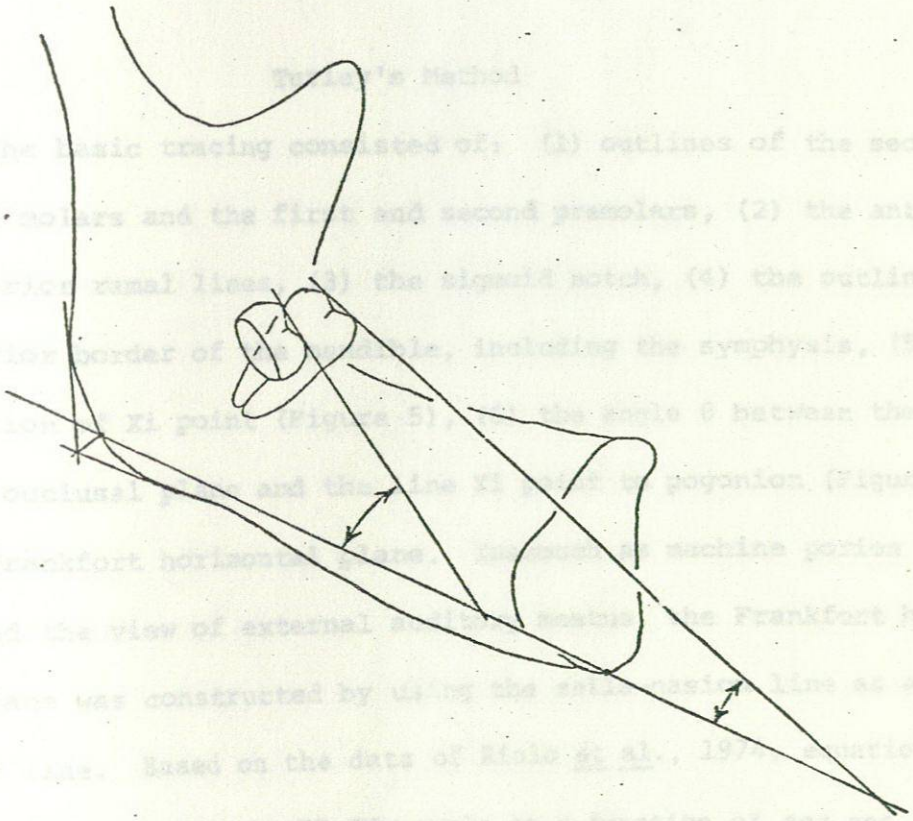


FIGURE 4

ANGULAR RELATIONSHIP OF THE THIRD
MOLAR TO THE MANDIBULAR PLANE
(according to Richardson, 1975)



the lower third molar, and the second tracing was done after the third molar had assumed its final position.

Based on the final status of the third molar, the sixty-two series were divided into compacted and erupted groups. Two comparisons were made between the impacted and erupted groups: the first characterized any differences in the initial (developmental) angulation, and the second dealt with the change in angulation of the third molar.

Turley's Method

The basic tracing consisted of: (1) outlines of the second and third molars and the first and second premolars, (2) the anterior and posterior ramal lines, (3) the sigmoid notch, (4) the outline of the inferior border of the mandible, including the symphysis, (5) the construction of Xi point (Figure 5), (6) the angle θ between the function occlusal plane and the line Xi point to pogonion (Figure 6), and (7) Frankfort horizontal plane. Inasmuch as machine porion obstructed the view of external auditory meatus, the Frankfort horizontal plane was constructed by using the sella-nasion line as a reference line. Based on the data of Riolo et al., 1974, equations were calculated to express the FH-SNa angle as a function of age and, thus, permit an average Frankfort horizontal to be constructed for each age (8-16) based on SNa. The equations (male and female were as follows:

Male: Angle = 7.7618182 - .2618182 x Age

Female: Angle = 7.7127273 - .1490909 x Age

FIGURE 5

THE CONSTRUCTION OF Xi POINT
(According to Ricketts, 1972)

