THE TREATMENT OF LOWER ANTERIOR CROWDING
BY METHODS OTHER THAN THOSE
INVOLVING PREMOLAR EXTRACTIONS

ROGER A. J. PEATE

UNIVERSITY
OF SYDNEY
DENTAL LIBRARY

A treatise submitted in partial fulfilment
of the requirements for the degree of
Master of Dental Surgery
at
the University of Sydney

November, 1980
I wish to express my gratitude to Professor Keith Godfrey, to Ives Lopes, and to my family, for their interest, encouragement and support during the synthesis of this treatise.
"treatise: a written formal composition on some subject, in which the principles of it are discussed or systematically explained"

(The International Webster Dictionary, 1973)
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section/Chapter</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Figures</td>
<td>i</td>
</tr>
<tr>
<td>List of Tables</td>
<td>iv</td>
</tr>
<tr>
<td>Introduction</td>
<td>vi</td>
</tr>
<tr>
<td><strong>SECTION A:</strong> The Development of an Occlusion</td>
<td></td>
</tr>
<tr>
<td>Chapter 1: Historical Résumé of the Incisor Relationships, Occlusion and Arch Form</td>
<td>1</td>
</tr>
<tr>
<td>Chapter 2: The Compromise of &quot;Ideal&quot; Occlusion</td>
<td>10</td>
</tr>
<tr>
<td>Chapter 3: Growth Changes in the Lower Anterior Segment:</td>
<td>17</td>
</tr>
<tr>
<td>1. Growth and Development Related to Incisor Position and Facial Profile.</td>
<td>17</td>
</tr>
<tr>
<td>2. Positional and Dimensional Changes of the Dental Arches and Mandibular Incisors During Growth and Matur-ation.</td>
<td>22</td>
</tr>
<tr>
<td><strong>SECTION B:</strong> The Assessment and Analysis of the Mandibular Dental Arch</td>
<td></td>
</tr>
<tr>
<td>Chapter 4: The Assessment of Arch Form, Arch Width and Arch Length:</td>
<td>31</td>
</tr>
<tr>
<td>1. The Arch Form and Arch Width</td>
<td>31</td>
</tr>
<tr>
<td>2. The Arch Length Deficiency Estimation:</td>
<td>34</td>
</tr>
<tr>
<td>(a) Analysis by Direct Tooth Measurements.</td>
<td>34</td>
</tr>
<tr>
<td>(b) Analysis by Periapical Radiographic Measurements.</td>
<td>43</td>
</tr>
<tr>
<td>(c) Analysis Combining Periapical Radiographic and Direct Tooth Measurements.</td>
<td>44</td>
</tr>
<tr>
<td>Chapter 5: The Applications of Cephalometric Analysis.</td>
<td>50</td>
</tr>
</tbody>
</table>
SECTION B:

Chapter 6: The Diagnostic Set-Up  
Chapter 7: Factors Influencing Lower Anterior Crowding:
   1. Variables Which May Affect Lower Incisor Alignment.  
   2. The Development of Mandibular Anterior Crowding.  
Chapter 8: Periodontal Considerations in the Lower Anterior Arch.  

SECTION C: Clinical Considerations in the Treatment of Lower Incisor Crowding by Methods Other Than Those Involving Premolar Extractions

Chapter 9: The Interproximal Reduction of Enamel:
   1. The Amount of Enamel Reduction.  
   2. Interproximal Stripping Techniques.  
   3. Periodontal Considerations of Interproximal Stripping.  

Chapter 10: The Mandibular Incisor Extraction:
   1. The Mandibular Incisor Extraction: Compromise or Design?  
   2. Indications for the Mandibular Incisor Extraction.  
   3. Advantages of the Lower Incisor Extraction.  
   5. The Treatment of the Ectopic Mandibular Incisor.
SECTION C:

Chapter 11: Relapse and Retention Following Treatment of Lower Anterior Crowding: 142
   1. Relapse 142
   2. Retention Following Correction of Lower Anterior Crowding. 146

Chapter 12: Appliances Used in the Correction of Lower Anterior Crowding. 148

Chapter 13: Surgical Procedures Involving the Lower Anterior Segment. 158

Conclusion 160

Bibliography 163
<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Illustration of Begg's 1954 findings relating to the &quot;natural wear&quot; of teeth:</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>i) a typical Class I malocclusion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ii) a typical Class III malocclusion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>iii) a Class III &quot;naturally worn&quot; malocclusion, as proposed by Begg</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Illustration of Neff's APR/overbite relationships (1957).</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Baum's superimposed cephalometric tracings of a typical male at the ages of</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>13 years 10 months, and 17 years 5 months (1961).</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>The usual directions of growth in the ramus and incisor regions, as described</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>by Thurow (1970) and Graber (1972).</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Mandibular canine arch width variations with age (as described by Moyers et</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>al., 1976).</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mandibular arch perimeter length variations with age (as described by Moyers</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>et al., 1976).</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Cephalometric reference points.</td>
<td>51</td>
</tr>
<tr>
<td>8</td>
<td>Cephalometric reference angles.</td>
<td>52</td>
</tr>
<tr>
<td>9</td>
<td>Cephalometric reference planes and axes.</td>
<td>53</td>
</tr>
<tr>
<td>10</td>
<td>Downs' cephalometric reference angles (1948).</td>
<td>55</td>
</tr>
<tr>
<td>11</td>
<td>Tweed's diagnostic triangle (1946).</td>
<td>58</td>
</tr>
</tbody>
</table>
Fig. 12 : Ricketts' incisor measurements relating to the APo plane (1957). 60

Fig. 13 : Holdaway's ideal values for angle ANB and for the distance of the lower incisor to the NB plane (1956). 63

Fig. 14 : Steiner's ideal values relating to the position of the mandibular and maxillary incisor axes (1959). 66

Fig. 15 : Edwards' coordinate relationships for the mandibular incisor (1968). 68

Fig. 16 : Riger's triangle of incisor angulations (1979), and, a typical diagnostic template. 71

Fig. 17 : An illustration of the use of the diagnostic template (as described by Riger, 1979).

i) severe maxillary incisor overjet which cannot be fully corrected by incisor retraction, as the new position of the maxillary incisor is outside the alveolus;

ii) moderate maxillary incisor overjet which may be successfully reduced within bony limits. 74

Fig. 18 : Keene and Engel's reference planes and angles (1979). 76

Fig. 19 : A cephalometric tracing demonstrating possible mandibular incisor repositioning (according to Kesling, 1956). 83

Fig. 20 : Sanin and Savara's model explaining possible development and self correction of mandibular incisor crowding (1973). 84

Fig. 21 : Graphic representation of Poulton and Aaronson's findings (1961) relating the periodontal status to the degree and type of malocclusion. 93
<p>| Fig. 22 | Force vectors which may operate to create labial periodontal recession on mandibular incisors. | 96 |
| Fig. 23 | Force vectors creating labial root torquing of the mandibular incisor. | 98 |
| Fig. 24 | Illustration of possible detrimental effects resulting from incorrect interproximal stripping. | 119 |
| Fig. 25 | Lower removable appliance as described by Betteridge (1979). | 150 |
| Fig. 26 | Lower removable appliance using labial bow or elastic (as described by Graber, 1972, and Adams, 1970). | 153 |
| Fig. 27 | Lower removable appliance using labial apron springs (as described by Adams, 1970). | 154 |
| Fig. 28 | Lower removable expansion appliances (as described by Adams, 1970). | 155 |</p>
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>Neff's APR/overbite relationships (1957).</td>
<td>14</td>
</tr>
<tr>
<td>Table 2</td>
<td>Watson's anterior ratios for completed orthodontic cases (1971).</td>
<td>16</td>
</tr>
<tr>
<td>Table 3</td>
<td>Mandibular incisor tooth dimensions and mesiodistal/faciallingual ratios (according to Moyers et al., 1976).</td>
<td>41</td>
</tr>
<tr>
<td>Table 4</td>
<td>List of multiple regression equations for prediction of mandibular canine and premolar widths (as supplied by Staley et al., 1979).</td>
<td>46</td>
</tr>
<tr>
<td>Table 5</td>
<td>Tweed's FMA, FMIA and IMPA values (1966).</td>
<td>57</td>
</tr>
<tr>
<td>Table 6</td>
<td>Ricketts' measurements of the mean distance of the lower incisor to the APo plane for various age groups (1960)</td>
<td>61</td>
</tr>
<tr>
<td>Table 7</td>
<td>Holdaway's ideal values for the distance of the lower incisor to the NB plane for various ANB angles (1956).</td>
<td>64</td>
</tr>
<tr>
<td>Table 8</td>
<td>Keene and Engel's multiple regression relationship for the sum of lower incisor widths (1979).</td>
<td>78</td>
</tr>
<tr>
<td>Table 9</td>
<td>Kesling's values relating the position of the mandibular incisor to the FMPA (1956).</td>
<td>82</td>
</tr>
<tr>
<td>Table 10</td>
<td>Comparison of periodontal status with the degree and type of malocclusion (according to Poulton and Aaronson, 1961).</td>
<td>92</td>
</tr>
</tbody>
</table>
Table 11: Diagnostic reference values for enamel thickness of lower incisors (according to Peck and Peck, 1973).

Table 12: Maxillary and mandibular incisor mesiodistal widths (as supplied by Garn et al., 1970).
INTRODUCTION

The purpose of this treatise is to examine the hypothesis that crowding of the mandibular incisor teeth may be explained in terms of natural evolution, and that this understanding may provide logical assurance that the reduction of tooth number or size in the mandibular anterior segment may be physiologically acceptable.

Salzmann (1966, p.714) typifies conventional thoughts by suggesting that lower incisors should not be extracted unless damaged beyond repair, severely crowded, or excluded from the arch. More recently Riedel (1978) has advocated extraction of one lower incisor in cases of mild crowding, and possibly two lower incisors in cases of severe crowding.

Neff (1957) recognised that a lower incisor extraction may be orthodontically desirable, but suggested that it "must be considered with caution", while Graber (1969, p.96) warns that "treatment may be very complex when only three incisor teeth are present because of the imbalance between anterior segments". Buchner (1945) remarked that "the relationship of teeth is incorrect when less than four lower incisor teeth are present".

Historically, therefore, the lower incisor extraction has been not recommended. In recent years the lower incisor extraction or interproximal tooth reduction of the lower anteriors has been viewed in a more tolerant atmosphere, and has been used as a beneficial treatment in many instances.
Jacobson (1973) summarizes the situation by stating that "the trend in orthodontics is a departure from empirical and mechanotherapeutic treatment to one which is scientifically and biologically orientated".
SECTION A

THE DEVELOPMENT OF AN OCCLUSION
CHAPTER 1: Historical Résumé of the Incisor Relationships, Occlusion and Arch Form

Begg (1954), in his study entitled "Stone Age Man's Dentition", attempted to describe the evolution of the teeth and jaws and to establish from this the basic principles from which one may form the foundations for orthodontic treatment.

At no stage in either the deciduous or secondary set of teeth did Begg find the occlusion of Stone Age man, (or the modern counterpart, the Australian aborigine), similar to the modern textbook ideal occlusion. This is due mainly to dietary differences, with modern diets being essentially too soft to create any significant wear of the teeth during the growing years of life.

In Stone Age man, Begg found that when the permanent incisors erupt there is initially an overbite, but with mastication the incisors gradually wear until eventually the plane of wear becomes horizontal, as the lower incisors move labially. By adolescence, in primitive civilizations, the incisor overbite has been reduced to an edge-to-edge bite, and the Curve of Spee has flattened.

Begg suggests that orthodontic treatment is a compromise throughout, as the orthodontist is dealing with a dentition which cannot possibly be made anatomically correct, due to lack of natural attrition. Normally, according to Begg, attrition would create interproximal wear, and interproximal contact is maintained by mesial migration of all the teeth. Therefore,
the amount of space required to accommodate the teeth in each jaw gradually becomes less, as interproximal and occlusal attrition proceeds. Once the occlusal attrition extends below the contact points, mesiodistal reduction is accelerated. Eventually, a typical Angle's Class III occlusal relationship develops, due to mesial migration of the mandibular teeth following interproximal reduction. Continual tooth eruption accompanies occlusal attrition, although not at the same rate, so a reduction in height of the clinical crown results.

Textbook normal occlusion, with the teeth almost unworn both occlusally and interproximally, and with high interlocking cusps and incisor overbite is, according to Begg, anatomically abnormal. He suggests that the natural phenomenon of mesial migration of the teeth, plus retention of incisor overbite, may be responsible for the progressive lower incisor overlapping and crowding, seen in modern dentitions.

Friel (1954) concurred with Begg's findings, stating that accompanying attrition there is a relatively greater forward movement of the mandibular posterior teeth than of the maxillary posterior teeth.

Figure 1 illustrates typical Class I and III malocclusions, as seen today, and a "naturally worn" Class III occlusion, as proposed by Begg. He suggests that, in the absence of occlusal and interproximal wear, the teeth are unable to be accommodated within the arches, and malocclusion results.
FIG. 1: ILLUSTRATION OF BEGG'S 1954 FINDINGS RELATING TO THE "NATURAL WEAR" OF TEETH

i) A typical Class I malocclusion:

ii) A typical Class III malocclusion:

iii) A Class III "naturally worn" malocclusion, as proposed by Begg:
As civilized man's diet does not cause occlusal and interproximal attrition, Begg proposed that the previously indispensable processes of continual vertical tooth eruption and mesial migration, although still operating, are frustrated and distorted. The failure of continual natural arch reduction causes misplaced teeth, ill-formed dental arches, and malocclusions.

This principle provides Begg with the justification of tooth extraction as an aid to orthodontic treatment. He states that tooth extraction as an aid to orthodontic treatment is scientifically correct because: (i) it simulates the natural loss of tooth substance by attrition; (ii) the inherited amount of tooth substance is sometimes too great, even in the presence of marked attrition and (iii) possibly the anteroposterior jaw malrelationships are so pronounced that a stable and good occlusion is unattainable without tooth extraction. In certain circumstances Begg advocates the removal of eight teeth - the first four permanent molars and four first premolars. He suggests that this may eliminate the need later to remove third molars, (often after anterior relapse has occurred). When the first permanent molars are extracted (as well as first premolars), Begg suggests that the second molars may erupt mesially, into an occlusion which more naturally resembles the occlusion of primitive man, in whom attrition would have resulted in mesial migration of the teeth.

Even following posterior extractions, anterior relapse often occurs, as the anterior segment fails to undergo the
natural reduction which would normally have been due to attrition. Begg considers that extraction of lateral mandibular incisors may more closely simulate attritional tooth reduction, but dismisses this as a possible solution for aesthetic reasons. While Begg (1954) did not suggest interproximal reduction by stripping the enamel of the mandibular incisors, (see Chapter 9, "The Interproximal Reduction of Enamel"), it would be reasonable to assume that the principles behind interproximal stripping would be consistent with the concept that the teeth, in the primitive state, would have undergone natural interproximal reduction.

As there is very little tooth wear in civilized diets, some investigators have reached the conclusion, as expressed by Dewel (1943), that "a moderate amount of crowding of the lower anterior teeth is possibly characteristic and typical of the human dentition". Berger (1959) supported this, and elaborated by suggesting that the accepted occlusion by today's standards, where there is about one third incisor crown overbite, (psalidonty), is a recent acquisition in evolutionary terms. The transition from the more primitive edge-to-edge bite, (labiodonty), has, according to Berger, and in support of Begg's theory, caused a cramping of the lower incisors as they have been forced into a narrower arch, constricted within the upper arch. McCarthy (1971) concurs with these findings, and describes the primitive dentition as one in which wear produces a flat occlusal platform, a helicoidal occlusal plane, and occlusal and interproximal attrition, with a reduction in arch perimeter and overbite. Beyron (1964) and Campbell (1925, p.64) have
described such occlusions occurring in the Australian aborigine in the primitive state, and McCarthy (1971) reports that Ackermann, in 1941 and 1946, also studied similar dentitions in the Eskimo in the primitive state.

McCarthy (1971) suggests that the helicoidal occlusal plane is an artificially created mechanism as a response to loss of cuspal inclines. Such an occlusion does not have cuspid protection as proposed by D'Amico (1961), but McCarthy suggests that this does not invalidate D'Amico's theory, as by the time the upper primary canines have erupted in the primitive dentition, there has been sufficient attrition of deciduous incisors and molars to allow wide eccentric functional excursions. The upper deciduous canines, erupting into such an occlusion, cannot establish a functional overbite.

Scaife (1969) describes the concept of cuspid protection as one in which the only tooth contact in all positions of the mandible, except centric relation, is between the maxillary cuspsids and mandibular cuspsids or first premolars and that cuspsids are not in contact in centric relation.

McCarthy concludes that modern man, without the influence of harsh diet, has an occlusion basically determined by cuspal guidance and genetics. He suggests that whether a cuspid-protected occlusion is a normal variant or a universally desirable feature is still unresolved, but to actively establish a cuspid-protected occlusion during orthodontic treatment may, in the absence of positive indications that such an occlusion was a genetic endowment, place an overwhelming burden on the
physiologic adaptiveness of the whole stomatognathic system.

Orthodontic manipulation of lower incisors invariably involves repositioning the lower canines. An appreciation of the type of canine occlusion before and after treatment is essential, as expressed by Kahn (1977), when he observes that "the importance of properly executed orthodontics in the preservation of the stomatognathic system becomes critically apparent" when considering the occlusion of the canines. He emphasises that the upper and lower canines should be placed in such rotational stances that the tip of the lower canine engages in the mesial groove of the upper canine, otherwise premature wear of the teeth may occur. This is, in effect, a Class I centric occlusion.

"Normal" occlusion is, therefore, very difficult to define in terms of tooth position, as the concept of normality differs greatly between the natural primitive dentition and modern man's dentition. For the purposes of orthodontic description, diagnosis and treatment planning, "normal" in the modern sense, suggests the most commonly occurring stable occlusion. Angle (1907) classified malocclusions into three basic types based on tooth position only. Tweed (1945), in his fundamental requirements for a normal occlusion, stated that there must be a full complement of teeth, with the qualification that four opposing and opposite premolars may be removed. However, he further stated that "there must be a normal relationship of teeth to their respective jawbones".
There are numerous modern definitions of "normal" occlusion. As Strang (1952) proposes, normal occlusion involves concepts of the teeth, individually and collectively, relating to one another and to the basal bones, and tooth inter-digitation, proximal contacts and axial positions, associated at all times with normal growth, development, and environmental tissues.

Hemley (1944, p.5) suggested that the ultimate standard of normality should be functional adequacy, and introduced the concept of "individual normal occlusion", which he described as differing from all other normal occlusions to some extent, but still satisfying all of the requirements of a normal occlusion. Hemley, therefore, recognised that variation may occur within the range of normal, which might otherwise be considered abnormal if orthodontists were to adhere to an idealised perfectionist's goal. He further notes that the ultimate standard of normal should be functional adequacy for the particular individual concerned.

The goals of orthodontics, according to Levin (1964) should consider the individual's normal occlusion as one which gives him functional adequacy, denture stability, dental longevity and aesthetic harmony. Function was also discussed by Lundström (1925) in his early work on the apical base. Lundström recognised that occlusal function was not the singular factor which exerted an effect on the teeth and the apical base. Rogers (1922) recognised the importance of a functional muscle balance in maintaining good occlusions, and Strang (1952)
believed that mandibular intercanine and intermolar widths were good indices of the muscular balance present, and therefore dictated the limits of arch expansion in these areas during treatment. Riedel (1960, 1969) concurred with this viewpoint when he stated that arch form in the mandibular arch cannot be permanently altered by appliance therapy.

Fisher (1957, p.54) takes issue with the "sanctity of the full complement of teeth" by concluding that "the primary factors in establishing dental occlusion and articulation, as well as the movements of the condyle in the glenoid fossa, are the forces exerted by the muscles surrounding the teeth and the ligaments supporting the mandible that limit those forces".

Weinstein, Haack, Morris, Snyder and Attaway (1963) described "An Equilibrium Theory of Tooth Position" which takes into account all previously suggested concepts which contribute to "normal" occlusion. They conclude that each tooth may have more than one stable position, and its final position is a sum of all the influences of forces exerted on the tooth.
CHAPTER 2: The Compromise of "Ideal" Occlusion

Salzmann (1966, p.154), McCarthy (1971), and Moyers (1973, p.91) describe the craniofacial growth, tooth size, shape and number, and the development of the dentition as being genetically determined, while Barrett and Hanson (1978, p.87) recognise that heredity influences arch form. Hatton (1955) found that tooth eruption also occurs primarily as an inherited genetic trait, until such time that there is an initial tooth contact, at which stage an "occlusal sense" develops, as described by Sillman (1953), involving occlusal reflexes and mandibular movements, which leads to the development of an occlusal function pattern.