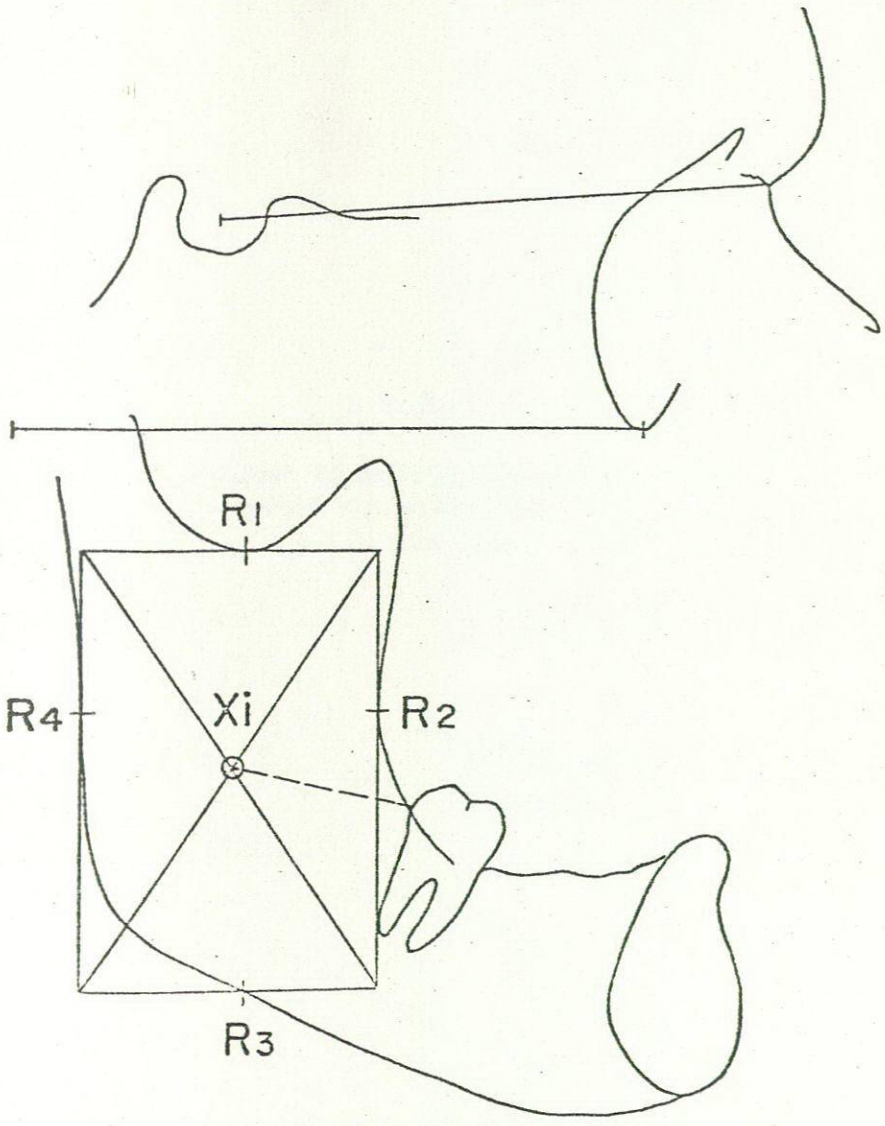
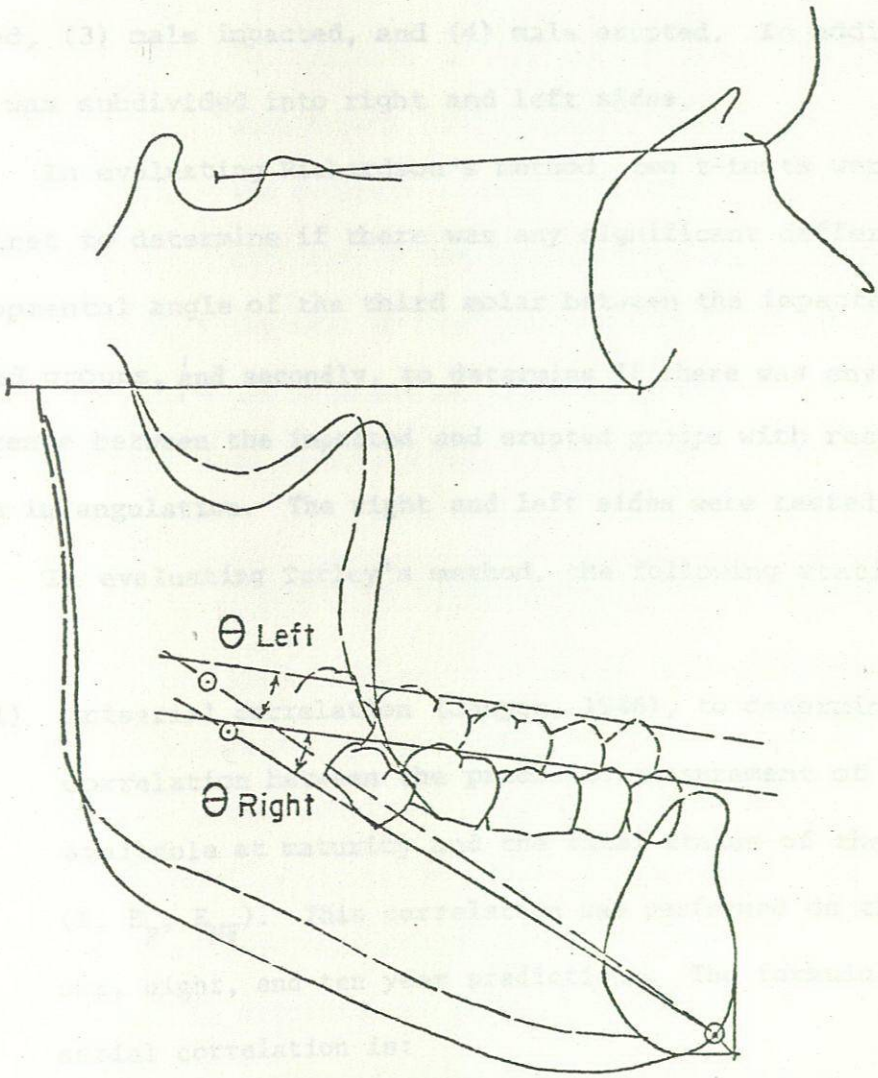

R1
R4
Xi
R2
R3

FIGURE 6

THE CONSTRUCTION OF ANGLE θ
(According to Turley
et al., 1975)


θ Left
θ Right

Statistical Methods

To evaluate the basic assumption of Leydard's technique, a t-test was used to test the null hypothesis that the combined mesio-distal diameters of the second and third molars is 21 mm. The data were divided into four groups: (1) female impacted, (2) female erupted, (3) male impacted, and (4) male erupted. In addition, each group was subdivided into right and left sides.

In evaluating Richardson's method, two t-tests were performed: the first to determine if there was any significant difference in the developmental angle of the third molar between the impacted and erupted groups, and secondly, to determine if there was any significant difference between the impacted and erupted groups with respect to the change in angulation. The right and left sides were tested separately.

In evaluating Turley's method, the following statistics were used:

(1) Triserial correlation (Jaspen, 1946), to determine the correlation between the predicted measurement of space available at maturity and the final status of the tooth (I, E_F, E_{NF}). This correlation was performed on the two, four, six, eight, and ten year predictions. The formula for triserial correlation is:

$$r_{tri} = \frac{ZaYa + (Zb-Za)Yb - ZbYc}{\sigma y\left[\frac{Za^2}{a} + \frac{(Zb-Za)^2}{b} + \frac{Zb^2}{c}\right]}, \text{ where}$$

a = the proportion of cases in the functionally erupted group,

b = the proportion of cases in the nonfunctionally erupted group, and

c = the proportion of cases in the impacted group.

$a + b + c = 1$

$q_a = a$,

$q_b = a + b$,

$q_c = a + b + c$.

Za = the ordinate of the normal curve, assuming a unit normal distribution, at q_a,

Zb = the ordinate of the unit normal curve at qb.

Ya = the mean of the functionally erupted group,

Yb = the mean of the nonfunctionally erupted group,

Yc = the mean of the impacted group.

(2) The root mean squared error

$$RMSE = \sqrt{\frac{\Sigma(\text{Predicted measurement} - \text{Actual measurement})^2}{N}}$$

(3) 3 x 3 contingency tables to show the relationship between the predicted and actual status of the third molar for each prediction-interval. Certain decisions (a prediction of I given E_F or E_F given I) are highly undesireable and, therefore, have been designated as "disasters."

(4) A t-test to determine if there was a significant difference between the predicted space available at 9 years, for males and females, and the actual space available at 19 years for males and 15 years for females. The t-test used here comes from page 122 of Dixon and Massey, 1969.

(5) A t-test, assuming equal variances, to determine if there was a significant difference in space available between the impacted and erupted groups at nine years and maturity (nineteen years for males, fifteen years for females).

Error Study

To characterize the reliability of the cephalometric methods employed here, twenty lateral cephalometric radiographs were selected with the aid of a table of random numbers. All landmarks and measurements were re-done, and the coefficients of linear correlation between the first and second measurements calculated for each dimension (Table III). This correlation, $r_{xx}2$, is a measure of intraobserver measurement reliability.

TABLE III

RELIABILITY COEFFICIENTS

Measure	Side	Correlation (r)	r^2
Xi to $\bar{7}$	R	.990	.981
Xi to $\bar{7}$	L	.992	.983
$\bar{6}$ to Ramus	R	.984	.969
$\bar{6}$ to Ramus	L	.979	.958
θ (Turley)	R	.921	.848
θ (Turley)	L	.934	.871
∠ $\bar{8}$ to Mand. Pl.	R	.989	.977
∠ $\bar{8}$ to Mand. Pl.	L	.973	.948

RESULTS

The results of the present study will be presented under the following headings: (1) Leydard's prediction method, (2) Richardson's prediction method, and (3) Turley's prediction method.

Leydard's Prediction Method

The means of the combined mesiodistal diameters of the second and third molars, and the t-values, are presented in Table IV. The t-test revealed generally significant differences between the combined mesiodistal diameters of the second and third molars and 21 mm. It may be seen that the means of the second and third molar diameters are greater than 21 mm. in every case.

Richardson's Prediction Method

The mean values of the initial angulation and change in angulation of the third molars, and the appropriate t-values, are presented in Table V. There was a significant difference between the impacted and erupted groups with respect to the initial angulation and change in angulation. Thus, the impacted group tended to have a steeper developmental angle and a lesser change in angulation when compared to the erupted group.

Turley's Prediction Method

The results of the triserial correlations, root mean squared

error, and the contingency tables are presented in Table VI, Table VII, and Figure 7 and Table VIII, respectively. The mean differences between the predicted and actual space available with appropriate t-values, and the mean values of space available at age nine and at maturity with the appropriate t-values are presented in Tables IX and X, respectively. The t-values in Table IX showed a significant difference between the predicted and actual space available. In Table X, the t-values showed a significant difference between the impacted and erupted groups with respect to space available. In every case the mean of the erupted group was greater than that of the impacted group.

TABLE IV

MEANS FOR THE COMBINED M-D DIAMETERS
OF SECOND AND THIRD MOLARS WITH
APPROPRIATE t-VALUES
(Ho: $\bar{X} = 21$)

	Erupted Male		Impacted Male		Erupted Female		Impacted Female	
	Right	Left	Right	Left	Right	Left	Right	Left
Number of Cases	19	19	21	21	6	6	14	14
$\bar{X}_{M-D}$ Diameter	22.67	22.98	23.83	24.08	21.95	22.47	22.96	23.10
S.D.	1.35	1.32	1.33	1.34	1.49	1.00	.99	.88
d.f.	18	18	20	20	5	5	13	13
t	5.39**	6.54**	9.75**	10.53**	1.56	3.60*	7.41**	8.93**

* = significant at $p<.05$

** = significant at $p<.01$

TABLE V

THIRD MOLAR ANGULATION: MEANS FOR IMPACTED AND ERUPTED SUBJECTS, BY SIDES; t-VALUES FOR THE DIFFERENCE

Variable		Impacted Mean	Erupted Mean	DF	t
Initial Angulation of 8 to M.P.	Left	40.12	33.57	30	2.26*
	Right	39.56	35.17	29	2.46*
Change in Angulation of 8 to M.P.	Left	18.64	26.71	30	3.70**
	Right	18.20	29.17	29	4.80**

* = significant at $p<.05$

** = significant at $p<.01$

TABLE VI

COEFFICIENTS OF TRISERIAL CORRELATION BETWEEN PREDICTED SPACE AND FINAL STATUS OF THIRD MOLARS

Prediction Interval (years)	Correlation Coefficient (r_{tri})
2	.596
4	.511
6	.395
8	.677
10	.633

TABLE VII

ROOT MEAN SQUARED ERROR
(in millimeters)

Prediction Interval (years)	Male	Female
1	2.17	1.19
2	3.09	1.69
3	3.61	1.70
4	4.09	1.85
5	3.64	2.05
6	3.78	2.36
7	3.86	2.59
8	4.20	
9	5.54	
10	5.73	
11	5.40	