Moyers (1964) suggests that the occlusal position in the primary dentition is learned in such a way that it provides maximum occlusal contact and minimum stress on tissues. He calls this the "ideal occlusal position", and suggests that it coincides with the unconscious swallowing position of the mandible. From this he concludes that, during eruption of the primary teeth and the development of occlusion, the swallowing reflex significantly influences occlusal position, so that the intercuspal position and the ideal occlusal position coincide. The swallowing reflex, therefore, determines initially the relative positions of the primary maxillary and mandibular teeth, and in pursuing years, influences the secondary dentition, as reflex adult swallowing continues to occur at an average rate of 585 times per day, as reported by Lear, Flanagan and Moorrees (1965).
The complex balance between the neuromuscular physiology of the jaws, and the physiology of occlusion has been described in detail by Ramfjord and Ash (1969, p.1) who view the masticatory system as a "functional unit composed of teeth, their surrounding and supporting structures, the jaws, the temporomandibular joints, the muscles ... and the vascular and nervous systems associated with these tissues".

The "ideal" occlusion, by modern standards, consists of interdigitating teeth, with cusp-fossa relationships, and a positive maxillary incisor overjet and overbite, as originally described by Angle in 1907. Graber (1972, p.195) introduces the concept of a "dynamic occlusion" in which size, shape and number of teeth, spacing, crowding, axial inclination, overbite and overjet may have a range of variability which may be acceptable, provided that they are not out of harmony with the overall pattern. "Ideal" or "normal" occlusion usually displays an overbite of maxillary incisors over mandibular incisors of approximately one third of the lower incisor crown; Bolton's detailed assessment of anterior tooth sizes (1958, 1962) relates to a mean overbite of 31.3% coverage of the clinical crown of the mandibular incisor by that of the maxillary central incisor.

If the postulations of Begg (1954), Friel (1954), Berger (1959) and McCarthy (1971) prove true, that is, that man's dentition has evolved to meet the requirements of a harsher diet than that provided by modern civilized communities and that an edge-to-edge bite, with occlusal and interproximal
wear, more closely resembles man's designed occlusal pattern, then it is not surprising to see many patients exhibiting cramping of the lower anteriors, in a situation where the lower incisors appear to be too large mesiodistally to be accommodated within the arch confined by the upper anteriors and the overbite.

The concept of the lower anteriors being too wide mesio-distally to be accommodated within the maxillary arch has been recognised and investigated by many clinicians, the most notable of whom include Ballard (1944), Nance (1947), Neff (1957) and Bolton (1958, 1962), who, while considering an overbite to be normal, realised that in such circumstances the size of one dental arch significantly influences the size of the opposing dental arch for a given amount of incisor overlap. Ballard (1956), in finding that more than 50 percent of the orthodontic patients he examined had an excess of total mesiodistal tooth widths in the lower six anterior teeth of more than 2mm than could be accommodated within the upper arch, concluded that "the human denture is not the ideally perfect mechanism, as thought by the early practitioners of orthodontia", and suggested that "this variation in tooth size and relationship of upper and lower anterior segments is of sufficient incidence and magnitude to merit serious consideration in the aetiology, diagnosis, and treatment planning in every orthodontic case". Lundström (1955) proposed that "Nature" has not adjusted the overbite and overjet relationships to accommodate for intermaxillary tooth width disharmonies.
In addition to findings relating to intermaxillary tooth width disharmonies, which support the "natural wear" theories on dental evolution, there is also evidence that crowding of the teeth may be contributed to by an evolutionary gradual reduction in the size of the denture and jaws, without such a dramatic reduction in dental dimensions, as outlined by Lavelle, Shellis and Poole (1977, p.40-83). Lavelle et al. (p.183-185) also found that posterior occlusal tooth surface areas are reducing at a rate of 2% per thousand years in the maxilla, and 1% per thousand years in the mandible, and that there is a relatively high incidence of agenesis in man which "may be a phylogenetic accompaniment of the reduction of the maxillo-mandibular skeleton, which is such a marked feature of human evolution". As the rate of reduction of posterior occlusal tooth surface area in the mandible is only one half that of the maxilla, Lavelle et al.'s results suggest that, in evolutionary terms, the maxillary arch is becoming relatively smaller in dimension at a greater rate than the mandibular arch.

One may conclude from these statements that orthodontists are, in many cases, attempting to mould an acceptable occlusion, both physiologically and aesthetically, within an arch whose individual components, pre-formed by Nature's design, are too wide to fit into modern man's concept of desirable occlusion. So-called "ideal" occlusion may in fact only be ideal from modern man's aesthetical viewpoint, and may be far from ideal in terms of function and evolution of the jaws. It is, therefore, a compromise, as evolutionary evidence supports theories that the modern picture of occlusion, with interdigitating cusps and cusp-fossa relationships, and
positive incisal overjet and overbite should only be a transitional stage towards an occlusally flat, edge-to-edge dentition.

In 1957 Neff attempted to relate the relative widths of the upper and lower anterior teeth to the degree of overbite. He described the Anterior Percentage Relationship (A.P.R.) which related the total mesiodistal anterior tooth widths in the maxilla to that in the mandible. That is, if the maxillary anteriors were 18% wider in total mesiodistal widths than the lower six anteriors, the A.P.R. was 18%. The A.P.R. measurements were related to overbite, and Neff found that an 18% A.P.R. produced no overbite, a 40% A.P.R. produced an overbite of 50%, while a theoretical A.P.R. of 55% would produce 100% overbite. Neff's results are depicted in Table 1, and Figure 2.

**TABLE 1: NEFF'S A.P.R./OVERBITE RELATIONSHIPS (1957)**

<table>
<thead>
<tr>
<th>A.P.R.</th>
<th>Overbite</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% - 18%</td>
<td>0</td>
</tr>
<tr>
<td>22%</td>
<td>15%</td>
</tr>
<tr>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>36%</td>
<td>35%</td>
</tr>
<tr>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>55%</td>
<td>100%</td>
</tr>
</tbody>
</table>

A.P.R. = Anterior Percentage Relationship
FIG. 2: ILLUSTRATION OF NEFF'S A.P.R./OVERBITE RELATIONSHIPS (1957)

Upper anteriors 18% wider than lower anteriors:

No Overbite

Upper anteriors 30% wider than lower anteriors:

30% Overbite

Upper anteriors 40% wider than lower anteriors:

50% Overbite
Neff suggests that if the A.P.R. is 18% or less, and an overbite exists, spacing must occur between the maxillary incisors. He describes the A.P.R. as relating the labio-lingual thickness of the teeth to the degree of overbite. Due to the compound curve shape of the lingual slope of the upper incisor, at a position where the upper incisor teeth overlap the lower incisors by an amount of one third of the lower incisor crown, the increase in A.P.R. is mainly due to overjet increase.

Bolton (1958, 1962) further analysed the relationship of tooth size between maxillary and mandibular dentitions, and found that, related to a mean overbite of 31.3%, a ratio of 77.2 existed when the sum of the mesiodistal widths of the mandibular anterior teeth was divided by the sum of the mesiodistal widths of the maxillary anterior teeth, in an "ideal" occlusion. Stifter (1958) tested Bolton's analysis and concurred with his findings in ideal occlusions. Watson (1971) also tested Bolton's analysis on orthodontically completed cases, which presumably had close to "ideal" occlusions. Watson's findings (see Table 2) were very similar to those of Bolton.

**Table 2 : Watson's Anterior Ratios for Completed Orthodontic Cases (1971)**

<table>
<thead>
<tr>
<th>Type of Case</th>
<th>Mean Anterior Ratio</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-extraction</td>
<td>77.79</td>
<td>74.1 - 80.7</td>
</tr>
<tr>
<td>Extraction of four first premolars</td>
<td>77.74</td>
<td>75.0 - 79.9</td>
</tr>
<tr>
<td>Extraction of four second premolars</td>
<td>77.74</td>
<td>75.1 - 80.0</td>
</tr>
</tbody>
</table>
CHAPTER 3: Growth Changes in the Lower Anterior Segment

1. Growth and Development Related to Incisor Position and Facial Profile

The lower incisors may be seen in many differing positions at various stages of eruption, and incisor position and facial contour alter with age, and differ between the sexes. During growth and maturation the dental arches undergo dimensional changes. A background knowledge of all of these factors is essential for the complete orthodontic assessment of the dental arches.

Baum (1961) found that the facial profile of an eleven to fourteen year old adolescent was more convex than that of an adult, with the incisors being relatively less upright, and the denture more protrusive. He found that females were generally more mature in characteristics, and concluded therefore that the eleven to fourteen-year-old girl has less growth potential than the same aged boy.

Similar conclusions have been reached by many other investigators: Baird (reported by Baum, 1961) found that girls tended to have less convex faces and more upright incisors; Barnes (see Baum, 1961) agreed with these findings, and added that, with maturation, the skeletal patterns of both male and female faces change in positional relationship, with the mandible becoming increasingly more protrusive, and the profile less convex; Björk also reached similar conclusions in an earlier study in 1947.
Brodie (1953) and Davis (see Baum, 1961) agreed that the later stages of growth are accompanied by a continuation of forward and downward movement of the anterior nasal spine and of pogonion. The growth of the supporting bone of the dental arch is relatively slower, which results in a decreasing prominence of the denture, with the incisal edge and labial surface of the lower central incisors becoming more retrusive in relation to the chin point. Downs (1956) found that vertical growth is greater in the area of the ramus than in the facial profile, and with growth the mandibular plane angle decreases from $28^\circ$ to $22^\circ$. The mandible moves forward at a greater rate than the maxilla, decreasing facial convexity. Meinhold, Schultz, and Seal (as reported by Baum, 1961); and Lande (1952) agreed with these findings.

Subtelny (1957) demonstrated the more rapid maturation of girls than boys by comparing their relative degrees of prognathism in childhood and when adult. He found that by the age of seven to eight years, girls showed three quarters or more of the amount of prognathism than they would as adults, while boys of the same age showed only one half.

Baum (1961) hypothesised that, following orthodontic treatment on a child, a progressive change in location of the denture in relation to the rest of the face can be expected, similar to that experienced in an untreated patient, as the child matures. Baum's investigations substantiated his hypothesis. He therefore suggests that the operator should consider the age and sex of his patient in determining the position of the denture, especially the incisors, in relation
to profile. For example, the ideal occlusion in a thirteen-
year-old boy should be planned with the expectation that in
succeeding years the growth changes will carry the rest of the
facial structures forward relative to the denture (see Fig. 3).
A girl, however, of similar age, would be relatively more mature,
and growth changes in the jaws would be to a lesser degree.
Baum concludes that the denture of an immature patient must be
placed in an "immature" position, i.e. more protrusive than in
a mature patient, to allow for retrusive changes in the denture
as the patient matures. Particular attention should be given
to the inter-incisal angle, this being more protrusive in the
young patient, and more upright in the mature patient. Baum
also suggests that the rates of maturity of the different sexes
should be taken into account, with guidelines to maturity
being statural growth, sexual development, skeletal maturation
(such as degree of ossification of the carpal bones), and
general overall impression,(incorporating height, weight, build
and emotional maturity for the age).
Baum suggests that a similar tracing for a girl would show smaller changes.

Measuring from the central incisor plane, with growth the distance to the tip of the nose has increased by 4mm, the distance to the bony chin has decreased by 3mm, and the relationship to the soft-tissue chinpoint has changed from -1 to +2mm. From this Baum suggests that the denture for a 13-year-old boy should be planned with the expectation that developmental growth changes will carry the facial structures forward relative to the denture.
The greatest rate of change in the dimensions and relative position of the jaws occurs during the pubertal growth spurt which, as reported by Bond (1972), occurs between the ages of 11 and 13½ years in girls, and 13 and 15½ years in boys. Bond adds that during these periods orthodontic corrections, especially Class I and deep bites, may be accomplished more readily. Bayley (see Baum, 1961) found that at the age of 15.2 years boys have achieved 96.59% of their mature height, while girls have achieved the same degree by the age of 13.2 years. Bambha (1961) found that, particularly in males, a small amount of facial growth may occur after skeletal maturation.

One of the more popular ways of assessing skeletal maturity is by examination of the degree of ossification shown on hand and wrist radiographs, as described by Greulich and Pyle (1959). More recently, however, Bowden (1976) noted that ossification sequences and maturational phenomena within the hand-wrist area show polymorphism and sexual dimorphism, which limit the effectiveness of hand-wrist radiographs as a predictor of adolescent stages. When a series of radiographs are taken such that the development in more digits is observed, Bowden suggests that the reliability of prediction of adolescent stages is increased. Smith (1980) concurs that sexual dimorphism occurs to such an extent that "although hand-wrist radiographs may provide some information of value to the orthodontist with male patients, the radiographic exposure is not justified for most females".
2. Positional and Dimensional Changes of the Dental Arches and Mandibular Incisors during Growth and Maturation

Thurow (1970, p.194) describes growth in the anterior region of the jaws resulting in a reduction of space for the teeth. The molar region grows by distal extension, and the posterior extensions at the condyle and tuberosity thrust the alveolar process forward as they grow vertically, associated with increases in facial height. The result is a distal migration of the dentition and apparent growth of the chin, as illustrated in Fig. 4. Thurow suggests that the distal migration of the dentition also accounts for crowding of the lower anterior teeth, and impaction of third molars.
FIG. 4: THE USUAL DIRECTIONS OF GROWTH IN THE RAMUS AND INCISOR REGIONS, AS DESCRIBED BY THUROW (1970 p.194), AND GRABER (1972 p.70)
Moore (1959) and Lombardi (1972) suggest that differential facial growth sites influence lower anterior crowding: if the mandibular condylar growth continues after maxillary tuberosity growth has ceased, the mandibular arch will be carried forward relative to the maxillary arch, and the lower incisors will be restrained by the upper anteriors, thereby cramping the lower incisors and creating overlapping and crowding.

Moyers (1973, p.227) describes the eruption pattern for lower anteriors, during which minor crowding of the lower permanent incisors may occur, and be considered a part of the normal eruption sequence. Moyers suggests that the loss of the deciduous molars creates a total leeway space of 4.32mm in the mandible, (2.16mm per side), which may permit mandibular anterior alignment, while leaving sufficient space for premolar eruption, but leaving nothing for natural adjustment of molar occlusion.

Sanin and Savara (1972) studied the development of an "excellent occlusion", and observed that at the age of seven years, irregularities such as deviation of the mid-line by 1.2mm and an end-to-end molar relationship may occur. They describe these as "common developmental irregularities", which may self-correct with maturation. They found that, with growth and development of the permanent dentition, the overall changes in overjet were too small to be of any clinical significance, but there was an average increase in overbite of 1.9mm from early mixed dentition to completion of the permanent dentition, and a decrease of 0.5mm from the age of twelve years
to twenty years. Ricketts (1969) described the features of normal occlusion as including a 2mm vertical overlap of anterior teeth, with lower anteriors having a labial inclination. Sanin and Savara (1972) found that, in their "excellent occlusion", the axial inclination of the mandibular central incisor to the mandibular plane changed from 78.5° at five years of age, to 101° at the age of 14 years, the greatest rate of change (19°) occurring between the ages of six to nine years. A more typical value for the angulation of the mandibular central incisor to the mandibular plane has been described by Tweed (1962) who, after many years of research, suggests that this angle (the IMPA angle) is typically 87° in mature patients with good occlusion, but may range from 76° to 99°. Edwards (1968) found that a typical Australian (Sydney) sample had a mean IMPA value of 93.92°, with a range between 72° and 107°. These values are consistent with Henry's findings (1963) that the Australian patient sample had a more forward, divergent face than other groups studied overseas. When compared with cephalometric findings of other investigators, including Steiner, Björk, Riedel and Downs, the Australian sample had SNA and ANB angles which were 1.6° and 0.5° respectively higher than the other groups. SNA was typically 83.6°, SNB was 80.5°, and ANB was 3.1°. (See Chapter 5: The Applications of Cephalometric Analysis, for further explanation of cephalometric reference angles).

The results of Henry and Edwards indicate that race should be considered when orthodontically manipulating teeth into "ideal" positions. The Australian population norm may have a more divergent anterior profile, displaying relatively
greater incision proclination.

The dental arches also undergo horizontal dimensional changes during growth. Moorrees (1959), Barrow and White (1952), Sillman (1964), DeKock (1972) and Moyers et al. (1976) found that a moderate increase in width of the dental arches can be expected, particularly in the anterior regions, until the permanent canines erupt. After this time arch width usually decreases in both the anterior and posterior regions. (See Chapter 4, Fig. 5: Mandibular Canine Arch Width Variations with Age).

Moyers (1973, p.204) notes that normal growth and development results in a radical shortening of the mandibular arch perimeter in the transition from the deciduous to permanent dentition, of about 5mm, due to the late mesial shift of the first permanent molars, the mesial drifting tendency of teeth, slight amounts of interproximal wear, and the lingual positioning of incisors due to differential mandibulo-maxillary growth.

While bone growth and remodelling influence the positions of the teeth, soft tissue forces also exert a significant influence on the teeth, both collectively and individually, and Wylie (1956) suggests that the muscle forces are a major factor influencing lower incisor position. More recently, Thurow (1970, p.147), Graber (1972, p.142) and Barrett and Hanson (1978, p.86), stress the importance of the musculature surrounding the dental arches, suggestive of a dentition trapped within a muscle force system. Fisher (1957,
p.54), Rogers (1950) and Brodie (1953), also supported this theory. Brash, McKeag and Scott (1956) noted asymmetries of the dental arches in cases with muscular dystrophy and facial paralysis, which supported the "muscle influence" theories, and Kydd (1957) performed experiments which demonstrated that the forces of the lips or the tongue, if unopposed, were capable of moving teeth. Barrett and Hanson (1978, p.89) note that in cases of glossectomy collapse of the dental arch ensues.

Barrett and Hanson (p.87) describe the forces acting on the teeth as being primarily those of occlusion and tooth eruption, postural pressure of the facial network, and tongue pressures. They describe the forces of occlusion as being strong but intermittent, balanced by the relatively light, constant eruptive forces.

Tooth position in the horizontal plane is a balance primarily of soft-tissue buccal and lingual muscle forces. Thurow (1970, p.146-154) summarizes the resultant force vectors as being:

i) buccal and labial soft tissue vectors, including the tongue, and the lower lip when tucked under the upper incisors.

ii) lingual vectors: derived from the buccinator, and lips (in normal occlusion).

iii) mesial and distal vectors: muscular forces, via lingual vectors on the anterior teeth, may direct a distal
vector onto posterior teeth. In the tuberosity region, where the buccinator muscle wraps around the distal portion of the molars, a mesial vector may be created.

iv) apical vectors: these may include the cheek, lips or tongue if interposed between the teeth.

v) occlusal vectors: the tongue may produce an uneven effect on the occlusion by resting on some teeth and not others, and may be responsible for an open or closed bite.

Brader (1972) investigated the pressure profile encompassing the dental arch, and concluded that the forces involved are bisymmetrically equivalent. The vestibular forces of the cheek and lip tissues resting against the teeth are inherent in the elastic tension of the circumoral tissue envelope. Barrett and Hanson (1978, p.88-89) describe this force, often referred to as the "buccinator mechanism", as consisting of a continuous band of muscle fibres encircling the dental arches and being anchored at the base of the occiput (on the atlas). Muscles contributing to the "buccinator mechanism" include the orbicularis oris, buccinator and superior constrictor muscles.

Brader (1972) found that the internal forces (from the tongue) are uniformly greater in size than the buccal and labial forces, and diminish progressively distal to the mid-sagittal line both buccally and lingually. Barrett and Hanson (1978, p.87) describe the buccal and labial forces as being relatively light but constant, while the tongue exerts an intermittent,
strong pressure. They suggest that in normal function the
tongue pressures are primarily braced against the palate, with
any residual pressure being absorbed in the horizontal plane
by the teeth in occlusion.

Arch form is primarily under the influence of the
muscles. Barrett and Hanson (1978, p.87) suggest that the
shape of the initial arch is determined by the basal bone, but
as the teeth erupt into the oral environment, muscular forces
supercede the diminishing influence of the basal bone in the
development and maintenance of the individual arch form.
Lavelle, Shellis and Poole (1977, p.112) describe the erupting
tooth as entering a "force field" consisting of the tongue and
the muscles of the elastic envelope of the cheek. They conclude
that "observed dental location along the arch curve may be
considered to reflect the counterbalance between energy con-
ditions of the environmental tissues".

It is generally agreed, therefore, that muscles exert
a strong influence in tooth position and arch form, and the
possible effect of musculature, and other external forces
introduced into the oral environment, (such as finger sucking),
should be considered when contemplating orthodontic corrections,
particularly in the anterior region, where any undesirable
force influence, from either external or internal sources, is
often reflected in the position and alignment of the mandibular
and maxillary incisors.
SECTION B

THE ASSESSMENT AND ANALYSIS OF THE MANDIBULAR DENTAL ARCH
CHAPTER 4: The Assessment of Arch Form, Arch Width and Arch Length

1. The Arch Form and Arch Width

Arch form must be examined in order to establish the dentofacial relationships, and the skeletal support for the dentition. Hawley (1905) and Pont, (see Stifter, 1958) devised formulae of arch form, but Thurow (1970, p.161) suggests that their use may be misleading when applied to malocclusions, as such formulae are derived from ideal occlusions, and that serious malocclusions often have disproportionate dentofacial relationships. Thurow elaborates on this, stating that it is not unusual for patients with malocclusions to require variations in arch form which differ markedly from the average "ideal" arch form, in order to accommodate the teeth in areas that provide adequate support and functional balance. He further suggests that arch form and tooth size are independent variables.