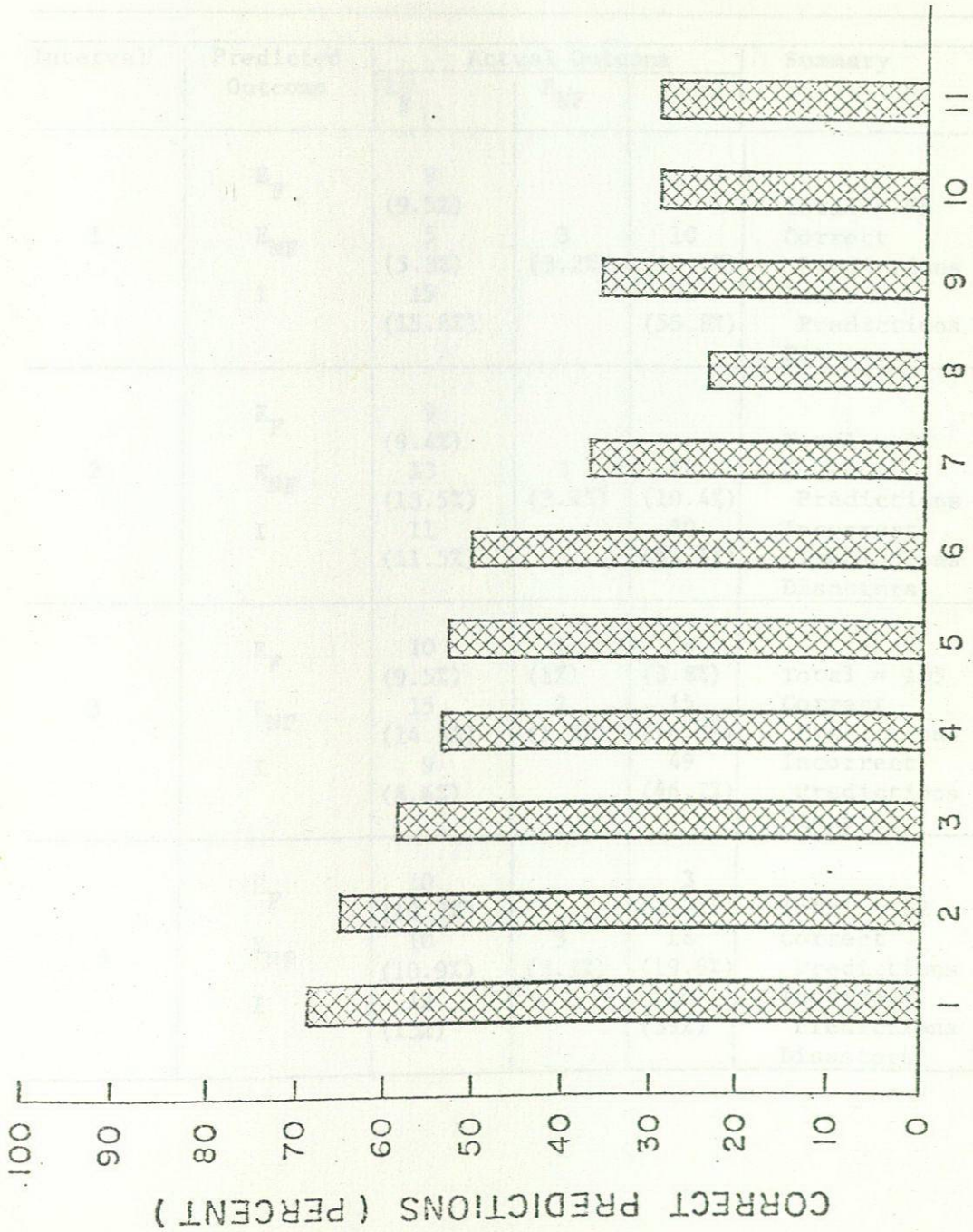


FIGURE 7. ACCURACY OF THE TURLEY PREDICTION METHOD

TABLE VIII

SUMMARY OF PREDICTION RESULTS, BY INTERVAL

Interval	Predicted Outcome	Actual Outcome			Summary
		E_F	E_{NF}	I	
1	E_F	9 (9.5%)			Total = 95
	E_{NF}	5 (5.3%)	3 (3.2%)	10 (10.4%)	Correct Predictions = 68.5%
	I	15 (15.8%)		53 (55.8%)	Incorrect Predictions = 31.5%
					Disasters = 15.8%
2	E_F	9 (9.4%)			Total = 96
	E_{NF}	13 (13.5%)	3 (3.1%)	10 (10.4%)	Correct Predictions = 64.6%
	I	11 (11.5%)		50 (52.1%)	Incorrect Predictions = 35.4%
					Disasters = 11.5%
3	E_F	10 (9.5%)	1 (1%)	4 (3.8%)	Total = 105
	E_{NF}	15 (14.3%)	2 (1.9%)	15 (14.2%)	Correct Predictions = 58.1%
	I	9 (8.6%)		49 (46.7%)	Incorrect Predictions = 41.9%
					Disasters = 12.4%
4	E_F	10 (10.9%)		3 (3.3%)	Total = 92
	E_{NF}	10 (10.9%)	3 (3.3%)	18 (19.6%)	Correct Predictions = 53.2%
	I	12 (13%)		36 (39%)	Incorrect Predictions = 46.8%
					Disasters = 16.3%

TABLE VIII--continued

5	E_F E_{NF} I	10 (11.1%) 11 (12.2%) 9 (10%)	2 (2.2%)	23 (25.6%) 35 (38.9%)	Total = 90 Correct Predictions = 52.2% Incorrect Predictions = 47.8% Disasters = 10%
6	E_F E_{NF} I	10 (11.7%) 15 (17.4%) 8 (9.2%)	3 (3.5%)	4 (4.7%) 16 (18.6%) 30 (34.9%)	Total = 86 Correct Predictions = 50.1% Incorrect Predictions = 49.9% Disasters = 13.9%
7	E_F E_{NF} I	6 (7%) 23 (26.7%) 7 (8.2%)	3 (3.5%)	1 (1.2%) 23 (26.7%) 23 (26.7%)	Total = 86 Correct Predictions = 37.2% Incorrect Predictions = 62.8% Disasters = 9.4%
8	E_F E_{NF} I	9 (14%) 20 (31.3%) 1 (1.5%)	3 (4.7%)	28 (43.8%) 3 (4.7%)	Total = 64 Correct Predictions = 23.4% Incorrect Predictions = 76.6% Disasters = 1.5%

TABLE VIII--continued

9	E_F	8 (19%)		2 (4.8%)	Total = 42
	E_{NF}	8 (19%)	3 (7.2%)	17 (40.5%)	Correct Predictions = 35.7%
	I			4 (9.5%)	Incorrect Predictions = 64.3%
					Disasters = 4.8%
10	E_F	8 (21.1%)	2 (5.3%)	2 (5.3%)	Total = 38
	E_{NF}	10 (26.3%)	1 (2.6%)	13 (34.1%)	Correct Predictions = 29%
	I			2 (5.3%)	Incorrect Predictions = 71%
					Disasters = 15.3%
11	E_F	8 (23.5%)			Total = 34
	E_{NF}	12 (35.4%)	1 (2.9%)	12 (35.3%)	Correct Predictions = 29.3%
	I			1 (2.9%)	Incorrect Predictions = 70.7%
Overall (Summary of all intervals)	E_F	97 (11.7%)	3 (.5%)	16 (1.9%)	Total = 828
	E_{NF}	142 (17.1%)	27 (3.3%)	185 (22.3%)	Correct Predictions = 49.5%
	I	72 (8.7%)	0 (0%)	286 (34.5%)	Incorrect Predictions = 50.5%
					Disasters = 10.6%

TABLE IX

PREDICTED AND ACTUAL AVAILABLE SPACE BY SEX AND FINAL MOLAR STATUS; t-VALUES FOR THE DIFFERENCES BETWEEN IMPACTED AND ERUPTED MEANS

	Number of Cases	$\bar{X}_P - \bar{X}_A$	RMSE	t
Female Impacted				
Age 9-Predicted	R: 7	+3.94	10.06	9.58**
vs.				
Age 15-Actual	L: 7	+3.73	9.14	7.14**
Female Erupted				
Age 9-Predicted	R: 3	+2.72	5.44	4.07*
vs.				
Age 15-Actual	L: 3	+2.56	3.82	9.13**
Male Impacted				
Age 9-Predicted	R: 4	+7.07	14.50	10.21**
vs.				
Age 19-Actual	L: 4	+6.13	14.91	10.11**
Male Erupted				
Age 9-Predicted	R: 8	+3.55	12.47	7.29**
vs.				
Age 19-Actual	L: 8	+3.71	13.52	5.04**

* = significant at $p < .05$
** = significant at $p < .01$

TABLE X

SUMMARY OF MEANS WITH APPROPRIATE
t-VALUES AT AGE 9 AND AT MATURITY

Sex	Age	Side	X_I	X_E	df	t
Female	9	Right	10.37	13.57	7	-1.98
		Left	9.53	12.80	7	-2.66*
	15	Right	17.36	20.47	17	-3.53**
		Left	17.14	20.00	17	-3.14**
Male	9	Right	10.38	12.88	17	-2.87**
		Left	9.98	12.74	17	-3.37**
	15	Right	21.91	24.63	24	-2.03
		Left	21.51	24.62	24	-2.39*

* = significant at $p<.05$
** = significant at $p<.01$

DISCUSSION

The purpose of prediction is to predetermine the outcome of a future event so that, should the undesirable be anticipated, appropriate preventive or palliative measures can be instituted. The purpose of the present study was to validate on sixty-two longitudinal series from the files of the Bolton-Brush Growth Study Center three methods that have been, or could be, applied to the prediction of lower third molar impactions. The results for the three techniques will be discussed separately.