Howes (1947) was one of the early investigators to consider skeletal support of the dentition in a critical evaluation of arch form, by the use of dental casts sectioned in the area of the apical base, where, he postulated, bone shows little or no response to tooth movement. Thurow suggests that the best guide to arch form is the patient himself, as this reflects the factors which created the arch form, and gives an idea of the foundational form of the dentition.

Expansion of the mandibular anterior arch is very hazardous, according to Thurow (1970, p.164) due to the
limitations of the labial alveolar bone, plus labial muscle pressure. He suggests that labial tooth movement to accommodate lower anteriors should be avoided if mandibular anterior arch expansion is an inevitable consequence. Moyers et al. (1976) found that arch width in the lower anterior segment undergoes an increase with growth and incisor eruption until about the age of nine years, following which there is a gradual decrease and levelling off of the mandibular arch width dimension over the adolescent years. Sillman (1964) observed the same effect, although in his sample he found that the increase in arch width ceased around twelve years of age. Moyers (1973, p.196) related some of the anterior arch expansion to the distal shunting of the deciduous canines on the eruption of the permanent incisors.

Therefore, from the age of about nine years onwards, there will be no natural expansion of the lower anterior arch width, and no growth compensation may be anticipated to relieve cases of lower incisor crowding.

The Moyers et al. (1976) results are illustrated in Figure 5.

Sillman (1964) took the measurement of canine width as being the dimension between the most distal edge of the opposite canines in the same arch. He suggests that the typical mandibular canine width in the mature patient is 29 to 30mm in males, and 28 to 29mm in females, and that a patient may be considered mature, with respect to increase in the mandibular canine width, from the age of twelve years onward.
FIG. 5: MANDIBULAR CANINE ARCH WIDTH VARIATIONS WITH AGE (as described by Moyers et al., 1976)

Measuring the distance between the mandibular canines at the centroids:

- ○ Male
- + Female

![Graph showing mandibular canine arch width variations with age](image)

- 28
- 27
- 26
- 25
- 24
- 23
- 22
- 21
- 20
- 19

Mandibular Canine Arch Width (mm)

![Age (years) axis](image)
2. The Arch Length Deficiency Estimation

The successful clinical management of arch-length deficiency problems in the mixed dentition depends on an accurate estimate of the crown widths of unerupted secondary teeth, especially mandibular canines and premolars, and an assessment of the dimensions of the erupted secondary teeth, typically the mandibular incisors. Many methods have been devised to obtain this information, relying on measurement of erupted secondary teeth, and radiographic measurements of unerupted teeth. Sanin, Savara, Clarkson and Thomas (1970), found that there was no correlation between the size of the deciduous teeth, and their succeeding permanent teeth. That is, a patient with smaller than average deciduous molars will not necessarily have smaller than average succeeding premolars. Therefore, the size of the deciduous teeth is an unreliable guide as to the size of the permanent successors, and techniques employed to estimate arch length deficiency should relate only to measurements of the permanent teeth.

(a) Analysis by Direct Tooth Measurements

Ballard and Wylie (1947) attempted to correlate the sum of the mesiodistal widths of the four mandibular incisors with that of the mandibular canine and premolars. They found that a moderately positive relationship existed. Moyers (1973, p.375) more recently has published prediction tables based on a similar correlation, between the sum of the widths of the mandibular incisors and the combined widths of the mandibular canine and premolars, and has proposed a Mixed
Dentition Analysis to evaluate the amount of space available in the arch for succeeding permanent teeth. Hixon and Oldfather (1958), also indicated that measurements of the lower incisors may provide much information about the arch lengths, and sizes of the unerupted canines and premolars. By performing a Mixed Dentition Analysis, utilizing Moyers' probability tables, it is possible, by measuring the widths of the lower incisors, to predict the probability of the canines and premolars (for both arches) fitting into the available space, and to estimate the space shortage, where one exists. From this it is possible to consider the effect of gaining space in the arch by the extraction of premolars or an anterior tooth, (or a combination of teeth), or by reduction of tooth size by interproximal stripping. Space may be gained by interproximal stripping alone, or stripping may be carried out in addition to the extractions.

Moyers' technique relies entirely on the accurate measurement of the four mandibular incisors, which is usually carried out on study casts. A reproducible, standardized measuring technique, on good quality, accurate study casts, is required. Moyers suggests the use of a Boley gauge, but this typically requires careful modification to narrow the beaks of the caliper, as described by Bau (1973). Bau also recommends the use of modified dial calipers to achieve accurate measurements. A standardized technique of measurement has been described by Sandilands (1965), Watson (1971) and Bau (1973), where the caliper beaks are placed parallel to the long axis of the crown and perpendicular to the mesiodistal plane. Bau
concluded that, with accurate instrumentation, the differences in measurements taken in the mouth and on study casts were statistically insignificant. For ease of manipulation of instruments, measurements are more readily made on study casts when performing a Mixed Dentition Analysis.

Of significance in Bau's findings was that the mean mesiodistal crown dimension, for both the mandibular central and lateral incisors in good occlusions, was found to be smaller than in the crowded incisor sample, as would be expected if theories on the evolution of the dentition and the compromise of "ideal" occlusion are to be believed.

Ballard and Wylie (1947) showed an average error in prediction of the mesiodistal widths of canines and premolars of 0.6mm per side, while Tanaka and Johnston (1974) showed an error of 0.85mm per side, when testing the method developed by Ballard and Wylie, and Moyers. This error could be clinically significant if it occurred as a space deficiency on both sides, in the final stages of orthodontic treatment.

Moyers (1973, p.369) also notes that the complete Mixed Dentition Analysis should take into account the expected radical shortening of about 5mm in the mandibular arch perimeter due to growth and development during the transition from the deciduous to permanent dentition, unless such shortening is stopped by orthodontic treatment, (see Fig. 6: Mandibular Arch Perimeter Length Variations with Age).
Moyers suggests that his analysis provides a method of predicting whether or not a space problem exists, and where one does exist, the degree of severity, taking into account growth changes which may determine the treatment plan.

While Moyers' analysis for the mixed dentition provides information about the probability of the canines and premolars being accommodated within a given arch, the analysis does not provide any information, other than the mesiodistal widths, about the morphology and desirability or otherwise in shape of the mandibular incisors.
FIG. 6: MANDIBULAR ARCH PERIMETER LENGTH VARIATIONS WITH AGE (as described by Moyers et al., 1976)

Measuring from the mesial midpoint of the mandibular first molars, or, in their absence, the distal midpoint of the mandibular deciduous second molars:

- Male
- Female

Mandibular Arch Perimeter Length (mm)

Age (years)
The concept that the mandibular incisors, themselves, may have "desirable" and "undesirable" morphology which may in turn predispose to instability of the arch form, was investigated by Peck and Peck (1972), who found that naturally, well-aligned mandibular incisors possess distinctive dimensional characteristics, these being relatively smaller mesiodistal widths and larger facio-lingual dimensions. Peck and Peck (1972) postulated that aberrations in anterior tooth morphology are critical to the aetiology of lower anterior crowding, and formulated a morphological index of lower incisor size and shape, this being: \[ \text{mesiodistal width} \div \text{faciolingual width} \times 100. \]

Peck and Peck also found that cases which displayed lower anterior crowding, (or cases which relapsed after orthodontic treatment), typically possessed larger indices than in uncrowded patients. The mandibular central incisors of a group with perfect alignment displayed a mean index of 88.4, with a standard deviation of 4.3. The mandibular lateral incisors in the same patient group had a mean index of 90.4, with a standard deviation of 4.8. Peck and Peck therefore proposed that they would expect any lower arch possessing central incisors with an index of 88.4 or less, and lateral incisors with an index of 90.4 or less, to have excellent incisor alignment. (They note that tooth shape alone is not the only factor determining tooth alignment, however). Also, teeth possessing higher indices than the ideal, have a greater chance of being crowded. Peck and Peck tested differences in lower incisor shape between males and females, and concluded that the slight difference, (approximately 2% of the incisor
index value), is clinically insignificant. They suggest, therefore, that their incisor index of \( \frac{\text{mesiodistal width}}{\text{faciolingual width}} \times 100 \) provides an "effective clinical method for diagnosing tooth shape deviations which influence and contribute to mandibular incisor crowding". Their clinical guidelines for the maximum limit of desirable index values are:

- Mandibular central incisor 88 to 92
- Mandibular lateral incisor 90 to 95

Mandibular incisors whose indices lie within or below these values are considered favourably shaped. If the incisor indices are above these maximum limits of desirability, then the incisors may be determined to have an unfavourable morphology with regard to a predisposition towards lower incisor crowding. However, a combination of favourable and unfavourable values for central and lateral incisors may still result in favourable alignment. They suggest that an index in excess of 100 represents a severe shape deviation, which represents 15 percent of the population with regard to lower central incisors, and 25 percent with regard to lower lateral incisors.

Peck and Peck use the basis of this study for their theories on interproximal stripping and prediction and prevention of lower anterior relapse. (See Chapter 9: The Interproximal Reduction of Enamel).

Moyers et al. (1976) compiled results of a study where the mesiodistal and faciolingual dimensions of the teeth were compared. Their findings are shown in Table 3.
In Moyers' et al.'s results the mesiodistal and faciolingual ratios are higher than the ideal ratios suggested by Peck and Peck. This may be due to sample size, race, age, or measuring techniques (in the mouth vs. study casts). Nevertheless, Moyers' et al.'s results confirm that the lower incisor dimensions are, by Peck and Peck's standards, tending towards having an unfavourable morphology with regard to lower anterior crowding.

**TABLE 3 : MANDIBULAR INCISOR TOOTH DIMENSIONS AND MESIODISTAL/FACIO-LINGUAL RATIOS (according to Moyers et al., 1976)**

<table>
<thead>
<tr>
<th>Tooth</th>
<th>M-D (mm)</th>
<th>S.D.</th>
<th>F-L (mm)</th>
<th>S.D.</th>
<th>Ratio</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central incisor - male</td>
<td>5.54</td>
<td>.32</td>
<td>5.84</td>
<td>.59</td>
<td>1.05</td>
<td>.12</td>
</tr>
<tr>
<td>Lateral incisor - male</td>
<td>6.04</td>
<td>.37</td>
<td>5.97</td>
<td>.62</td>
<td>1.07</td>
<td>.12</td>
</tr>
<tr>
<td>Central incisor - female</td>
<td>5.46</td>
<td>.34</td>
<td>5.42</td>
<td>.57</td>
<td>1.07</td>
<td>.10</td>
</tr>
<tr>
<td>Lateral incisor - female</td>
<td>5.92</td>
<td>.34</td>
<td>5.73</td>
<td>.62</td>
<td>1.07</td>
<td>.09</td>
</tr>
</tbody>
</table>

S.D. = Standard Deviation

Therefore, the analysis of the lower arch by direct measurement techniques may give information concerning the relative size of the incisors, canines and premolars, the probability of the canines and premolars fitting into a given arch, the space shortage in the arch where one exists, and the morphological desirability in shape of the mandibular incisors.
This information may be an invaluable aid in determining the treatment plan and prognosis: the results of analysis by direct measurement may indicate that space shortage in the lower arch is so great that extractions may be required; or that the space shortage is only minimal and space regaining procedures, or tooth reduction by interproximal stripping, may be sufficient to create a favourable tooth size - arch length relationship. The amount of space shortage may also aid in determining the choice of tooth extraction, whether it be one anterior tooth, or two posterior teeth, or a combination of teeth. Where extractions are deemed desirable, the space surplus or shortage following the extraction may be calculated. In some cases it may be established that both interproximal stripping of the lower anteriors, and extraction of teeth, are required. This situation would arise especially when Peck and Peck's index of incisor dimensions is determined to be excessive and undesirable, and a large lower arch space shortage exists. Interproximal stripping plus extractions may also be used where extractions alone do not quite supply sufficient space for tooth alignment, and stripping may supply an additional amount of available space.

In cases where Peck and Peck's index is excessive, but teeth may be aligned without the need for additional space created by interproximal stripping, flattening of the interproximal surfaces of the teeth and creating a more favourable tooth size index may still be desirable to create long-term stability.
(b) **Analysis by Periapical Radiographic Measurements**

The size of the unerupted canines and premolars may also be predicted from radiographs. To aid accuracy, a standardized technique, such as the long-cone technique, as described by Ennis, Berry and Phillips (1967, p.110) will minimize distortion.

In 1947 Nance suggested the use of periapical radiographic measurements to predict the widths of unerupted teeth. Later, Cohen (1954) recognised that radiographic measurements consistently tended to enlarge the teeth, so that tooth size was overpredicted. He suggested that this error may be allowed for if the enlargement factor was calculated by measuring the radiographic width and the actual width of an erupted tooth. The enlargement factor was thus equal to the radiographic measurement divided by the real measurement.

Huckaba (1964) used similar reasoning when he advocated that the mathematical equation $X : X' = Y : Y'$, or, $X = \frac{X_Y}{Y'}$, be used to calculate the radiographic error. In this equation $X$ equals the true size of the unerupted tooth, $X_Y$ equals the radiographic measurement of the unerupted tooth, and $Y$ and $Y'$ equal the real and radiographic sizes respectively of the unerupted tooth.

Foster and Wylie (1958) compared the radiographic estimation technique with the mathematical regression equation methods as proposed by Ballard and Wylie (1947) (and similar
to Moyers'), and found that the radiographic method more accurately predicted the widths of the unerupted teeth.

When the sizes of the unerupted canines and premolars are determined radiographically, the sum of these measurements may be compared with the total available space measured in the mouth or on study casts, and the space shortage, if any, determined. This result may then be used to assist in determining the desirability of posterior or anterior extractions, or anterior interproximal tooth reduction, or a combination of these, to gain the required space for tooth alignment.

(c) Analysis Combining Periapical Radiographic and Direct Tooth Measurements

Staley, Shelly and Martin (1979) devised a multiple regression analysis to determine the best combination of measurements from dental study casts and radiographs for predicting the mesiodistal widths of the mandibular canines and premolars.

They found that the radiographic width of the mandibular second premolar was the best single predictor of the sum of the widths of the canine and premolars in males, while in females the radiographic width of the mandibular first premolar was the most accurate predictor. Predictions were also generally more reliable in males than in females, and were more accurate when taken from the left side of the arch than the right. Combinations of three predictor variables, such as three
radiographic measurements, or two radiographic and one study cast measurement, produced very high correlation coefficients, and were therefore used in the development of the multiple regression equations. Due to the significantly larger mandibular canine widths in males than in females, Staley, Shelly and Martin developed separate prediction equations for each sex. Their equations are listed in Table 4.
### Table 4: List of Multiple Regression Equations for the Prediction of Mandibular Canine and Premolar Widths (as supplied by Staley et al., 1979)

<table>
<thead>
<tr>
<th>Prediction Equation</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Males</strong></td>
<td></td>
</tr>
<tr>
<td>Prediction of right canine and premolar widths (mm.):</td>
<td></td>
</tr>
</tbody>
</table>
| \[
\frac{x(0.827)}{27x} + \frac{(0.614)}{28x} + \frac{(1.073)}{29x} + 2.280 = \] |          |
| \[
\frac{y(0.954)}{27x} + \frac{(1.263)}{29x} + \frac{(0.494)}{25} + 1.801 = \] |          |
| \[
\frac{z(0.697)}{28x} + \frac{(1.041)}{29x} + \frac{(0.905)}{26} + 2.625 = \] |          |
| Prediction of left canine and premolar widths (mm.): |          |
| \[
\frac{x(0.965)}{20x} + \frac{(0.797)}{21x} + \frac{(0.504)}{22x} + 4.080 = \] |          |
| \[
\frac{y(0.762)}{20x} + \frac{(0.988)}{21x} + \frac{(0.855)}{23} + 2.870 = \] |          |
| \[
\frac{z(1.232)}{20x} + \frac{(0.699)}{22x} + \frac{(0.471)}{24} + 3.864 = \] |          |
| **Females**         |          |
| Prediction of right canine and premolar widths (mm.): |          |
| \[
\frac{x(1.049)}{28x} + \frac{(0.764)}{29x} + \frac{(0.788)}{26} + 2.629 = \] |          |
| \[
\frac{y(1.110)}{28x} + \frac{(0.758)}{29x} + \frac{(0.719)}{25} + 3.002 = \] |          |
| \[
\frac{z(0.978)}{27x} + \frac{(0.759)}{28x} + \frac{(0.792)}{29x} + 2.401 = \] |          |
| Prediction of left canine and premolar widths (mm.): |          |
| \[
\frac{x(0.597)}{20x} + \frac{(1.050)}{21x} + \frac{(0.455)}{22x} + 5.247 = \] |          |
| \[
\frac{y(0.638)}{20x} + \frac{(1.063)}{21x} + \frac{(0.559)}{24} + 5.010 = \] |          |
| \[
\frac{z(0.727)}{20x} + \frac{(1.012)}{21x} + \frac{(0.429)}{23} + 5.162 = \] |          |

Numbers under the lines indicate teeth to be measured; Number alone = plaster cast mesiodistal width; Number followed by an X = radiographic mesiodistal width. Tooth notation: 1 to 32
To accurately use this technique, measurements of teeth to 0.05mm are required, which requires the use of accurate dial calipers, or less accurately, a Boley gauge. Staley, Shelly and Martin (1979) suggest that the calculations for the multiple regression equations may be readily performed on modern electronic pocket calculators.

They propose that this technique is more accurate and desirable than previous techniques as it permits a choice in the selection of the predictor variables. The operator may use radiographic measurements obtained from three teeth (the mandibular canine and first and second premolars), or alternatively, a combination of two radiographic measurements (the first and second mandibular premolars or one premolar and canine) and the direct measurement of one erupted tooth (either central or lateral incisor).

Staley, Shelly and Martin give an example of their technique using multiple regression equations for a boy aged eight years, eight months. According to Nolla (1960), the formation of the crowns of the mandibular premolars is completed by about the age of seven and a half years, so this would therefore be the earliest age at which the multiple regression equations may be calculated. By using measurements of unerupted canines and premolars on radiographs, Staley, Shelly and Martin suggest that a prediction could be accomplished either before the permanent incisors had erupted, or as they were erupting. They note that all other accurate techniques require measurements
of erupted incisors.

Staley, Shelly and Martin's multiple regression analysis provides another formula for establishing tooth size in the mandibular canine and premolar areas. Having estimated the tooth sizes for the canines and premolars, the total mesiodistal widths may be compared with the available space, and as in the previously described techniques of direct or radiographic analyses, the space shortage, if any, may be estimated, and the most desirable treatment determined.

The multiple regression analysis is not an additional aid, but rather an alternative method in determining tooth size, as it does not take into account the incisor morphology (as does Peck and Peck's index) or supply any additional information other than tooth size of the mandibular canines and premolars.

The main advantage of the multiple regression analysis is that it may be carried out slightly earlier than other techniques, as it requires only partial eruption of one lower incisor. It is doubtful whether this is clinically an advantage, however, as the ultimate treatment plan relies upon the complete eruption of the four mandibular incisors to determine their morphology and note any developmental lesions which may determine choice of tooth for extraction at a later date.

Bearing in mind that dimensional changes in the mandibular arch perimeter length will occur with growth and the transition from the mixed to the permanent dentition, it
may be questionable whether the degree of mathematical computation required for the multiple regression analysis proposed by Staley et al. is clinically worthwhile, or the results obtained using this technique be of any greater clinical value than previously described techniques.
CHAPTER 5: The Applications of Cephalometric Analysis

Moyers (1973, p.406) suggests that the clinical applications of cephalometric analysis are used to firstly determine the nature, extent and location of the abnormality and then to depict the specified treatment goal and assist the derivation of a plan of treatment.

Metzdorf (1977) proposed that the angulation and positioning of the mandibular incisor may determine the course and type of treatment which patients receive.

The cephalometric points, angles and planes of reference which have been defined or adopted by Downs (1948, 1952), Graber (1958), and Tweed (1946, 1954, 1962) and are generally accepted and used by clinicians, and are referred to in the following analyses, are illustrated in Figs. 7, 8 and 9.
FIG. 7: CEPHALOMETRIC REFERENCE POINTS

S : Sella turcica
N : Nasion
O : Orbitale
A : Subspinale
B : Supragnathale
Go : Gonion
Pog : Pogonion
Ba : Basion

ANS : Anterior Nasal Spine
PNS : Posterior Nasal Spine
Gn : Gnathion
Me : Menton
Po : Porion (derived landmark, from the top of the ear rod's shadow, external auditory meatus)
FIG. 8: CEPHALOMETRIC REFERENCE ANGLES

SNA Angle
SNB Angle
ANB Angle
Inter-incisal Angle (shadowed)

(Several other angles have been described by various investigators. These will be discussed in the relevant sections).
FIG. 9: CEPHALOMETRIC REFERENCE PLANES AND AXES
Many cephalometric norms have been developed and used in an attempt to evaluate the ideal position of the lower incisor. One of the first to determine these was Downs (1948), who found that the angle between the upper and lower incisors averaged 135.4°, (the inter-incisal angle), the mandibular incisor to the occlusal plane angle averaged 75.5°, and the mandibular incisor to the mandibular plane angle averaged 91.4° (see Fig. 10).