Leydard's Method

Based on the present results, it appears that Leydard's method is predisposed to the prediction of third molar impaction, regardless of the actual outcome. In every group, except one (females, erupted, right side), the combined mesiodistal diameter of the second and third molar was significantly greater than either the actual or predicted available space. The discrepancy in this one group could be possibly attributed to sampling variation, especially in view of the small number of observations and the resulting reduction in the power to discriminate even large differences.

The distance from the distal surface of the mandibular first molar to the anterior border of the ramus was 21 mm, or greater, in eleven of the 124 observations--8.9% of the cases. In the present sample, this dimension averaged 15.5 mm. By comparing this to the

mean mesiodistal diameter of the second and third molars (23 mm), it seems obvious that impaction would be the most probable result if the assumption that impaction is an exact function of the available space at maturity is correct. The accuracy of the Leydard method can be seen in the following summary of prediction outcomes:

Male erupted--4 of 19 correct (21%)

Male impacted--21 of 21 correct (100%)

Female erupted--2 of 6 correct (33%)

Female impacted--13 of 14 correct (93%)

Based on the findings of the present study, it may be concluded that Leydard's prediction method cannot distinguish between future impaction and eruption with sufficient efficiency to warrant widespread clinical use.

Richardson's Conjecture

Richardson's observations on the general significance of the angulation between the lower third molar and the mandibular plane have been corroborated, in broad outline, by this study. "Steeply angled" third molars tend to become impacted and tend to upright less.

In the erupted group, it was seen that with a greater initial angulation, there was a correspondingly greater change in the angulation. Thus, it would appear that the degree of uprighting is an important factor in eruption of third molars. To my knowledge, however, there is, as yet, no way to predict the extent to which the third molar will upright. In order for Richardson's observations to become a clinically useful prediction method, it would be necessary

to know, based on the initial angulation of the third molar, the change in the angulation expected. Until this can be done, Richardson's "method" cannot be considered a prediction technique,per se, although the descriptive statistics presented here might form the basis of a formal prediction method that could, in turn, be validated in a subsequent study. It may be noted, however, that the addition of data on available space would probably be required to achieve an efficient method.

Turley's Method

In contrast to Richardson, Turley (1975) has assumed that eruption is a function of available space: (1) 30 mm or more from Xi to the second molar is adequate for the third molar to erupt in function, (2) 25 to 29 mm from Xi to the second molar is marginal (probable eruption, but not in function), and (3) 24 mm or less from Xi to the second molar is inadequate space for third molar eruption. Because I found third molars to be erupted and in function with measurements as low as 17 mm, five cephalometric radiographs and tracings were sent to Mr. R. J. Schulhof, President of RMDS. The five radiographs were of subjects in their twenties and all had third molars erupted and in function (as verified from plaster study models). The radiographs were returned by RMDS with measurements of 17.5, 18.5, 21, 28.5, and 30.5 mm. These determinations were obtained by averaging the cephlometric images of the right and left sides. Thus, to predict impaction of both mandibular third molars, only one set of data was employed, and, accordingly, a separate prognosis for the

two sides could not be provided. In tracing the radiographs from my sample, I drew each side individually; accordingly, a separate prognosis was performed on each lower third molar. In comparison to RMDS' measurements, my measurements (in millimeters) were: 17.5 and 16.5, 17.8 and 17.9, 20.5 and 20.5, 27.35 and 28.9, and 31 and 31--only slightly different from the commercial readings.

Mr. Schulhof made several comments on the two sets of measurements. He felt that my definition of the Frankfort horizontal was substantially different from that of RMDS. He mentioned that, if Frankfort horizontal were drawn from orbitale to machine porion, the parallels constructed to that plane would give a slightly smaller measurement from Xi to the second molar. Although the Frankfort horizontal employed in this study was based on the sella-nasion line, the resulting measurements did not differ from those of RMDS by more than 1.15 mm, a difference that may be attributed, in part, to variation in tracing technique and which, in any event, would not lead to a markedly different prognosis.

Furthermore, Schulhof pointed out that the RMDS sample included some orthodontic cases. It would seem more appropriate, however, to generate standards in the absence of treatment and to adjust the resulting prediction based on the known impact of the various modalities of therapy (extraction, "distalization," etc.). For example, it has been shown that nonextraction treatment has a tendency to impact third molars (Rice, 1940; Silling, 1974), whereas in extraction cases, the mesial movement of the posterior teeth could facilitate the eruption of the lower third molar and thus produce

somewhat more available space than would otherwise be expected.

In analyzing the performance of Turley's method, three aspects of the problem must be examined: (1) the significance of the relation between space and eruption, (2) the extent of the relationship between predicted space and actual space, and (3) the overall relation between predicted space and the final status of the third molars.

In the present sample, of seventy-five third molars that were impacted, sixty-nine had Xi - $\overline{7}$ dimensions that were in the 16 to 24 mm range and the remaining six were in the 25 to 29 mm range. Of five third molars that were erupted but not in function, three were in the 20 to 24 mm range, and the other two were in the 25 to 29 mm range. Of forty third molars that were erupted and in function, twenty were in the 16 to 24 mm range, fourteen were in the 25 to 29 mm range, and six were greater than 30 mm. Contrary to Turley and Chaconas (1975), it would appear that a measurement of 30 mm from Xi to $\overline{7}$ is not always necessary for the eruption of the third molar into functional occlusion. Although Leydard and Turley assumed that the eruption of the third molar was a function of available space, the findings in the present study showed this not to be the case. If one were to adhere to the standards developed by Turley, it would be very likely that one would predict impaction and, perhaps as a result, routinely prescribe enucleation.

The present investigation has shown that the predicted space for both males and females at nine years of age was generally significantly larger than the actual space at maturity (Table IX). An

examination of the root mean squared errors reveal that, as age increased, the amount of prediction error decreased. This tendency for error to decrease with time is probably a function of the smaller amounts of growth to be predicted at the shorter intervals. Moreover, the contingency tables showed that the predictions never achieved the 90% accuracy that was claimed by RMDS (Schulhof, 1976). Overall, the Turley prediction was correct in 49.5% of the cases and wrong in 50.4% of the cases. Although the purpose of Turley's method is to determine, at an early age, the future status of the lower third molar, it is at these earlier ages that its error in predicting the final status of the tooth is the greatest.

The triserial correlation between the predicted measurements and the final status of the tooth was only "moderate," averaging .527, and the efficiency (E), as estimated by the formula, $E \simeq [(1 - \sqrt{1-r^2})100]$, is 15%. Thus, only 15% of the variability in this final status of the third molar is "accounted for" by Turley method. This reduction in error would not seem high enough to warrant widespread use.

The present study has shown that, for both males and females, a significant difference exists between the erupted and impacted group, with respect to the initial Xi to $\overline{7}$ measurement at nine years. A prediction method could conceivably be based on the distance between Xi and $\overline{7}$ at nine years of age compared to the means reported here for the erupted and impacted groups (Table XI). Of course, the

TABLE XI

INITIAL Xi-7 DISTANCE: MEANS FOR IMPACTED AND ERUPTED PROCESS: BY SEX AND SIDE: 95% CONFIDENCE INTERVAL FOR THE DIFFERENCE

Sex	Side	Impacted $\bar{X}_I$	Erupted $\bar{X}_E$	95% C.I. for Difference
Female	R	10.37	13.57	3.20±3.89
	L	9.58	12.80	3.37±2.84
Male	R	10.38	12.88	2.50±1.84
	L	9.98	12.74	2.76±1.73

efficiency of such a method would have to be validated on another sample.

In order to evaluate the success of Turley's method, RMDS compared the actual number of impactions to the number expected on the basis of a forecast of future space. A χ^2 test showed that there was no significant difference between observed and expected frequencies. Interestingly enough, the same test was performed by substituting an expected frequency of .5, independent of the magnitude of the Xi to $\overline{7}$ prediction (Johnston, 1976). Again, there was no significant difference. If one were to look at only the extremes (impacted and erupted with function), the prediction method was correct 80% of the time. However, the clinically interesting and challenging cases do not fall into the extremes, but into the middle; cases that present with little space or with a great deal of space from Xi to $\overline{7}$ would seem relatively easy to predict (given, of course, the assumption that eruption is a function of available space).

Since the Turley method does not achieve the success claimed by RMDS, the clinician must decide whether this technique is sufficiently accurate to justify its use as a routine diagnostic procedure. Moreover, because it is assumed that the orthodontist will act on the outcome of the predictions, any forecasting method must be evaluated, not only in terms of its accuracy, but also in terms of the long-term consequences of the decisions prompted by the prediction scheme.

Science of Decision-Making

Clinically, there is a continual need to make decisions, and the orthodontist must be prepared not only to act on them but also to live with the consequences. In order to provide a reasoned perspective for a discussion of the problem of third molar prediction, a brief examination of the process of decision-making is, perhaps, appropriate.

In evaluating the status of the lower third molar, the orthodontist is faced with the problem of making a decision in the face of what might be termed "structured uncertainty"; that is, the possible future states of the third molars are known (I, E_{NF} or E_F), but not the exact probability associated with each. In dealing with uncertainty, the assumption that the decision-maker is in a state of complete ignorance is usually made (Ackoff, 1962). Ackoff, however, believes that the assumption of complete ignorance is to assume too little, for some knowledge of nature usually is available (such as the empirical probabilities reported here) and should be used in the decision process. When making a decision in the face of uncertainty, more than one course of action may be available, and the "best" course of action must be identified. This is the type of decision situation which has been the subject of extensive study under the heading "game theory."

The most widely used criterion is the so-called "maximin utility principle," according to which the worst possible outcome (minimum gain) associated with each possible decision is identified, and the course of action chosen whose "minimum gain is maximum"

(Ackoff, 1962).

The application of this criterion can be described with reference to a hypothetical "payoff matrix"(Table XII). In this and subsequent tables, the strategies of the "player" (read "orthodontist") are labelled $a_1 \ldots a_J$, and the strategies (outcomes) of his "opponent" (Nature) are labelled $S_1 \ldots S_K$. In selecting the best prediction method, the player will always choose row two: he notes the minimum return for each alternative (-6 for row 1 and 2 for row 2) and chooses the row that promises the highest minimal winnings (the maximin). Thus, by selecting row two, he is assured of winnings at least equal to two. The most common criticism is the maximin criterion is conservative, if not pessimistic, inasmuch as it is based on an "expectation of the worst" (Ackoff, 1962). This can be seen in another example (Table XIII). Row one is the best row to select using this criterion since it contains the maximin. Many, however, might choose row two with its greater overall expectation of gain (as long as row one does not lead to an unacceptable result, i.e., bankruptcy or, in the case of the clinical orthodontist, frank harm to the patient and a possible lawsuit).

To lessen the pessimistic effect of the maximin utility principle, Hurwicz introduced a so-called "index of optimism," α, which magnifies (multiplies) the greatest gain for each strategy, whereas its complement, $1 - \alpha$, multiplies the lowest; the middle values are ignored. The strategy with the highest expected gain is chosen as the optimal course of action.

By ignoring the middle values, certain possible strategies of Nature are ignored and attention is, instead, focused on the

TABLE XII

PAYOFF MATRIX--MAXIMIN CRITERION

Player's Strategy	Strategy of Nature			
	S_1	S_2	S_3	
a_1	-5	5	-6	
a_2	2	3	7	←Maximin

TABLE XIII

PAYOFF MATRIX--MAXIMIN CRITERION

Player's Strategy	Strategy of Nature			
	S_1	S_2	S_3	
a_1	1	3	5	←Maximin
a_2	-1	200	500	

extremes. The decision maker is free to select a value of based on personal preference. If a decision maker wanted to select a course of action whose associated minimum gain is maximum, he would set α near zero. Consider the game against Nature involving the payoffs shown in Table XIV. Given a coefficient of optimism $\alpha = 1/4$, and $1 - \alpha = 3/4$, it appears that row two is the optimal choice. If the decision maker preferred to maximize the maximum gain, he would set α near to one. For the game shown in Table XV ($\alpha = 3/4$ and $1 - \alpha = 1/4$), it appears that row one is the optimal choice.

Two common criticisms of this criterion may be noted: (1) the estimation of α is completely subjective, and (2) the effect of intermediate values is ignored.

A third criterion is that of "minimal regret." For each state of nature (for example, E_F, E_{NF}, I), it can be determined which course of action would yield the maximum gain, and then a "regret" matrix is constructed in which the difference between the payoff obtained and that which have been obtained if the best course of action had been chosen. According to this criterion, the course of action will be selected for which the maximum regret is minimum. This criterion may be examined in Table XVI. It can be seen that the decision-maker should choose that course of action associated with minimal regret, in this case a_2.