Downs (1956), along with Holdaway (1956) and Ricketts, (1957) later recognised the significance of the mandibular incisor in relation to the facial profile, and Downs suggested relating the lower incisor to the APo line.

Many other operators, including Linder-Aronson (1976), Schudy (1963), Williams (1969), and Schulhoff (1977), have also emphasised the importance of the APo line as a diagnostic landmark in locating the final position of the mandibular incisor in treatment, and in relating the maxillary position to the lower incisor.

Tweed (1946, 1954) related the mandibular incisor axis to the mandibular and Frankfort planes, while Steiner (1953) related the mandibular incisor to the NB plane.
Thus the main planes of reference have, until very recently, been the mandibular plane, the A-Pogonion plane, and the Frankfort (horizontal) plane and the incisor axes. Recently Keene and Engel (1979) have introduced a further relationship of lower anterior stability which includes the corpus length.

Graber (1958, 1961), in a review of the mandibular plane, found that the slight variations between the GoGn GoMe or GoPog mandibular planes were clinically and diagnostic-ally insignificant in terms of angular relationships to other cephalometric planes and measurements, providing that consistency is used in any cephalometric construction for the same patient, or when comparing patients.

Tweed (1946, 1954) developed a diagnostic triangle which related mandibular incisor inclination to the mandibular plane and the Frankfort plane, and devised "ideal" angles for the intersections of these reference planes.

Following many years of investigation of the Frankfort-Mandibular Plane Angle (the FMPA or FMA), the Incisor-Mandibular Plane Angle (IMPA), and the Frankfort-Mandibular Incisor Angle (FMIA), in 1966 Tweed produced figures for these angles which he described as being "uncannily accurate". These are depicted in Table 5.

Tweed advocates the use of his diagnostic facial triangle (illustrated in Fig. 11) in the analysis and treatment
of orthodontic patients, believing that the lower incisors are the key to treatment planning in that if they are firstly located in a "desirable" position, then the remaining denture should relate to them.

**TABLE 5: TWEED'S FMA, FMIA, AND IMPA VALUES (1966)**

<table>
<thead>
<tr>
<th>FMA (degrees)</th>
<th>FMIA (degrees)</th>
<th>IMPA (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 and upwards</td>
<td>65</td>
<td>85</td>
</tr>
<tr>
<td>29 mean 25</td>
<td>65 mean 68</td>
<td>85 mean 87</td>
</tr>
<tr>
<td>21</td>
<td>73</td>
<td>86</td>
</tr>
<tr>
<td>20 and less</td>
<td>66 approx.</td>
<td>Do not exceed 94</td>
</tr>
<tr>
<td></td>
<td>Range 66 - 68</td>
<td></td>
</tr>
</tbody>
</table>
FIG. 11: TWEED'S DIAGNOSTIC TRIANGLE (1946)
Ricketts (1957, 1964) adopted similar beliefs to Tweed regarding the position of the lower incisor, but related the incisor to the A-Pogonion plane, both in incisal tip distance to the plane and the incisal long axis angulation with the APo plane. Ricketts believed that the lower incisor was more adequately defined by the anteroposterior measurement of its incisal tip to the APo plane, than by its axial inclination. That is, the "ideal" position was between -2mm (lingual to) and +3mm (labial to) the APo plane. This is illustrated in Fig. 12.
FIG. 12: RICKETTS' INCISOR MEASUREMENTS RELATING TO THE APo PLANE (1957)
In 1960 Ricketts found the following relationships:

Mean distance of incisal edge to APo plane : +0.5mm
  Range : -10mm to +10mm
  Standard Deviation : ± 2.7mm

Mean axial inclination of the lower incisor
to APo plane : 20.5°
  Range : -11° to +33°
  Standard Deviation : ± 6.4°

TABLE 6: RICKETTS' MEASUREMENTS OF THE MEAN DISTANCE OF THE LOWER INCISOR TO THE APo PLANE FOR VARIOUS AGE GROUPS (1960)

<table>
<thead>
<tr>
<th>Age of Patient (years)</th>
<th>Mean Distance of Lower Incisor to A-Pogonion Plane (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 - 6</td>
<td>-0.9</td>
</tr>
<tr>
<td>7 - 10</td>
<td>+0.4</td>
</tr>
<tr>
<td>11 - 14</td>
<td>+0.7</td>
</tr>
<tr>
<td>15 - 18</td>
<td>0</td>
</tr>
</tbody>
</table>
Holdaway (1956) related the long axis of the mandibular incisor to the NB plane, and with the ANB angle. He suggested that treatment should firstly correct apical base relationships (indicated by the ANB angle) and then determine the position of the mandibular incisor.

The distance of the lower incisor to the NB plane, he stated, was ideally +3mm, (anterior to the plane), with an ANB angle of 4° (see Fig. 13). He developed the "Holdaway Ratio", which expressed the relationship of the mandibular incisor distance from the NB plane, to the Pogonion distance from the NB plane, and considered that the most stable position of the mandibular incisor occurred when this ratio was 1:1. He also suggested that any relationship where the labial surface of the lower incisor was not more than 3mm behind or in front of Pogonion was equally acceptable. Where it was not possible to reduce the distance of the lower incisor to NB plane to 3mm, Holdaway suggested the values depicted in Table 7 be adopted.

Holdaway, therefore, considered both the relationship of the lower incisor to the apical base of the mandible, and to the maxilla, believing this to be equally as important as the occlusal interrelationship of the dental arches.
FIG. 13: HOLDAWAY'S IDEAL VALUES FOR ANGLE ANB AND FOR THE DISTANCE OF THE LOWER INCISOR TO THE NB PLANE (1956)
TABLE 7: HOLDAWAY'S IDEAL VALUES FOR THE DISTANCE OF THE LOWER INCISOR TO THE NB PLANE FOR VARIOUS ANB ANGLES (1956)

<table>
<thead>
<tr>
<th>Angle ANB (degrees)</th>
<th>Distance of Lower Incisor to NB Plane (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 4</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>3.5</td>
</tr>
<tr>
<td>6</td>
<td>4.0</td>
</tr>
<tr>
<td>7</td>
<td>4.5</td>
</tr>
<tr>
<td>8</td>
<td>5.0</td>
</tr>
<tr>
<td>9</td>
<td>5.5</td>
</tr>
<tr>
<td>10</td>
<td>6.0</td>
</tr>
<tr>
<td>11</td>
<td>7.0</td>
</tr>
<tr>
<td>12</td>
<td>8.0</td>
</tr>
</tbody>
</table>
Steiner (1959) added to Holdaway's concept, believing that the mandibular incisor was ideally placed, when it was 4mm anterior to the NB plane, (which is consistent with Holdaway's distance of 3mm with a tolerance of ± 3mm), and the long axis of the mandibular incisor intersected the NB plane at an angle of 25°. He believed that acceptable ranges were: ANB 2-8°, angle of lower incisor to NB: 25-31°, distance of lower incisor to NB, 4-5.5mm, respectively.

Steiner emphasised the variability possible, and that factors such as age, sex, race, growth patterns and growth potential need to be considered as variations within the overall analysis. He developed a diagram of ideal values relating the incisors to the NA and NB planes to assist case analysis. (See Fig. 14).
FIG. 14: STEINER'S IDEAL VALUES RELATING TO THE POSITION
OF THE MANDIBULAR AND MAXILLARY INCISOR AXES (1959)

Linear Measurements (mm)
Edwards (1968) reviewed the cephalometric formulae for positioning the mandibular incisor, as proposed by Holdaway, Ricketts, Steiner and Tweed, and discussed the deficiencies of their analyses. Edwards found that little thought had been given to the soft tissue influences on the teeth, and that the formulae did not define the changes in tooth position during treatment, especially with regard to the position of the mandibular incisor apex. He examined the position of the mandibular incisor apex in relation to its apical base, in a study of young adults with good occlusion, and found that the root apex lies midway anteroposteriorly in the apical base of the mandibular symphysis. Edwards proposed, therefore, that "the vertical and anteroposterior position of the mandibular incisor root apex should be defined by co-ordinates related to axes tangential to the outline of the mandibular symphysis, one axis being the cephalometric mandibular plane, the other a line perpendicular to this plane, tangent to the lingual surface of the symphysis".

This is illustrated in Fig. 15.
**FIG. 15:** EDWARDS' COORDINATE RELATIONSHIPS FOR THE MANDIBULAR INCISOR (1968)

**Diagram:**
- L: Vertical Coordinate
- M: Menton
- X: Horizontal Coordinate
- Y: Vertical Coordinate
- L - M': Line at right angles to the mandibular plane, tangent to the lingual surface.
By comparing the pre-treatment and post-treatment coordinates of X and Y, the change in the position of the apex of the mandibular incisor can be estimated, in order to determine whether or not bodily movement, or apical torquing, of the mandibular incisor has occurred during treatment. The analysis of Holdaway, Ricketts, Steiner and Tweed assume that the position of the incisor apex is relatively constant, and their measurements are based on this assumption. If an analysis, such as proposed by Edwards, indicates that the apex has changed position, then an allowance may need to be made for such changes, when analyses of cephalometric radiographs before, during and after treatment are employed.

Nordeval (1975) demonstrated a strong relationship between lower incisor alignment and craniofacial morphology. He found that crowded cases have a larger ANB angle and a more severe mandibular inclination relative to the maxillary base represented by the ANS-PNS axis. He found that aligned cases demonstrated a larger gonial angle, and suggested that lower incisor dimensions may be well-correlated with skull dimensions.

More recently, Riger (1979) found that a high correlation exists between the upper incisor angulation to the APo line, and the interincisal angle; and between the lower incisor angulation and the interincisal angle. Riger did not find, however, any correlation between the angulation of the upper incisor to the APo line, and the angulation of the lower incisor to the APo line. He suggested, therefore, that the interincisal angle is closely involved with both upper and lower incisor angulations to the APo line, but that the upper
and lower incisor angulations are relatively independent of each other, varying more with interincisal angle value.

Riger proposed that an "incisor diagnostic triangle" template, as formed by the intersection of the incisor planes with the APo skeletal reference line, may be used to predict the success of possible outcome of orthodontic treatment, and in fact if the correction is orthodontically possible. He constructed templates using interincisal angles of $125^\circ$, $130^\circ$, $135^\circ$ and $140^\circ$, and used an idealized linear position of the tip of the lower incisors on the APo line, the upper incisor angulation, and the interincisal angle. Upper incisor angulations to the APo line were $23^\circ$, $27^\circ$ and $31^\circ$. An example of template construction is illustrated in Fig. 16.
FIG. 16: RIGER'S TRIANGLE OF INCISOR ANGULATIONS (1979)

and: A TYPICAL DIAGNOSTIC TEMPLATE
By the use of such a template, Riger demonstrated how on a cephalometric radiograph, the mandibular incisor can be visualised in its new position (i.e. with the incisal tip on the APo line) and the positional movements required for the upper incisor can be seen.

Riger incorporated Madigan's findings, reported in 1977, that for every 1.5mm retraction of the maxillary incisor, there is a 1mm retraction of point A, and that the maximum possible retraction of point A is 3mm. As a change in point A would, in turn, alter the APo line, Riger constructed a grid to indicate angular changes in relation to horizontal changes in point A or point Po. He notes, however, that even with the maximum possible retraction of point A, of 3mm, only small angular changes of the incisors to the APo line occur, which would be clinically insignificant. Very large alterations in point A may occur with facial surgical reconstruction, in which case the relocation of the APo line would need to be taken into consideration.

The incisal templates, therefore, are used as follows:

1. The APo lines on the cephalometric tracing and on the template are made to coincide.

2. Overbite, or openbite, is halved.

3. Due to the fact that orthodontic movements of the lower incisors are far more limited than those of upper incisors, because of bone morphology, a template is selected for
the proposed interincisal angle which will facilitate feasible movements of the lower incisor (such as slight tipping or torquing). Thus, the template chosen should allow the lower incisor of the template and the patient's cephalometric tracing to nearly coincide.

Riger suggests that the templates permit an easy method of viewing proposed incisor changes, by relating them to the APo line, which is more intimately associated with the patient's facial profile than more distant skeletal reference planes such as the SN, Frankfort or mandibular planes. If the required upper incisor retraction is not possible within bony limits, this can also be seen prior to commencement of treatment.

Fig. 17 illustrates the use of a typical diagnostic template, as described by Riger.
i) Severe maxillary overjet which cannot be fully corrected by incisor retraction, as the new position of the maxillary incisor is outside the alveolus (template incisors indicated by solid teeth):

![Diagram of severe maxillary overjet]

ii) Moderate maxillary incisor overjet which may be successfully reduced within bony limits:

![Diagram of moderate maxillary incisor overjet]
Also in 1979, Keene and Engel sought to develop a cephalometric method by which cases which may prove difficult to treat and retain may be identified prior to treatment. They suggested that, ideally, determination of potential crowding should involve the calculation of a patient's optimal incisal size according to his specific skeletal dimensions, the advantage being that skeletal/tooth relationships can be diagnosed early, and corrective steps undertaken during treatment, if necessary.

Keene and Engel's results demonstrated a multiple regression relationship between the mandibular arc, the mandibular plane angle and the corpus length, and the mandibular incisor dimensions, in well-aligned dental arches, (see Fig. 18).
The mandibular arc is formed by the angle between the corpus and the condylar axis.

Xi point has been described by Ricketts (see Schulhoff and Bagha, 1975, and Ricketts, Bench et al., 1980) as being the centre of the ramus, derived from the point of intersection of the corpus and condylar axis, and the occlusal plane.

The corpus length is the distance between the mandibular Xi point and Pogonion.
From their investigations, Keene and Engel conclude that post-treatment stability of the lower incisors is a function of the relationship of the lower incisor size and the size of the face and jaws, and that the general facial pattern is important in the prognosis for the anterior segment. Those cases which can accommodate wider incisors possess greater values for the corpus length and mandibular arc, and mandibular plane angles, thereby demonstrating shorter, wider, brachyfacial characteristics.

They suggest that discrepancies between the teeth, face and jaws, and ultimately the available bone support, can, in many cases, be clinically diagnosed before orthodontic treatment is initiated. Such a diagnosis is necessary if relapse of the anterior segment is to be avoided, regardless of posterior treatment rendered.

Table 8 depicts Keene and Engel's multiple regression relationship formulae for determining the sum of the lower incisor widths, related to the mandibular arc, the corpus length, and the mandibular plane angle, for any given age, male or female.
TABLE 8: KEENE AND ENGEL’S MULTIPLE REGRESSION RELATIONSHIP
FOR THE SUM OF THE LOWER INCISOR WIDTHS (1979)

Sum of lower incisor widths = .11 x (mandibular arc - $\bar{x}_1$) +
                      .09 x (corpus length - $\bar{x}_2$) +
                      .07 x (mandibular plane angle - $\bar{x}_3$) +
  11.66 (constant)

where $\bar{x}_1 = 34.09 - (X-Y)/2$
$\bar{x}_2 = 75.5 - (X-Y) \times 1.6$
and $\bar{x}_3 = 19.97 + (X-Y)/3$

where X = 18(years) for males, and
      15(years) for females

and Y = actual patient age in years

Keene and Engel's computation gives the sum of the
lower incisor widths desirable for a given skeletal pattern.
Should the actual value (measured on the patient or on study
casts) exceed this result by 1.2mm, Keene and Engel classify
them as potential relapse cases, where reduction of total
anterior tooth width (by interproximal stripping or extractions)
should be carried out prior to commencing active orthodontic
treatment.
Keene and Engel's computation is mathematically quite involved, and would require careful estimation, even with an electronic calculator. The complexity of such a formula may make it clinically unattractive to the operator, especially if other direct and cephalometric measurement techniques are reliable. However, the advent of computer dental records (such as Rocky Mountain Data Systems, USA), may make future multiple regression-type analyses clinically viable. Of greatest significance in Keene and Engel's findings is the fact that a relationship may exist between the size and relationship of facial bones and tooth size, such that for any given skeletal pattern, the most desirable sum of the lower incisor mesiodistal widths may be determined.

Peck and Peck (1980) express reservations regarding Keene and Engel's results. Peck and Peck claim that they recomputed Keene and Engel's figures, and determined that "there is no significant difference between the two groups", that is, between the dimensions of relapse-prone mandibular incisors, and the dimensions of stable mandibular incisors, when related to cephalometric skeletal associations. Peck and Peck state further that "knowledge of Keene and Engel's statistical error nullifies their cephalometric equation".

Peck and Peck appear to not be in favour of computer systems, (or at least the Rocky Mountain Data Systems), when used "to systematise the vagaries of individual growth". Nevertheless, Keene and Engel's computations are an attempt to draw together concepts of tooth size and cephalometric skeletal relationships. At this stage, the multiple regression-type
equation, and the computer record and analysis system appear to have a definitive role in the future of dental case analyses, although the computer is unlikely in the foreseeable future to be self-programmable in terms of devising scientific hypotheses. The computer's use at present is still experimental and in the early stages of development. The complete computer bank must eventually hold information relating to patient's age, size, development, skeletal characteristics, dental maturity, sex and race, plus statistical information related to sample size, measuring techniques, limitations and error significance. Possibly the discrepancies between Keene and Engel's results and Peck and Peck's computations, lie somewhere in the vast range of variables.

Multiple regression relationship formulae, such as those devised by Keene and Engel, may, in the future, provide a worthwhile contribution to the dento-facial analysis, with particular regard to analysis of lower anterior crowding, its treatment and prevention of relapse.
CHAPTER 6: The Diagnostic Set-up

A procedure for the diagnostic set-up has been outlined by Kesling (1956). He suggests that the possible outcomes of treatment may be previewed by vertically sectioning the plaster cast between each tooth, and subsequently resetting the teeth in their new, desired positions (with some teeth removed if required, simulating their extraction).

Kesling states that the advantage of this technique is that the actual tooth replicas are reset on the basal bone, as supplied by the study cast. He uses the mandibular central incisor as the key to the set-up, relating it to the Frankfort Mandibular Plane Angle, (FMPA), as suggested by Tweed (1946). Kesling's FMPA and IMPA values are depicted in Table 9. For a given FMPA value, he establishes the ideal IMPA value on a cephalometric radiograph by tracing a proposed incisal plane. By comparing this with the existing incisal plane, Kesling is able to measure the distance the incisal tip is required to move for correction, assuming the apical position remains unaltered, (see Fig. 19). This measurement may then be transferred to the trial set-up, provided that care is taken to maintain the apical root position.

In the trial set-up Kesling emphasises that under no circumstances should arch length be gained by increasing the arch width, and that it is essential that the apices of the teeth are not repositioned in a more labial or lingual direction.
TABLE 9: KESLING'S VALUES RELATING THE POSITION OF
THE MANDIBULAR INCISOR TO THE FMPA (1956)

<table>
<thead>
<tr>
<th>FMPA (degrees)</th>
<th>IMPA (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>95</td>
</tr>
<tr>
<td>21</td>
<td>94</td>
</tr>
<tr>
<td>22</td>
<td>93</td>
</tr>
<tr>
<td>23</td>
<td>92</td>
</tr>
<tr>
<td>24</td>
<td>91</td>
</tr>
<tr>
<td>25</td>
<td>90</td>
</tr>
<tr>
<td>26</td>
<td>89</td>
</tr>
<tr>
<td>27</td>
<td>88</td>
</tr>
<tr>
<td>28</td>
<td>87</td>
</tr>
<tr>
<td>29</td>
<td>86</td>
</tr>
<tr>
<td>30</td>
<td>85</td>
</tr>
<tr>
<td>31</td>
<td>84</td>
</tr>
<tr>
<td>32</td>
<td>83</td>
</tr>
<tr>
<td>33</td>
<td>82</td>
</tr>
</tbody>
</table>

FMPA = Frankfort Mandibular Plane Angle
IMPA = Incisor Mandibular Plane Angle
FIG. 19: A CEPHALOMETRIC TRACING DEMONSTRATING POSSIBLE MANDIBULAR INCISOR REPOSITIONING (according to Kesling, 1956)
CHAPTER 7: Factors Influencing Lower Anterior Crowding

1. Variables Which May Affect Lower Incisor Alignment

Sanin and Savara (1973) proposed a hypothetical model to explain the development and self-correction (if possible) of crowding of the mandibular incisors. This model is depicted in Fig. 20.

FIG. 20: SANIN AND SAVARA’S MODEL EXPLAINING POSSIBLE DEVELOPMENT AND CORRECTION OF LOWER ANTERIOR CROWDING (1973)