A fourth criterion is the "criterion of the mean" (Laplace Criterion). The average value (expectation) of each row is estimated, and the row with the highest total is chosen as the optimal course of action (Table XVII). A criticism of the Laplace criterion is that in playing a game with three columns the risks of several courses of

TABLE XIV

PAYOFF MATRIX--HURWICZ "INDEX OF OPTIMISM"

Player's Strategy	Strategy of Nature			Expected Gain
	S_1	S_2	S_3	
a_1	8 x 1/4 =2	-3 x 3/4 = -2.25	4 x 0 =0	$-1/4/3 = -.08$
a_2	2 x 0 =0	3 x 1/4 =.75	-1 x 3/4 = -.75	$0/3 = 0$

$\alpha = 1/4$

$1 - \alpha = 3/4$

TABLE XV

PAYOFF MATRIX--HURWICZ "INDEX OF OPTIMISM"

Player's Strategy	Strategy of Nature			Expected Gain
	S_1	S_2	S_3	
a_1	8 x 3/4 =6	-3 x 1/4 = -.75	4 x 0 =0	$5.25/3 = 1.75$
a_2	2 x 0 =0	3 x 3/4 =2.25	-1 x 1/4 = -.25	$2/3 = .67$

$\alpha = 3/4$

$1 - \alpha = 1/4$

TABLE XVI

APPLICATION OF THE CRITERION OF MINIMUM REGRET

Player's Strategy	Payoff For Strategy of Nature			Regret		
	S_1	S_2	S_3	S_1	S_2	S_3
a_1	30	25	5	0	0	-45
a_2	10	25	50	-20	0	0

TABLE XVII

THE CRITERION OF THE MEAN

Player's Strategy	Strategy of Nature			Expected Winning/a_i
	S_1	S_2	S_3	
a_1	4	2	0	6/3 = 2.0
a_2	2	3	4	9/3 = 3.0
a_3	5	0	2	7/3 = 2.3

TABLE XVIII

THE CRITERION OF THE MEAN

Player's Strategy	Strategy of Nature			Expected Winning/a_i
	S_1	S_2	S_3	
a_1	-24	0	24	0
a_2	0	0	0	0
a_3	-50	0	50	0

action may be quite different even though the totals are equivalent (Table XVIII).

With each of these criteria, an estimate of the payoff for each outcome must be used. Every outcome can be specified; however, the assignment of values to each is often too complex and subjective to be of any immediate practical significance. Thus, any criterion chosen by a decision-maker can be disputed on the basis of the subjectivity of the estimate of anticipated payoffs. However, even an attempt to estimate the possible consequences of a career of decisions would be of considerable heuristic and, in all probability, practical significance.

Given that some rational estimate of "payoffs" can be achieved, the problem of which criterion is the best in a particular situation can be discussed. As noted by Arrow (1958):

> It is clear that we do not really have a universally valid criterion for rational behavior (best choice) under uncertainty. Probably the best thing to be said is that different criteria are valid under different circumstances.

Ackoff (1962) has suggested the possible development of a "meta-criterion," which would allow the determination of "which of the available criteria of best choice is the best criterion."

Since the Turley method is based on overall statistical expectation, the criterion of the mean will be used in the examination of the Turley prediction method and three other common, but invariant clinical assumptions: (1) impaction in every case, (2) eruption (not in function) in every case, and (3) eruption (in function) in every case. The criterion of minimum regret will also be examined, because it can also be argued that there are certain highly undesirable out-

comes (i.e., extracting a good tooth or leaving an impacted tooth) that might cause the orthodontist considerable regret.

The three ultimate states of the third molar (E_F, E_{NF}, and I) imply three distinct courses of action. If a tooth is predicted to erupt into function, then, obviously, no action should be taken. If the third molar is predicted to erupt, but not into function, again no action should be taken, inasmuch as the outcome is questionable. For instance, if the tooth erupts with both mesial and distal marginal ridges exposed, then complications would not necessarily result. However, if the tooth is partially impacted, with only the mesial marginal ridge exposed, complications (i.e., pericoronitis, caries, periodontosis, etc.) are commonly seen. In any event, this borderline situation would seem to require too accurate a prediction to permit an early, irrevocable, decision. Therefore, a "wait and see" approach should be taken. Finally, if the impaction of the third molar is predicted, enucleation of the tooth bud might then be prescribed in order to avoid complications later in life.

To examine the Turley method from the standpoint of decision theory, payoffs were assigned to each specific outcome. The payoffs were derived by multiplying the empirical probability of impaction, eruption and not in function, or eruption and in function by a subjective estimate of the consequence of each specific outcome. Although the dentist may well be dealing with structured uncertainty, the probabilities associated with impaction and eruption were estimated here and, for the purpose of discussion, will be used to calculate the mathematical expectations. The values (gains or losses) assigned to each outcome are summarized in Table XIX.

TABLE XIX

VALUES (GAINS OR LOSSES) ASSIGNED TO EACH OUTCOME

Outcome		Actual		
		E_F	E_{NF}	I
Predicted	E_F	5	2	-25
	E_{NF}	4	5	1
	I	-50	0	10

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The values were assigned so that a decision leading to a Type I or Type II error (i.e., extracting a good tooth and leaving an impacted tooth) would be penalized and correct decisions would be rewarded. The large negative values given to the two highly undesirable outcomes could just as easily have been made smaller. If an orthodontist were to have all third molars enucleated, there would be no way that eruption could occur and, thus, the patient and the orthodontist would never know that a mistake had been committed. Accordingly, a smaller value could then be assigned to this outcome. Instead, the viewpoint taken here is that the enucleation of third molars that would ultimately erupt is wrong, inasmuch as a patient might need the tooth later in life. Similarly, if the third molar were predicted to be erupted and it actually impacted, a smaller value could have been assigned to this outcome since this result could be resolved later in life by the removal of the impacted tooth. However, this type of incorrect prediction can be known and, as a result, could be damaging to the orthodontist's reputation. In addition, if the patient had the impacted teeth extracted and developed complications (pain, infection, etc.), the patient could conceivably blame the orthodontist. Therefore, to penalize these unfortunate occurrences, high negative values were assigned to both outcomes. It may be noted that a value of $-\infty$ could have been assigned to both; however, for the purpose of discussion, lesser penalties were imposed.

The payoff (expectations) for the various outcomes are summarized in Table XX. It may be seen that the overall value of the

TABLE XX

OUTCOME OF ALL TURLEY PREDICTIONS
(LaPlace Criterion)

Predicted Outcome	Expectation (V x P)*			
	Outcomes			Overall
	E_F	E_{NF}	I	
Strategy a_1: Turley Method				
E_F	5 x .18 = .9	2 x .05 = 1	-25 x .02 = .5	0.50
E_{NF}	4 x .17 = .68	5 x .03 = .15	1 x .22 = .22	1.05
I	-50 x .09 = -4.50	0 x 0 =0	10 x .35 = 3.5	-1.00
			Total	.55
Strategy a_2: Predict I				
I	-50 x .44 = -.22	0 x .08 =0	10 x .59 =5.9	-16.1
Strategy a_3: Predict E_{NF}				
E_{NF}	4 x .44 = 1.76	5 x .08 =.4	1 x .59 = .59	2.75
Strategy a_4: Predict E_F				
E_F	5 x .44 = 2.2	2 x .08 = .16	-25 x .59 = -14.75	-12.39

*V = value assigned to outcome (see pp. 70); P = empirical probability (see pp. 45).

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game using Turley's method (obtained by adding the average gains of each row) is .55. When this is compared to the three invariant actions (always predicting I, E_{NF}, or E_F), the best overall course of action, according to the Laplace criterion, would be the invariant prediction of E_{NF}. Morever, the Turley method as applied to ten-year prediction interval (the interval advocated by RMDS) again was inferior to thr prediction of E_{NF} (Table XXI). In addition, the best course of action, according to the criterion of minimum regret, would be the invariant prediction of E_{NF}as shown by the regret matrix in Table XXII. However, if a higher expectation is associated with the prediction technique when compared to the expectation associated with predicting E_{NF} for every case, the orthodontist would be faced with two choices which could, perhaps be handled by the criterion of minimum regret. Associated with the prediction method are the two highly undesirable outcomes (i.e., extracting a good tooth and leaving an impacted tooth) that, for many would more than outweigh any overall advantage afforded by the predictions. Thus, it would seem more prudent to base a decision on the criterion of minimum regret and, thereby, avoid these undesirable outcomes. Thus the optimal course of action would be to predict nonfunctional eruption and to wait until the patient has passed the age of third molar eruption. The decision to extract would then be based on the final position of the tooth, thereby avoiding any grossly undesirable (and irreversible) outcomes for both the patient and the orthodontist.

Ethical Constraints on Enucleation

Inasmuch as Ricketts and associates (1976) have advocated enucleation based on the outcome of the Turley prediction method, it

TABLE XXI

OUTCOME OF THE TURLEY TEN YEAR PREDICTION-INTERVAL
(Laplace Criterion)

Predicted Outcome	Expectation (V x P)*			Overall
	Outcomes			
	E_F	E_{NF}	I	
Strategy a_1: Turley Method				
E_F	5 x .21 =1.05	2 x .05 = .1	-25 x .15 = -3.75	-2.60
E_{NF}	4 x .26 = 1.04	5 x .03 = .15	1 x .34 = .34	1.50
I	-50 x 0 =0	0 x 0 = 0	10 x .05 =.5	.50
			Total	.57
Strategy a_2: Predict I				
I	-50 x .47 = 23.50	0 x .08 = 0	10 x .54 = 5.4	-18.10
Strategy a_3: Predict E_{NF}				
E_{NF}	4 x .47 =1.88	5 x .08 = .4	1 x .54 =.54	2.82
Strategy a_4: Predict E_F				
E_F	5 x .47 = 2.35	2 x .08 = .16	-25 x .54 = - 13.5	-10.99

*V = value assigned to outcome (see pp. 70);
P = empirical probability (see pp. 45).

TABLE XXII

APPLICATION OF THE CRITERION OF MINIMUM REGRET

Player's Strategy	Payoff for Strategy of Nature			Regret		
	E_F	E_{NF}	I	E_F	E_{NF}	I
Turley Method	-2.92	.25	3.22	-4.68	-.15	0
Predict E_{NF}	1.76	.04	.59	0	0	-2.63

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would seem appropriate to comment, from the standpoint of a dentist, on its routine use in dental practice.

One assumption made by many orthodontists is that the third molar does not increase the efficiency of occlusion, and that its loss is of no great significance. Unfortunately, no one can predict the future loss of the first and second molars due to caries or injury. If such a loss occurs, the third molar could possibly be used as an abutment to a prosthetic appliance. Even though the third molar is not needed at a particular time, this is not sufficient reason to ignore the possible future need of this tooth.

Another commonly held belief is that the impacted third molar causes crowding of the mandibular incisors. Thus, many orthodontists extract the third molar to prevent relapse of the lower anterior teeth. This belief has been seriously challenged by many (Broadbent, 1943; Björk, 1956; Shanley, 1962; Fuder, 1969), and, although Vego (1961) has reported crowding of mandibular incisers in association with the presence of impacted third molars, he also noted crowding of lower incisors when third molars were congenitally missing.

Daschi and Howell (1961) have shown that 37% of the impacted mandibular third molars were found radiographically to have radiolucent areas (cysts) around the crown. A cyst may not only affect the third molar but also, in time, the adjacent teeth. Because cyst formation is associated with the impacted third molar, many clinical orthodontists believe that enucleation is justified. However, it could be argued (but not yet proved) that cyst formation might also

be caused by epithelial remnants left behind during enucleation.

Handleman (1976) felt that the enucleation of the third molars may cause a psychological problem for the child. The child

> . . . is asked to accept a surgical procedure in the back of his mouth, and the loss of two permanent teeth, when they are not in pain, and can see no relationship to straightening their teeth. Perhaps we have a trade-off: the less traumatic surgical procedure of enucleation for the more psychologically traumatic loss of unknown "body parts" in the young child.

If an orthodontist chooses routinely to enucleate the lower third molars, thereby ignoring the arguments--both real and imagined--against enucleation, he could only do so if an accurate prediction method were available and the significance of the various outcomes were taken into consideration (with reference to some known criterion). This investigation has shown that such accuracy cannot be obtained from the three methods examined. However, if the perfect prediction method did exist, certain variables must be considered as part of the overall decision apparatus. It would be necessary to know if the patient would need comprehensive orthodontic treatment and whether it would involve extraction or not, so that space could be added or subtracted from the prediction formula. The decision to enucleate at such an early age, in turn, would depend on additional decisions that can only be made at a later time. It appears, therefore, that enucleation would be a questionable procedure even if a perfect prediction method were available.

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SUMMARY AND CONCLUSIONS

Although the prediction of lower third molar impaction has been attempted for many years, a prediction service only recently has been made commercially available by Rocky Mountain Data Systems, Inc. It is claimed that their technique (described by Turley and Chaconas in 1975) can predict ten years in advance, the space available for third molar eruption to ±2.8 mm and that, because the third molar eruption is a function of space, eruption can and should be predicted. Although an increasing number of orthodontists employ this service, little independent support for its efficacy is available. Accordingly, an investigation of the accuracy of this technique, as well as that of two other workers (Leydard and Richardson), was undertaken.

Sixty-two longitudinal cephalometric series, spanning the period from eight years of age to maturity, were selected from the files of the Bolton-Brush Growth Study Center. Each subject had an average of thirteen cephalometric radiographs.

Separate predictions were obtained for both lower third molars by tracing both right and left sides of the mandible, teeth, and occlusal plane for the three techniques. The accuracy of the prediction methods were examined by a variety of statistical tests and the following conclusions were drawn:

(1) Leydard's method was biased toward the prediction of impaction. Of forty-five erupted third molars, only eight

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were predicted.

(2) Richardson's general observations that steeply angled third molars tend to be impacted and tend to upright less were corroborated by this study. However, Richardson did not present a prediction method per se; therefore, these observations do not constitute a formal validation of a prediction technique.

(3) For Turley's method, the coefficient of triserial correlation between the predicted measurements and the final status of the tooth was of only "moderate" magnitude, averaging .527 for all prediction intervals.

(4) Overall, the Turley method was correct in only 49.5% of the cases. Its accuracy decreased in direct proportion to the length of the prediction interval.

(5) Because with the Turley method several highly undesirable outcomes have a finite probability, the orthodontist may well choose to "watch and wait," a simpler course of action that may well have both a higher expected "payoff" and a lesser risk.